Energy Policy Review

Sweden 2024

INTERNATIONAL ENERGY AGENCY

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Executive summary

Sweden has ambitious energy goals and is in a promising position to achieve them. It already has a relatively low emissions energy system as well as favourable natural resource endowments, a broad political and public consensus on its net zero ambitions, and a clear strategy to meet its goals (primarily through electrification of end-use sectors). Its energy sector stands out in several ways, including its largely decarbonised power and buildings sectors and its leading efforts on low-carbon heavy industry. These and other factors can help it remain in the vanguard of clean energy transitions and maintain a competitive edge as an export-oriented economy. An important next step in Sweden's energy transition will be to take a co-ordinated approach to aligning its policy and regulatory settings across different sectors of the economy. The IEA Energy Policy Review aims to provide practical, timely advice to Sweden as it advances its energy and climate strategy, including in two key focus areas: 1) accommodating electrification; and 2) expanding the role of fossil-free hydrogen.

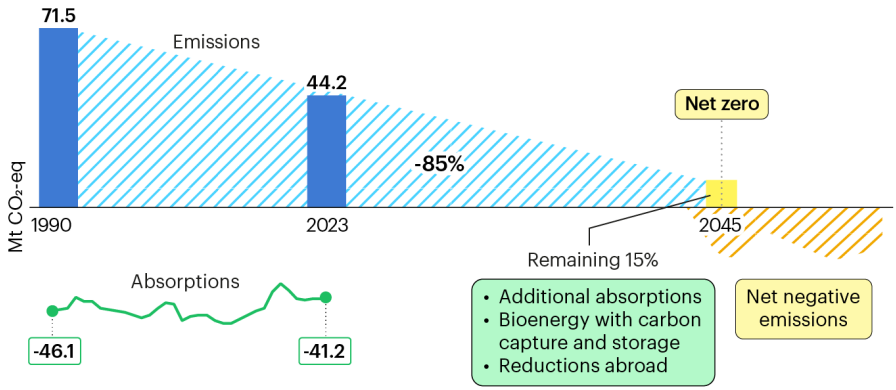
Sweden's legally binding 2045 net zero emissions target together with energy sector targets guide its energy policy. Net zero equates to an 85% cut in domestic greenhouse gas (GHG) emissions from 1990 levels (38% below 1990 levels in 2023), after allowing for expected absorptions. This target is supported by a robust policy framework that includes binding interim targets, a climate action plan to meet these targets (updated every four years), supportive climate legislation and a Climate Policy Council (that assesses Sweden's climate policies yearly). Overall, this framework provides long-term clarity on goals, together with regular reflection and course-correction, and independent expert assessments and recommendations.

Leveraging and expanding Sweden's low-carbon power sector to electrify the wider energy system is key to achieving the next stage of its transition. The combination of Sweden's well-functioning, market-based electricity system and near zero-emissions power mix (relying primarily of hydropower, nuclear and wind) provides a strong foundation upon which to electrify the wider energy system. This will require a large buildout of new clean power generation capacity accompanied by broader reforms that enable end-use sectors to reap the benefits. Steps taken to open the investment environment to nuclear will help to ensure that future fossil-free generation choices are technology-neutral. A policy priority is to ensure that this is accompanied by an efficient licensing and financial risk-sharing model, if Sweden's goal of 2.5 gigawatts (GW) of new nuclear power capacity by 2035 is to be realised. In parallel, there is a pressing need to debottleneck permitting roadblocks (a challenge common to many countries) – particularly for offshore and onshore wind – if clean energy generation capacity is to scale up at the pace needed in the near to medium term.

Sweden's electricity system will be the cornerstone of its energy transition plans. However, sizeable uncertainties exist in the long-term forecasts, including the scale of industrial electricity demand in the north, offshore wind development in the south, and the outlook for existing and new nuclear power plants. In addition, current processes for planning and approving transmission lines can be lengthy, acting against the needs of a rapidly transitioning energy system. As the supply side grows to meet a potential doubling of electricity use in the decades ahead and adapts to the shifting demand patterns across the country, there is an imperative for broader system-level planning, as well as co-ordinated grid expansion, and actions to accelerate grid approvals, construction and connections (such as through an improved selection progress and enhanced flexibility mechanisms).

Favourable conditions in northern Sweden are shaping a green industrial transformation that will boost both economic prospects and energy demand. Sweden's industrial transformation will draw heavily on electricity, resulting in sizeable new demand and in new demand locations, which the system will need to accommodate at the same time as managing the retirement of some existing generation assets. This places a renewed premium on system-wide energy planning and may prompt a need to rebalance electricity price variations across regions. An inquiry into Sweden's electricity market development and regulation is underway. The findings are due by April 2025.

85% **Emission reductions** from 1990 to 2045 **target**, excluding absorptions

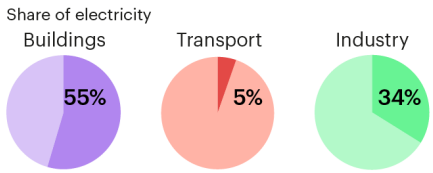


60%
Share of **electric vehicles** in car sales in 2023

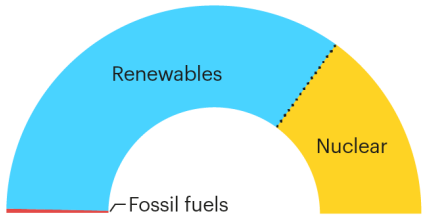
300 TWh
Approximate planning target to meet a doubling of **electricity demand** by 2045

3.1 tonnes CO_2
per capita, third-lowest **carbon intensity** among IEA countries in 2023

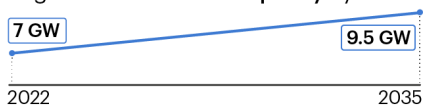
36%
Electrification rate of total final energy consumption in 2022



99%
Low-emissions electricity generation in 2023



+2.5 GW
Target for new **nuclear capacity** by 2035



22-100 TWh
Forecasted electricity demand for **low-carbon hydrogen production** by 2050

Leveraging access to fossil-free electricity, Sweden's industrial sector is focused on low-emission hydrogen as a key decarbonisation pathway. Programmes like Industrial Leap have helped to support the development and deployment of emissions-reduction solutions in industry, including hydrogen. Sweden is pioneering the production of green steel based on fossil-free hydrogen, with investments planned or moving forward without heavy state planning or large subsidies. While encouraging, the sector would benefit from a hydrogen strategy that: clarifies the envisioned role for hydrogen in the energy system, includes scenarios for its geographic distribution, and maps out roles and responsibilities for system development. There is also a need to undertake co-ordinated analysis and planning that spans the development of the electricity and hydrogen systems.

Despite notable progress in deploying biofuels and electric vehicles (EVs), policy shifts will challenge Sweden meeting 2030 transport emissions targets. Thanks in part to a suite of supportive policies, Sweden has both a high share of biofuels in the transport fuel mix (25% in 2022) and a high share of EV sales (60% in 2023), helping to displace a significant volume of oil product demand. However, both areas saw significant policy reversals in 2023 that may have negative implications for achieving a 2030 transport emissions target already viewed as challenging (a 70% reduction relative to 2010 levels). If it is to meet this target, Sweden will need to consider additional policy actions, such as on charging infrastructure, transport-related taxation and encouraging modal shifts.

Sweden's strategy for decarbonising its buildings sector is focused on renovations and fuel switching. It employs an array of policy tools to achieve this, including buildings regulations, energy performance certificates and support schemes to single-family homes to switch out of fossil heating. Though already low emissions, the buildings sector would benefit from an increased focus on policy measures that constrain expected electricity demand growth. More broadly, introducing sectoral energy intensity targets could help stimulate valuable new actions, such as the adoption of more efficient industrial processes. Overall, a greater focus on energy efficiency policy actions is needed to help Sweden meet targets under the updated European Union (EU) Energy Efficiency Directive.

Sweden's transition will result in sizeable shifts in the workforce, necessitating a major expansion of clean energy skills across all education levels. Sweden has made progress mapping the skills needed for the transition, with the Swedish Energy Agency identifying 35 professions that are both critical to the electrification of

society and have considerable skills shortages. It is already advancing several measures to improve the situation, such as through the development of a STEM (science, technology, engineering and mathematics) strategy and targeted investments to expand engineering education. Such actions must be built upon over a sustained period, together with others, such as vocational training and location-specific plans at the municipal level.

Policy recommendations for Sweden

1
Clarify strategies, define intermediate milestones and accelerate implementation of policy measures to meet climate and energy targets.

2
Prioritise policy action on energy efficiency as a guiding principle of energy transitions.

3
Step up measures to lower transport emissions, ensuring strong growth for both biofuels and electric vehicles.

4
Undertake system-level analysis and planning to adequately prepare for increased electrification.

5
Accelerate grid connections through an updated and more transparent selection process, and promote flexibility mechanisms.

6
Ensure a level playing field and technology-neutral approach across generation options and time horizons.

7
Facilitate the permitting of new generation capacity, especially wind.

8
Establish a framework for efficient licensing, project management and financing for nuclear new builds.

9
Issue a hydrogen strategy that guides the establishment of rules and responsibilities for system development and operation.

10
Co-ordinate system planning across the hydrogen and electricity sectors.

Energy system and policy landscape

Introduction

Sweden is undertaking its energy transition from a favourable starting point. The country's energy system is already highly decarbonised compared to other countries, in particular its nearly fossil-free electricity generation mix as well as a high share of electricity in space heating and bioenergy in district heating (DH). Sweden is also blessed with a strong resource endowment to underpin its future decarbonisation pathway.

The next stage of its energy transition will entail leveraging its low-carbon electricity system to decarbonise other sectors through electrification. This will require not only a massive new buildout of fossil-free generation sources, but likewise sectoral reforms to accommodate the upcoming changes to the electricity system that the energy transition will bring.

A market-based energy system and historically well-functioning electricity system all work to Sweden's advantage. Going forward, the government will need to holistically assess the energy system and its policy levers to ensure that they are aligned with the accelerated decarbonisation outcomes that climate targets require. Sweden's opportunities to become a global leader in clean energy technologies and low-carbon industry are considerable, and actions taken in the short term will inform its long-term ability to capitalise on this opportunity.

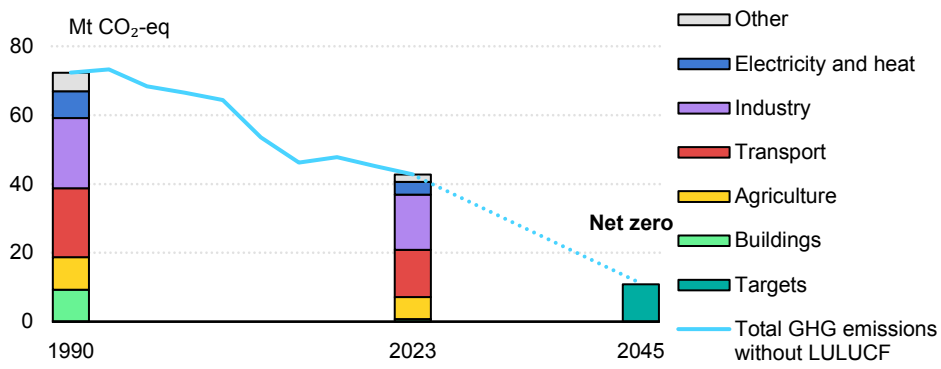
Climate and energy strategy

Climate trends and targets

Sweden has enshrined into law a target to achieve net zero GHG emissions by 2045, five years earlier than the EU target. This equates to a domestic reduction of GHG emissions of 85% below 1990 levels by 2045 (not counting absorptions). The remaining 15% are planned to be met by a combination of other measures, such as additional forest and land absorptions, carbon capture and storage from bioenergy combustion, and supporting emissions reductions in other countries. The clear delineation of targets to clarify the role of domestic emissions reductions relative to offsets and absorptions is unique in the world and should be strongly commended. After 2045, Sweden plans to achieve negative emissions.

Industry is the largest emitting sector in Sweden (36% of economy-wide emissions in 2023, including those not related to energy), followed by transport (31%), agriculture (15%), and electricity and heat generation (8%). Many sectors experienced a notable drop in emissions from 2005 to 2023, with emissions from buildings declining by 80%, electricity and heat by 54%, transport by 37%, and industry by 25%. Absorptions from land use, land-use change and forestry (LULUCF) offset almost 90% of emissions in 2021, having an outsized impact on Sweden's total net emissions.

Greenhouse gas emissions by sector in Sweden, 1990-2023



Note: Mt CO_2-eq = million tonnes of carbon dioxide equivalent.

Source: IEA based on UNFCCC (2023); Swedish Environmental Protection Agency (2024); EEA (2024), Greenhouse gas emissions under the Effort Sharing Legislation, 2005-2022.

As a member of the European Union, Sweden is subject to EU climate policy and regulation. Large combustion facilities in the power and industry sectors are part of the EU Emissions Trading Scheme (ETS), whereas non-ETS emissions (transport, buildings, agriculture and waste) are subject to binding national GHG targets under the EU Effort Sharing Regulation (ESR). For the European Union as a whole, the ETS target is to reduce GHG emissions by 62% from 2005 levels by 2030, while the ESR target is to reduce emissions by 40% from 2005 levels by 2030. Under the ESR, Sweden's updated national obligation is to reduce emissions by 50% from 2005 levels by 2030.

Climate policy framework

Sweden's climate policy is guided by an overarching framework passed by parliament in 2017 and which took effect in 2018. It covers climate targets, climate legislation and the creation of a Climate Policy Council. In addition to enshrining the net zero by 2045 target into law, it also establishes interim targets to cut emissions from sectors not covered by the EU ETS by 63% from 1990 levels by 2030 (with a maximum of 8 percentage points achieved through flexibility mechanisms) and 75% by 2040 (with a maximum of 2 percentage points through flexibility mechanisms). In addition, it sets a target to reduce domestic transport (not including aviation) emissions by at least 70% from 2010 levels by 2030, though the government announced that it would review the 2030 target to better align with EU targets.

The framework package included the passage of the Climate Act. The Act directs the government to enact policies based on the climate targets established under the framework and to present a climate report as part of the annual budget bill. It also requires the government to draft an updated climate action plan every four years to meet the targets, which reports on how policy will help meet climate goals and what additional measures are needed if the goals are out of reach. The latest plan was published in December 2023 (following the first one in 2019). The government has recently stated its intent to re-evaluate the transport target laid out in the Climate Act.

Lastly, Sweden established an independent Climate Policy Council with a mandate to evaluate the government's policies against Sweden's climate targets. The Climate Policy Council, which is comprised of experts from various fields such as environmental policy, economics, social science and behavioural science, must submit an annual assessment report.

The Climate Policy Council's latest report (2024) finds Sweden needs to step up efforts to meet its climate targets. It notes that Sweden's near-term emissions will actually increase, especially in the transport sector. The report recognises the government's efforts to advance fossil-free electricity, but it likewise notes that the government's electrification goal may overshadow other priorities such as energy efficiency and CO_2 absorptions. It also questions the government's plans to re-examine the climate goals laid out in the Climate Act.

From a climate governance perspective, the framework represents good practice. It is robust and provides long-term clarity to the economy on the government's goals, while the updates to action plans every four years allow for regular course correction based on shifting market conditions and technology developments. Meanwhile, the Climate Policy Council allows for expert, independent assessments of government policies to ensure that the country is on track to meet its targets and gives recommendations for improvement.

Sweden's updated National Energy and Climate Plan (NECP) assesses existing government policy in relation to EU goals. Sweden submitted its NECP to the European Commission in June 2024. The updated plan reflects stronger EU targets for renewables and energy efficiency as well as the new national energy policy bill and the latest national Climate Action Plan.

Energy targets

Sweden has set some energy sector targets to guide its emissions reduction trajectory. In 2018, it set a cross-sectoral target to achieve 50% more efficient energy use by 2030 compared to 2005. The target is defined in terms of energy intensity (total energy supply/gross domestic product [TES/GDP]) rather than absolute primary or final energy consumption. The government is currently in the process of re-evaluating this target; the target could limit the growth of new energy-intensive industries (even if low-emission) and does not provide much clarity on sectoral breakdowns. Since 2023, Sweden also has a target of 100% fossil fuel-free electricity by 2040. The Swedish government has recently proposed additional targets related to electricity planning and security of electricity supply (see Focus Area "Preparing for electrification").

Sweden aims to achieve its energy savings targets mainly by keeping energy and carbon taxes above the EU minimum taxation levels. Other measures include a grant

for single family homes, regulations and a renovation strategy for buildings, energy efficiency networks for industry and other sectors, energy audit programmes, and consumer information sharing and training strategies. In the final updated NECP, Swedish measures are estimated to create savings of 594 petajoules (PJ) (165 terawatt hours [TWh]) cumulatively between 2021 and 2030, mainly from the buildings and transport sectors.

With the new Energy Efficiency Directive (EED), Sweden will have to revise its policies to consider higher ambitions. Currently, the 594 PJ savings meet the original 0.8% new annual savings requirement under the EED for 2021-30 (based on 2016-18 data at 1 336 PJ). However, the EED revision sets higher annual savings rates of 1.3% for 2024-25, 1.5% for 2026-27 and 1.9% for 2028-30. Sweden will need to strengthen initiatives to meet these new, higher annual savings rates.

National targets for energy and climate policy in Sweden

Targets	2021 status	Base year	2030 target	2040 target	2045 target
Total GHG emissions	-33%	1990			Net zero
Non-ETS GHG emissions	-32%	1990	-63%	-75%	
Transport emissions	-27%	2010	-70%		
Electricity production	99.2% fossil-free			Fossil-free	
Energy efficiency (TES/GDP)	-32%	2005	-50%		

Note: TES = total energy supply. GDP is expressed in terms of 2015 USD prices.

Source: Sweden, Ministry of Climate and Enterprise (2024), Sweden – Final updated National Energy and Climate Plan (NECP) 2021-2030.

Taxation and carbon pricing

Sweden has a robust system of taxation that reflects emissions reduction goals. Carbon pricing in Sweden is implemented through the EU ETS and the Swedish Act on Excise Duties on Energy. The Swedish system of energy taxation is based on a combination of a carbon tax and an energy tax on fuels. There is also an energy tax on electricity. Sweden's carbon and energy taxes generate considerable revenues for the general budget, but there is no "earmarking" of revenues for specific purposes.

The carbon tax on fuel used in co-generation and heat plants for DH under the EU ETS was lifted in January 2023 to stimulate electricity production, leaving the ETS as the only guiding measure for carbon.

Sweden's carbon tax is relatively strong by international standards. The carbon tax has been raised in several increments since it was first implemented in 1991. In total, it has increased from 0.25 Swedish krona per kilogramme (SEK/kg) (1991) to 1.45 SEK/kg (2024). A yearly indexation of the carbon and energy tax rates is applied to adjust for changes in the consumer price index. Most biofuels are currently not subject to carbon taxation. As the EU ETS2 takes effect in 2027, it is expected to become the key price signal for those sectors it covers (buildings, road transport and other sectors not covered by the existing EU ETS).

The energy tax is primarily a revenue-raising tool. It also steers energy use towards Sweden's energy efficiency, renewables and climate targets. The energy tax on fuel varies depending on use and sector, and energy-intensive industries receive some tax exemptions (to minimum EU levels). Gasoline and diesel used in road vehicles, off-road machinery, and private ships and boats are subject to both the energy and the carbon tax, while fuel used in electricity generation is exempted from both.

Energy research and development

Sweden has a dedicated programme for energy research and innovation. The government is expected to present a bill to parliament on energy research and innovation for the period 2025-28 at the end of 2024. The energy research and innovation budget for 2023 was SEK 1.4 billion (Swedish kronor)[1], a slight decline from the previous year.

The Swedish Energy Agency has overall responsibility for implementing the National Energy Research and Innovation Programme. The Swedish Energy Agency's research and innovation portfolio covers the entire innovation system and is designed to work in conjunction with, and as a complement to, other policy instruments to achieve the nation's energy and climate policy objectives. The largest proportion of the Swedish Energy Agency's budget for research and innovation consists of

[1] Exchange rate: 1 Swedish krona (SEK) = EUR 0.08 = USD 0.09 (as of 28 October 2024).

approximately 20 thematic programmes. The four largest thematic areas are: 1) electricity production and the electricity system; 2) the transport system; 3) industry; and 4) buildings within the energy system.

Sweden values international co-operation in research and innovation. Swedish researchers are engaged in IEA Technology Collaboration Programmes, the EU Framework Programme for Research and Innovation (Horizon Europe) and related European partnerships, the SET Plan, the Nordic Energy Research, and bilateral agreements with strategically selected countries. Sweden is also a member of the Clean Energy Ministerial and Mission Innovation .

Policy spotlight: Skills planning for the energy transition

Sweden's energy transition will result in sizeable shifts in the workforce. A major expansion of skills across all education levels in clean energy industries is necessary, notably in low-carbon industry, hydrogen and electricity (including nuclear) so that skills shortages do not become an impediment to the transition. Towards this end, the Swedish government is proactively taking steps to align its electrification strategy for the energy sector with workforce planning. The government has tasked the Swedish Energy Agency with co-ordinating a national effort to supply skills for the electrification of society, which is a welcome step towards addressing the skills challenge.

Sweden has already made progress with skills mapping for the transition. The Swedish Energy Agency, in its report Skills Supply for Electrification – Mapping and Analysis, identified 35 professions critical to the electrification of society that have considerable skills shortages. These skills shortages apply to engineering professionals as well as professions with upper secondary or higher vocational levels of education. Even though a record number of students earned either a bachelor's or a master's degree in engineering in Sweden in 2021, energy sector demand still outstrips the supply of workers. The study also noted that skilled teachers are one of the most significant areas with shortages.

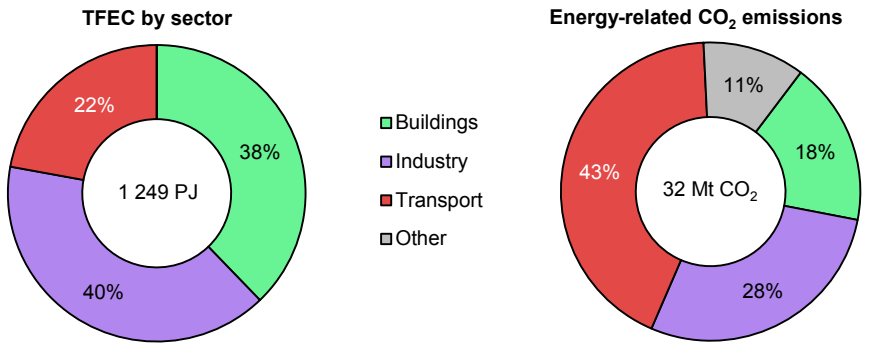
The government has taken several measures to improve the situation. It is implementing a specific initiative to increase the number of people with engineering degrees to, among other things, support the energy transition. Graduates in STEM fields are particularly needed as are higher numbers of women in these fields. The government plans to develop a STEM strategy that spans all levels of education from preschool to postgraduate education. In addition, the 2024 Budget Bill includes targeted investments to expand engineering education. Vocational training will also be important, especially at the municipal level.

Northern Sweden, in particular, is expected to see a surge in job creation associated with the green industrial revolution. To meet the challenge, a local coalition of companies and Luleå University of Technology established a recruitment platform called T25, whose goal is to attract 25 000 workers to northern Sweden to support industrial growth in the region. The Swedish Public Employment Service collaborates with T25, resulting in policies and programmes to support recruitment and skills training. The success of the collaboration highlights a role for the Public Employment Service to support green growth in other regions. Measures will likely also be needed to attract talent to rural areas with more limited infrastructure and services, where the bulk of industrial growth is expected.

End-use sectors

While industry accounts for the largest share of energy demand, the transport sector is the largest emitting sector. In 2022, total energy consumption was 1.2 exajoules (EJ), slightly down from 1.3 EJ in 2019. Industry accounts for 40% of total energy demand, followed by buildings (38%) and transport (22%). Energy-related CO_2 emissions are calculated by including the emissions from electricity and heat used in each sector. With this method, transport makes up 43% of emissions. Industry and buildings produce a smaller share of emissions compared to other IEA countries, mainly because of the high use of bioenergy and clean electricity.

Total final energy consumption and energy-related emissions by sector in Sweden, 2022



Notes: TFEC = total final energy consumption. Emissions from buildings, industry and transport include those from electricity and heat generation used in these sectors.

Source: IEA (2024), World Energy Balances (database).

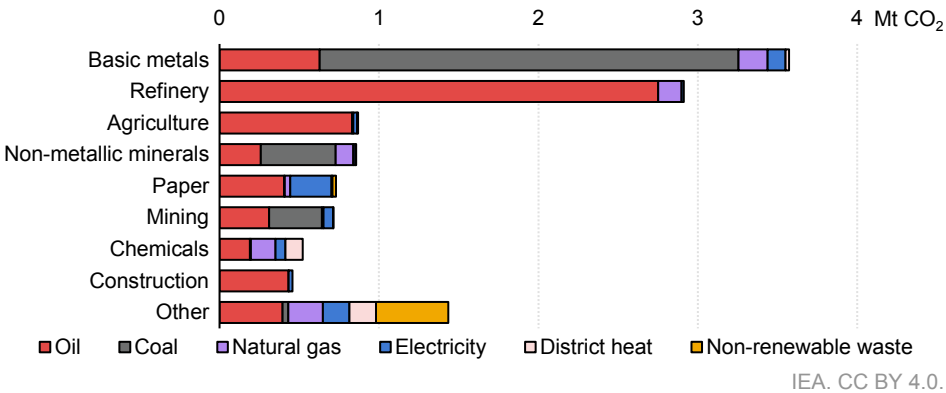
Industry

Sweden's industry sector has a relatively small dependence on fossil fuels. In 2022, the industry sector's fuel mix was dominated by biomass (42%) and electricity (32%). Fossil fuels accounted for 18% of consumption, mainly oil (10%), followed by coal (5%) and natural gas (3%). District heat (6%) and waste (1%) complete the sector's energy mix.

Total emissions from industry are decreasing, but some sectors are harder to decarbonise. Energy-related CO_2 emissions from industry and other energy transformation (such as refineries) accounted for 39% of energy-related GHG emissions and decreased by 3% from 2012 to 2022. Major investments in innovation and technological advances are required to bring the sector to net zero by 2045 (see Focus Area “Hydrogen for decarbonising industry”).

Refining and basic metals are together responsible for half of total emissions from the industry sector. Emissions from the refining sector are caused by the high use of oil, while coal is the main source of emissions for basic metals (mainly steel production). The largest energy-consuming sector is paper manufacturing, but the sector uses mainly biomass residues from its processes, which keeps CO_2 emissions low. Other sectors include agriculture, non-metallic minerals (such as cement) and mining.

Industrial emissions by subsector in Sweden, 2022



Source: IEA (2024), Energy End-uses and Efficiency Indicators (database).

The refining and steel industries are exploring options for lower emissions. With falling oil product demand, refining activity is expected to decrease in the coming years. Some refineries in Sweden have already started to convert their production to biofuels (see the Fuels section). Other diversification paths for the sector include hydrogen production and plastic recycling. For the Swedish steel industry, the main decarbonisation pathway is to produce steel based on direct reduced iron produced with low-emissions hydrogen at industrial scale (see Focus Area “Hydrogen for decarbonising industry”).

The EU ETS will continue driving down emissions in major industry sectors. The EU ETS covers heavy industry sectors (including refinery, basic metals and paper). For example, it created the incentive for forest industries to integrate heat and power production, fuelled by biomass by-products, into manufacturing. The revised EU ETS directive contains a strengthened emissions reduction target (for the whole European Union) of 62% by 2030 compared to 2005 levels.

Energy savings and energy efficiency measures also drive down emissions from the sector. As part of the revised EU EED, companies with annual energy consumption higher than 85 terajoules (TJ) need to have a certified energy management system and those with annual energy consumption higher than 10 TJ need to carry out energy audits every four years. There is no requirement to implement the savings measures identified in audits.

Carbon capture and storage

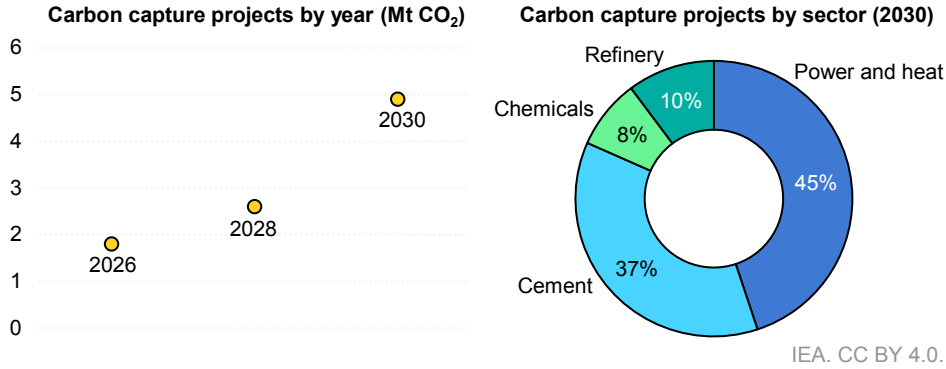
Carbon capture and storage (CCS) is an important pathway for decarbonising industry. Sweden is looking at various carbon capture technologies, including CCS from bioenergy (bio-CCS or BECCS). In 2023, the government tasked the Swedish Energy Agency with planning, co-ordinating and promoting CCS in the country, and the Geological Survey of Sweden with investigating suitable locations for permanent storage of CO_2 in the country (due by 2026). For now, domestic storage is not possible, so captured CO_2 needs to be exported. In July 2024, the government announced SEK 36 billion in support for BECCS over 2024-26, and the first reverse auction was launched in August 2024.

Planned projects in Sweden have the potential to capture up to 4.9 Mt CO_2 per year by 2030. The largest projects include building the world's first carbon-neutral cement plant, aiming to capture up to 1.8 Mt CO_2 annually; carbon capture from biomass-fired co-generation plants (such as in Stockholm); from a refinery; and carbon utilisation to produce sustainable methanol. Government plans include making Stockholm Norvik Port a hub for CO_2 transport, potentially handling around 9 Mt CO_2 per year. To date, Sweden has signed agreements with Denmark and Norway to remove barriers to international transport of CO_2 and storage at Norwegian storage sites.

BECCS at bioenergy plants is a growing sector and provides negative emissions. The largest BECCS project is Stockholm Exergi, which recently received environmental permits to build a large carbon capture facility in connection with a bioenergy

co-generation plant. Plant construction is planned to begin in 2025 and have a capture capacity of 800 000 tonnes of CO_2 per year when fully operational. Microsoft signed a deal with Stockholm Exergi for CO_2 removal of 3.33 million tonnes over a ten-year period from 2028.

Carbon capture projects pipeline by year and sector in Sweden



Source: IEA (2024), CCUS Projects Explorer.

Policy spotlight: Fossil Free Sweden

Sweden has initiated a joined-up approach with industry to guide decarbonisation strategies. Based on the goal of becoming the world's first fossil-free welfare nation, the Swedish government launched Fossil Free Sweden (FFS) in 2015 to support the decarbonisation of Sweden's economic sectors. FFS is a platform that brings together relevant stakeholders in government, industry and municipalities under the leadership of a national co-ordinator. FFS presents decarbonisation proposals to the government that have broad support among key implementing actors.

FFS roadmaps clarify decarbonisation pathways for each industry. Under FFS, 22 sectors have developed roadmaps for fossil-free competitiveness, including electricity generation, gas, cement, light and heavy transport, and aviation. The sectors involved accounted for 70% of Sweden's greenhouse gas emissions in 2022. Roadmaps include interim targets and signposts for the industry and offer policy recommendations to the government to remove bottlenecks to investment. The effort highlights the important collaborative role industry can play in supporting the government's net zero ambitions. FFS publishes annual progress reports on the roadmaps, which show good examples from other sectors and identify areas for improvement.

Selected industrial roadmaps and targets by sector in Sweden

Sectors	2030 targets and milestones	2045 targets and milestones
Heating	Fossil-free sector	Turn into a carbon sink for society
Gas	GHG emissions from LNG vehicles down by 70-90% vis-à-vis diesel and petrol	Fully fossil-free gases and potential renewable gas production
Electricity	Fossil-free production	Expand per security, competitiveness and sustainability needs
Aviation	Fossil-free domestic flights	Fossil-free domestic and foreign flights from and to Sweden
Cement	First climate-neutral cement plant and carbon sink	
Steel		Fossil-free production
Mining and minerals	Fossil-free mining	Climate-neutral processing and fossil-free energy use

Note: LNG = liquefied natural gas.

Source: Fossil Free Sweden (2021), Roadmaps for Fossil Free Competitiveness – Follow-up 2021

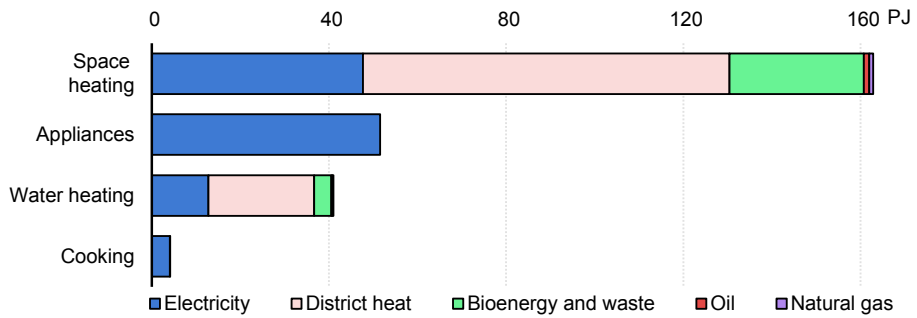
Buildings

The building sector's contribution to total GHG emissions is low, and its final energy consumption is slowly decreasing. The buildings sector accounted for 18% of total energy-related CO_2 emissions in 2022. Emissions from buildings have been declining for several decades, mainly thanks to heat pumps and the replacement of oil with bioenergy in heating. From 2015 to 2022, they decreased by 13%. Meanwhile, buildings accounted for 38% of TFEC in 2022; energy consumption is falling, with a 1.4% decline from 2015 to 2022.

Electricity and DH are the main sources of energy for buildings. Space heating accounts for slightly less than 60% of end-use energy demand in residential buildings, and half of it is provided by DH. The number of heat pumps installed in the country is increasing and reached 46% of households in 2022. Annual heat pumps sales grew until 2022 but slowed in 2023 to slightly less than 200 000 units.

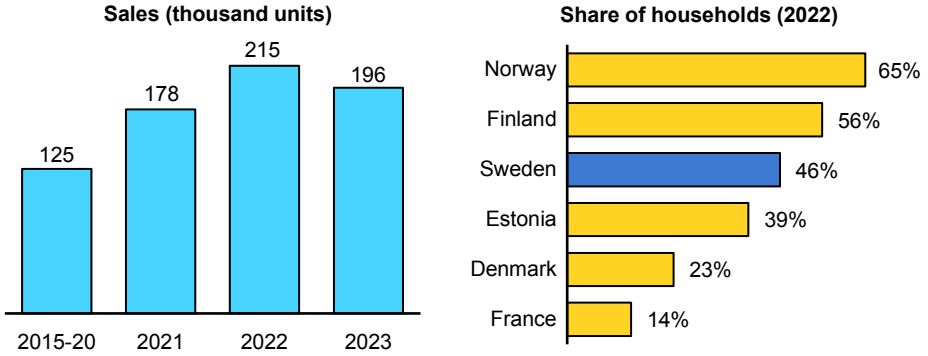
The long-term renovation strategy established energy consumption goals. Sweden seeks to achieve declining energy consumption of the building stock (expressed in kilowatt hour per square metre [kWh/m^2]) over successive decades to 2030, 2040 and 2050. This is expected to be achieved by increasing the share of buildings with energy classes A to C. The strategy further intends to limit the share of fossil fuels in the energy consumption of buildings to 1% in 2030 and phase them out by 2040.

Energy use in residential buildings by end use in Sweden, 2022



Source: IEA (2024), Energy End-uses and Efficiency Indicators (database).

Annual heat pump sales (2015-2023) in Sweden and share of households with a heat pump (2022) in selected countries



Sources: IEA analysis based on data from SKVP (2024), Heat Pump Sales and Bruegel (2024), European clean tech tracker.

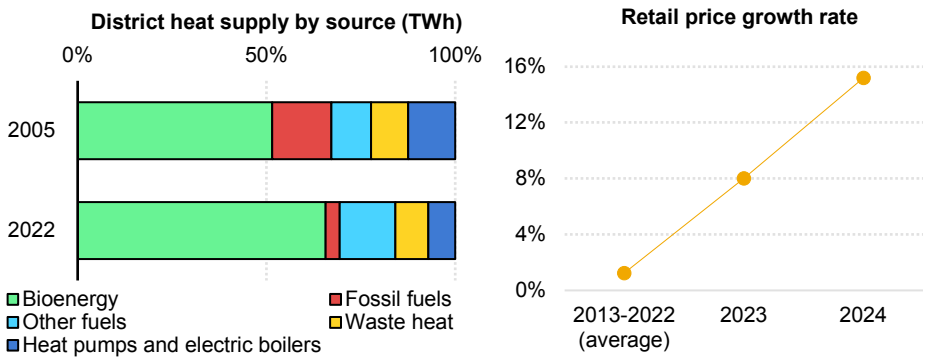
Sweden employs several policy tools to lower energy consumption and emissions from buildings. Building regulations determine an overall minimum energy performance requirement for both new and renovated buildings. In addition, buildings also employ energy performance certificates that provide information on energy consumption for various uses; they are required for all sold, rented or newly constructed buildings, as well as for larger buildings that are frequently visited by the public. Sweden also applies EU Ecodesign and Energy Labelling requirements for appliances domestically.

The government offers several support schemes to support energy efficiency and climate upgrades. In 2022, it allocated an overall budget of SEK 1.2 billion for 2023-25 in energy efficiency grants for single-family homes to support the conversion of heating systems and energy efficient renovations. The government also offers some tax deductions for renovations and upgrades to homes as well as for surplus renewable generation that households or businesses feed into the grid from their own installations. Government funding is also available for energy advisers, knowledge dissemination and local networks to promote energy efficiency in buildings.

District heating

Sweden has high levels of bioenergy-based DH. District heating provides 36% of the energy consumed in residential buildings, the second-largest share in the IEA after Denmark. Around 50% of heat is produced in co-generation plants, mainly fuelled by bioenergy. The carbon price on fossil fuels, along with abundant biomass feedstock from forest waste, are the main drivers for the expansion of DH (and the switch to bioenergy) in nearly all municipalities.

District heat supply by fuel (2005 and 2022) and average price (2013-2024) in Sweden



Sources: IEA analysis based on SEA (2024), Energy in Sweden – Facts and Figures 2023 and NHR (2024), District heating (accessed 20 September 2024).

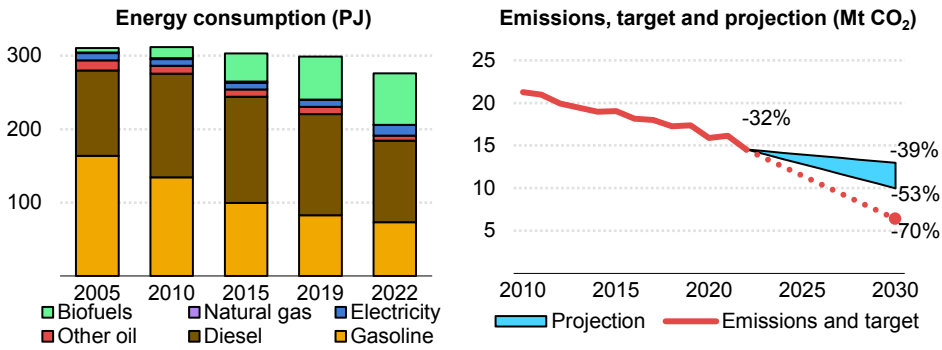
Sweden's DH market was liberalised in 1996 and prices remain unregulated. A 2008 law established a District Heating Board to oversee disputes between consumers and producers. Since 2011, the voluntary Price Dialogue scheme between consumers and producers sets out consultation and implementation processes for implementing price changes, which has proven effective at managing price shifts and improving transparency around pricing. Recent price spikes stemming from the Russian Federation's (hereafter "Russia") invasion of Ukraine have reignited debates about DH prices. The government should closely monitor the price environment for DH to ensure that district heating providers do not engage in monopoly pricing and prompt consumers to move to electrical heating options. Importantly, shifting the heating of

buildings from electrical heating to DH can bring substantial benefits from a power system perspective, in particular by freeing up electrical grid and power generation capacity during peak load hours.

Transport

Transport remains a key sector for action to achieve Sweden's climate targets, accounting for 22% of the country's TFEC. Transport emissions accounted for 43% of energy-related CO_2 emissions in 2022 (with road transport accounting for 95% of these emissions). Sweden's updated NECP targets a 70% reduction in GHG emissions in the transport sector by 2030 compared to 2010. From 2010 to 2022, emissions from the sector dropped by 32%, the second-highest drop in transport among IEA countries, after Luxembourg. Among IEA countries, in 2022 Sweden had, by far, the largest share of biofuels in the transport sector (25%) along with the second-largest share of electricity consumption in the transport sector (5.3%). Nonetheless, the gap to 70% reductions remains wide and current policies in the sector do not place the country on track to meet the target; on the contrary, they are actually expected to increase near-term emissions from transport.

Transport sector energy consumption (2005-2022) and emissions (2010-2022) in Sweden

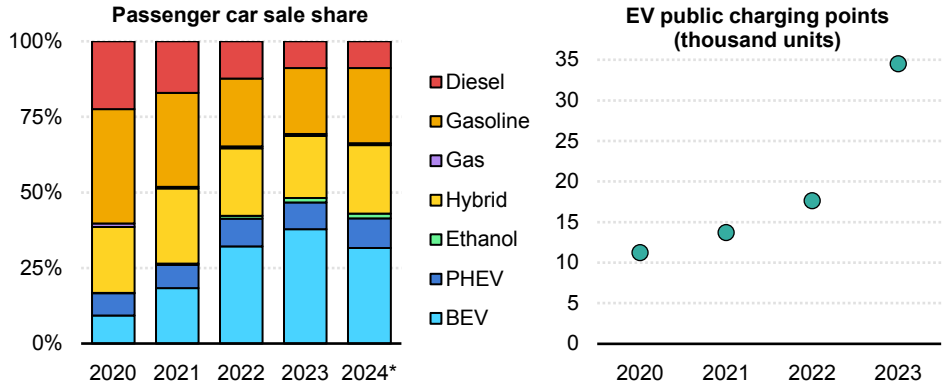


Sources: IEA (2024), World Energy Balances (database); NECP (2023).

Sweden phased out its incentives for low emissions vehicles. Support for low emissions vehicles was introduced in 2018 with a bonus-malus system, which provided a bonus to purchase new low-carbon passenger cars, light buses and light trucks and a vehicle tax (the malus) for gasoline and diesel vehicles in the first three years. The bonus was phased out in February 2023, as the government considered it had fulfilled its purpose of introducing more low-carbon vehicles into the market. Nonetheless, lower emissions vehicle models still enjoy beneficial tax rates compared to high-emissions vehicles. The government has also introduced a temporary car scrappage scheme to replace older cars with EVs in 2024-25. Meanwhile, local measures such as congestion charges and traffic regulations in major cities and public transport subsidies aim to encourage other forms of transport over driving.

In 2023, around 60% of all cars sold in Sweden were electric, versus 8% in 2018. In turn, internal combustion engine vehicle sales (gasoline and diesel fuelled) decreased from 85% to 31% of vehicle sales in the same period. However, data for 2024 to date show a decline in the share of EV sales. The number of public charging stations soared in 2023 (+96% from 2022), of which 13% are fast-charging. The Climate Leap programme supports the expansion of charging infrastructure. Within the programme, the government has earmarked SEK 1.4 billion from 2023 to 2025 for charging station investments. So far, the programme has granted support to over 180 000 charging points, a majority of which are at residential charging stations. There is also a tax reduction for charging stations at homes and workplaces. Nonetheless, it remains challenging to deploy charging points in multi-family housing. Electricity used in road transport does not benefit from preferential taxation.

Passenger car registrations by powertrain and electric vehicle charging points in Sweden, 2020-2024



* Data for 2024 do not refer to the whole year, but only to the period from January to August 2024.
Notes: Charging points data not available for 2024. BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle.

Sources: Statistics Sweden (2024), Vehicles (accessed 16 September 2024); IEA (2024), Global EV Data Explorer.

A biofuels policy U-turn has reversed positive trends that lowered oil demand and emissions. When Sweden's biofuels mandate was introduced in 2018, it was the most ambitious in the European Union (19.3%). It required fuel suppliers to lower the GHG intensity of the fuel they supply by a set percentage each year. The GHG intensity of fuels is calculated on a life cycle basis, relative to gasoline and diesel. The ambitious biofuels mandate, with increasing rates (up to 66% and 28% by 2030 for diesel and gasoline, respectively), was a key driver of lowering oil demand and emissions from the transport sector. However, the mandate was drastically cut in 2023 as a way to lower fuel prices, when the government brought the blending requirement down to 6% over 2024-26, the EU minimum, and scrapped it entirely for 2027-30. Diesel taxation was simultaneously relaxed. More recently, in August 2024, the government announced an increase in the blending quotas from 6% to 10% for both petrol and diesel between 2025 and 2030, along with a reduction in taxes on both gasoline and diesel (to EU minimum levels). The 10% renewables obligation can also be met using electricity. Based on the updated policy, the government expects Sweden to reach its EU ESR commitments for 2030. Biofuels will remain important to Sweden meeting its 2030 GHG emissions targets for transport, given that

EV penetration will take more time (especially in a context where EV support has been lowered). Moreover, the policy changes might also impact investments in domestic biofuels production.

Biofuels mandates in Sweden

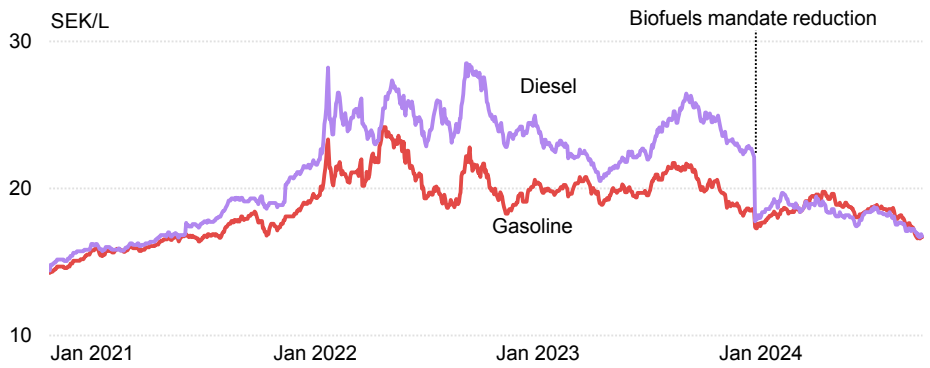
Biofuels mandate	Diesel	Gasoline
Before 2018	Tax reduction	Tax reduction
2018	19.3%	2.6%
2019	20%	2.6%
2020	21%	4.2%
2021	26%	6%
2022 and 2023	30.5%	7.8%
2024	6%	6%
From 2025	10%	10%

Notes: The target is intended to be a percentage reduction of GHG emissions associated with the use of each biofuel. The 2025-30 figure includes electricity.

Sources: Government of Sweden (2023), Memorandum - Reduction of the reduction obligation for petrol and diesel; Government Offices of Sweden (2024), Ministry of Finance, Reduced tax on petrol and diesel and reformed reduction obligation (press release).

Non-passenger transport segments also benefit from government support. Sweden also offers investment support for the purchase of electric buses, zero-emission or clean heavy trucks, biomethane heavy trucks, light-duty electric trucks, and electric or clean work machines. In addition, public electric charging and hydrogen refuelling infrastructure for heavy-duty vehicles benefit from several government support schemes. The government has also put in place incentives to promote night trains over flights, as well as biofuel blending requirements for aviation fuels and climate-based taxes on airlines (though the government also allocated SEK 1 billion in the Spring Budget for the aviation sector to offset high fuel prices). Environmental taxes are also applied to maritime transport.

Fuels prices in Sweden, January 2021- August 2024



Sources: Ekonomifakta (2024), Gasoline prices (accessed 19 September 2024); Ekonomifakta (2024), Diesel prices (accessed 19 September 2024).

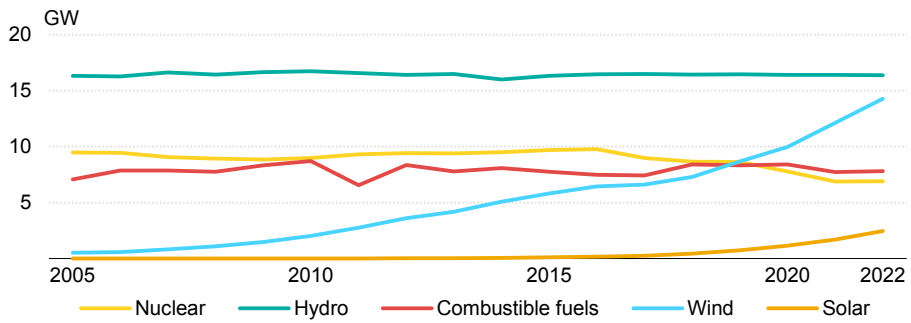
Electricity

Sweden's electricity system is mostly fossil-free, putting the country in a good position to undertake its energy transition. In 2022, Sweden's electricity was generated mainly from hydro (40%) and nuclear (30%). Wind power increasingly contributes to Sweden's electricity system, accounting for 19% of electricity output in 2022, doubling its generation since 2015. The remaining share mainly came from bioenergy and waste in co-generation plants connected to DH production or industry. Natural gas, oil and coal only made up 0.7% of output in 2022.

The growth of total electricity output outpaced electricity demand in Sweden and supported electricity exports. Electricity demand has remained relatively constant at around 140 TWh since 1990. Buildings have the highest electricity consumption (58% in 2022), followed by industry (38%) and transport (3.3%). Despite stable electricity demand, total electricity output increased 9% from 2005 to 2022, encouraging Swedish exports. Sweden is one of the largest electricity exporters in Europe, exporting 33 TWh in 2022 (19% of total electricity output), mainly through its connections with Denmark and Finland. However, Sweden's electrification target suggests a steep increase in domestic demand over the next decade (see Focus Area "Preparing for electrification").

The country's electricity generation capacity has experienced changes in recent years. Total capacity has been growing, with increases in wind and solar in particular. Since 2016, however, nuclear capacity has decreased by 29%, with half of Sweden's nuclear reactors undergoing decommissioning. Today, a total of six reactors from three plants remain in operation, representing 16% of national generation capacity and producing almost a third of Sweden's electricity. To meet its overall climate objectives, Sweden will need to significantly increase its fossil-free generating capacity and plans to use a combination of nuclear, wind and solar (see Focus Area "Preparing for electrification").

Electricity capacity in Sweden, 2005-2022



Note: Fossil fuels include oil, natural gas and coal. Combustible fuels include oil, natural gas, coal, peat and bioenergy.
Source: IEA (2024), Electricity Information (database).

Electricity market operation

Sweden liberalised its energy market in 1996. The three largest electricity producers – Vattenfall, Fortum and Uniper – together control around 63% of electricity generation in the country. Svenska kraftnät, the transmission system operator (TSO), owns and operates the national high-voltage electricity grid and is responsible for electricity system balancing. Meanwhile, the country has around 140 distribution system operators (DSOs), responsible for supplying electricity to end users.

Retail markets are competitive. Retail customers are free to choose among various fixed- or variable-price electricity contracts. Variable-price contracts are more

common and accounted for almost 56% of all contracts in February 2024, according to Statistics Sweden; 13% of customers had hourly price contracts. The proportion of customers with fixed-price contracts fell steadily during 2023 and early 2024 to 13.5% in February 2024, driven mainly by increased prices for fixed-term contracts owing to uncertainty over future electricity prices amid the energy crisis.

Sweden's electricity system is well-integrated with its neighbours. It has interconnections to Denmark, Finland, Germany, Lithuania, Norway and Poland. The country's interconnection capacity is 10.3 GW, which equates to around 21% of interconnectivity, well above the EU 2030 target of 15%. A new interconnector between northern Sweden and Finland (the Aurora Line) will further add around 750 megawatts (MW) of capacity and is expected to be in service in 2025.

Sweden is also well-connected with the European electricity market. As such, it is subject to the EU common electricity market regulations. Sweden is part of the pan-European market for the day-ahead and intra-day markets. Though balancing markets are currently regional among Nordic countries, the TSO plans to connect to European market coupling platforms for balancing energy within the next few years.

Sweden is divided into four bidding zones. Northern Sweden, with pricing zones SE1 and SE2, is currently a surplus area while the south is in a deficit in terms of production relative to consumption, especially pricing zone SE4 (see Focus Area "Preparing for electrification"). A European review of bidding zones is underway and will include Sweden.

Municipalities' veto right has hindered the development of renewable energy. Under the Swedish Constitution, municipalities are responsible for local issues, including spatial planning and construction permitting, giving them authority over the development of renewable energy projects within their regions. Municipal rejections have, for instance, slowed the approval rate of wind power licences in Sweden. Municipal rejections have been increasing in recent years with the proportion of rejected applications for new wind projects increasing to 78% in 2021 compared to 18% in 2018.

Fuels

Fossil fuels in Sweden account for just 24% of TES (2022), the lowest share among IEA member countries (the IEA average is 78%). Oil is the fossil fuel with the highest

share in TES (20%), as it is still used widely in the transport sector. Coal and natural gas are used mainly in industry and account, respectively, for just 3% and 1% of TES.

Oil

Oil is used in transport (47%), industry (26%) and for international bunkering (19%). In the transport sector, the lowered biofuel blending mandate is expected to increase oil consumption in 2024. The reduced blending quotas (now set at 10% over 2025-30) could also impact oil demand in the coming years. Energy and climate goals are broadly focused on increasing electrification and lowering oil consumption in transport.

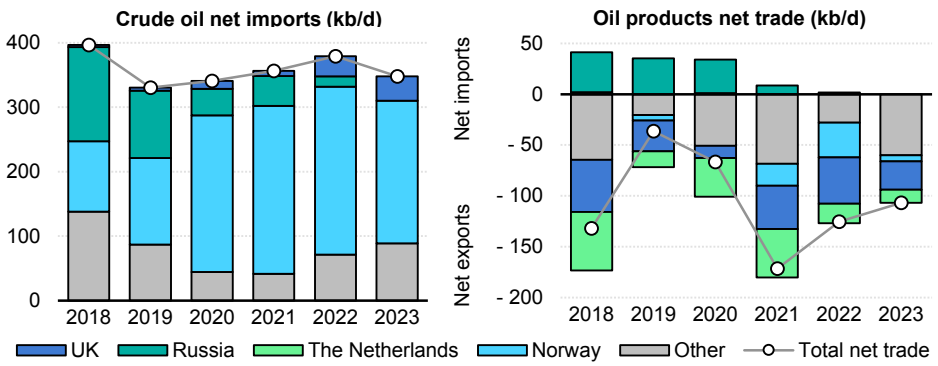
Without any domestic production, Sweden imports all its crude oil, mainly from Norway. In the early 2010s, Russia was the main supplier of crude oil (46% of total net imports in 2015). After 2016, however, imports from Norway started to increase significantly at the expense of Russia. In 2022, the share of Russian crude imports was just 4%. In 2020, Sweden also started to import from the United States, which accounted for 10% of net imports in 2022.

Swedish refineries produce oil products that are exported mainly to the United Kingdom, the Netherlands and Norway. Sweden has three fuel-producing refineries, which have a combined capacity of around 30 million tonnes per year of crude oil. The country used to import oil products from Russia (49 thousand barrels per day [kb/d] in 2016), but these imports drastically decreased to 1.6 kb/d in 2022.

Recently, refineries invested to increase their biofuels production capacity. In 2023, Preem announced a SEK 5.5 billion (EUR 472 million) investment to increase capacity and become the largest producer of sustainable aviation fuel in northern Europe, and the second-largest refinery, St1, announced a SEK 3 billion (EUR 258 million) investment to increase biofuel capacity.

Sweden has a market-based, competitive retail fuel sector. The sector is dominated by 4 large, private companies operating around 2 700 refuelling stations, which are supported by a network of storage depots throughout the country.

Crude oil and oil products net imports by country in Sweden, 2018-2023



Source: IEA (2024), Oil Information (database).

Natural gas

Sweden's consumption of natural gas is relatively low. In 2022, total natural gas consumption – used in industry (66%), buildings (15%), and electricity and heat generation (9%) – was less than 1 billion cubic metres (bcm). Natural gas is used in industry for energy and non-energy uses, including as a process fuel or raw material, mainly by chemical and petrochemical facilities. The increase in natural gas consumption in industry in 2017 is attributable to non-energy consumption growth in chemical industries, while the drop in 2022 is connected to high gas prices.

Sweden has no domestic production of natural gas, and primarily relies on Danish imports. All natural gas used in Sweden is imported, and Denmark made up almost 80% of imports in 2022. Swedish gas imports are transported by one pipeline between Denmark and Sweden. The long-standing Danish-Swedish trade relationship was reinforced in 2019 by the establishment of a common balancing zone for the Danish and West Swedish natural gas markets.

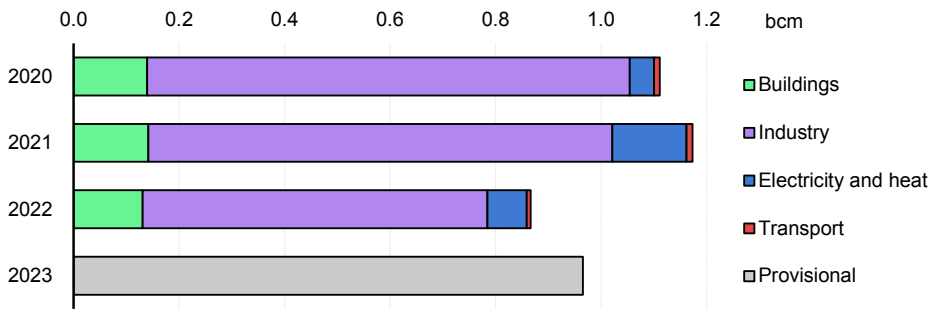
Sweden has diversified its gas imports in recent years. Since 2017, it has expanded trade with the Netherlands, Norway and Russia. However, amid the energy crisis that started in 2022, Sweden's imports of natural gas fell by 37% from 2021 to 2022 and slightly increased in 2023. More recently, Sweden has increased Norwegian imports following the 2022 commissioning of the Baltic Pipe (10 bcm/year capacity) from

Norway to Poland. Sweden began importing LNG to a port in Gothenburg in 2018, but it only supplies gas to local shipping, industry and heavy transport; the government decided not to allow a pipeline connection from the terminal to the gas transmission network.

Some biogas is produced domestically with incentives for high-quality gas that can be integrated into the grid. Since 2015, Sweden has employed a biogas support scheme to support biogas production from manure. In 2023, the scheme supported a total of SEK 72.5 million at a maximum of 0.40 SEK/kWh of biogas produced. Most of this biogas is used in the transport sector. Since 2022, there is an additional support to produce biogas upgraded to biomethane at a quality that can be injected into a methane distribution network.

Sweden has a well-developed gas infrastructure in its south-western regions and a competitive gas market. Swedegas owns and operates the national gas network that extends from Dragör in Denmark to Stenungsund in Sweden, supplying 33 municipalities, several co-generation plants and industries with gas. Swedegas also operates the Skallen gas storage in Halland, with a capacity of 10 million cubic metres, which can supply gas to customers in the event of supply disruptions or consumption spikes. As the gas TSO, Swedegas also has overall responsibility for the long-term development of the national grid and for ensuring that the market is well-supplied. Sweden has several gas network operators aside from Swedegas.

Natural gas consumption by sector in Sweden, 2020-2023



Note: Industry includes non-energy consumption. The breakdown by sector for 2023 is not available.
Source: IEA (2024), Natural Gas Information (database).

Recommendations

1. Clarify strategies, define intermediate milestones and accelerate implementation of policy measures to meet climate and energy targets.

Sweden has a number of targets that make up its pathway to net zero emissions by 2045. These include EU targets for sectoral emissions reductions, renewables and energy efficiency as well a domestic 2030 emissions reduction target for transport and a target of 100% fossil-free electricity by 2040. While the targets provide clear guidance on ultimate goals, the pathway to meeting those targets still faces some uncertainty. Though Sweden takes a market-led approach to energy sector development, in several cases the scarcity of sectoral strategies and limited policy levers creates challenges to realistically meeting the targets. This is evident across sectors, in buildings, transport, industry and electricity. Operationalising sectoral roadmaps created by Fossil Free Sweden would be a good place to start. Moreover, while Sweden's consultative approach to governance is commendable, the volume of inquiries into various policy settings for the energy sector are creating near-term uncertainty for investors and impeding faster progress on energy transition investments that are urgently needed to meet the scale of the emissions reduction and electrification challenge. This is especially true for 2030 targets, where even one- to two-year delays from inquiries will make reaching the targets more difficult and more expensive. Sweden should quickly transition to an implementation stage and prevent ongoing inquiries from resulting in delays to project advancement. The government should also avoid narrow terms of references for inquiries to ensure that new ideas are able to emerge from the investigations.

2. Prioritise policy action on energy efficiency as a guiding principle of energy transitions.

As a northern country with a cold climate and a sizeable energy-intensive industry sector, Sweden's energy intensity of GDP is relatively high compared to other IEA countries, both economy-wide (11th highest for total energy supply in 2023) and on a sectoral basis (4th highest for industry and 14th highest for residential buildings in 2022). However, to date, Sweden does not appear to apply the energy efficiency first principle to its energy policy framework. Effective support programmes as well as enforcement and implementation of existing requirements (such as buildings

certifications) seems to be limited. The buildings sector, in particular, would benefit from additional measures to support energy efficiency. While historically affordable electricity and highly decarbonised electricity and heating sectors do not always encourage energy efficiency measures from an affordability or carbon emissions perspective, lowering energy consumption should still be prioritised in its own right, as the cheapest energy is that which is not used. In a similar vein, energy efficiency improvements lead to overall cost reductions for consumers and improved competitiveness. Moreover, in light of the considerable additional demand for electricity that the energy transition will bring through electrification of end-use sectors (notably industry and transport), electricity savings achieved through energy efficiency can play a critical role in directing increasingly scarce electricity supply to the most pressing and economically efficient uses. Current market prices do not reflect these future demands on the electricity system. A greater focus on energy efficiency will also help Sweden meet targets under the updated EU Energy Efficiency Directive, while introducing energy-intensity sectoral targets would help accommodate new, efficient energy-intensive industrial processes.

3. Step up measures to lower transport emissions, ensuring strong growth for both biofuels and electric vehicles.

From a sectoral perspective, Sweden's transport sector presents the greatest challenge to meeting climate targets, especially the sectoral target of 70% emissions reductions by 2030. The transport challenge is not uncommon across countries, but Sweden's emissions trajectory in the sector is, in fact, poised to increase in the near term (by 5.1 Mt CO_2-eq to 8.4 Mt CO_2-eq by 2030, putting the country on a pathway to achieve 39-53% reductions by 2030). Sweden has made impressive progress on EV penetration in passenger vehicles, supported by tax benefits for low emissions vehicles, and EVs are poised for additional growth in the coming years as costs continue to come down. Additional policies may be necessary to accelerate uptake, including reconsidering a bonus for purchases in certain market segments, supporting charging points in multi-family buildings and offering a tax reduction on electricity used for charging. The government could also reconsider its relaxation of diesel taxes, which erodes the competitiveness of zero-emissions vehicles.

Notwithstanding EV progress, a large driver for the increase is a previous decision to retract the biofuels mandate, which was among the most ambitious in the world and had proven successful in displacing oil consumption in transport since it was first put

in place in 2018. The policy reversal was motivated by the 2022 energy crisis, which saw fuel prices spike, and the relaxation of the biofuels mandate (along with lowering diesel taxes) has coincided with price relief at the pump. More recently, the government's decision to increase the blending mandate from 6% to 10% over 2025-30 is a welcome development and could help meet 2030 EU Effort Sharing Regulation targets. Nonetheless, the new obligation is still significantly lower than the previous mandate and it is unclear to what extent electricity will push out biofuels from the system. The government should, therefore, consider a stronger biofuels policy from an emissions reduction perspective (especially in the period over which EVs ramp up), instead addressing affordability issues through more targeted support for low-income consumers. Complementary to a biofuels policy, the government should also consider alternative measures such as promoting modal shifts from road to rail and expanding the blending mandate to include other low emissions fuels such as renewable electricity and hydrogen. Moreover, policy U-turns such as the biofuels shift create investor uncertainty for certain sectors (in this case the domestic refining and biofuels production sectors) and undermine the overarching narrative for the energy transition imperative at a time when strong public messaging for emissions reduction policies is needed to accelerate action to meet targets.

Focus areas

Preparing for electrification

As in all countries, Sweden's decarbonisation pathway will involve large-scale electrification, placing its electricity sector at the centre of its energy transition. Though Sweden's buildings sector already uses a sizeable share of electricity, the transport and industry sectors are poised for considerable electrification in the coming years. Moreover, suitable conditions for energy-intensive industries in northern Sweden, including steel production and battery manufacturing, position the country for a green industrial transition that will draw heavily on electricity. As such, the electricity system needs to expand and adapt to accommodate the expected surge in load. Addressing system expansion, from both a generation and grids/system integration perspective, is currently one of Sweden's key challenges.

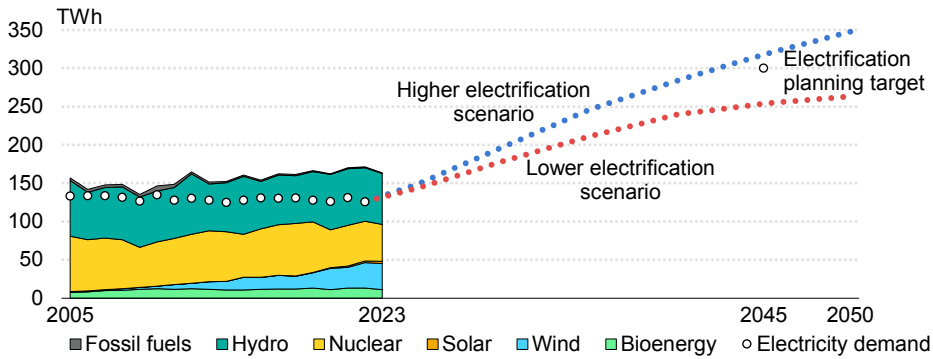
In response to the challenge posed by electrification, in March 2024 the Swedish government introduced an energy bill to parliament that is based on two central pillars: system planning and security of supply. A key objective of the bill is to ensure that Sweden can meet annual electricity demand of at least 300 TWh by 2045, and that supply and demand needs be clarified for each geographic zone for every five-year increment between 2030 and 2045.

Load growth

In the past three decades, Sweden has had relatively stable electricity demand. Today, electricity accounts for around a third of TFEC, among the highest levels in the world. However, as additional electrification takes hold in the industry and transport sectors to meet climate targets and the green industrial transition gets underway, the latest (2023) estimate by the Swedish Energy Agency, Svenska

kraftnät, the Swedish Energy Markets Inspectorate and the Swedish Transport Administration finds that electrification of end-use sectors will drive electricity demand from 140 TWh in 2023 to 160-210 TWh in 2030 and 200-340 TWh in 2045. Industry will underpin the lion's share of this growth, mainly from a few large projects. Depending on industry's plans for decarbonisation (along with broader low-carbon industrial development), which is the main uncertainty in the forecast, total electricity demand by 2045 could increase anywhere between 40% and 140%.

Electricity generation and demand and scenarios in Sweden, 2005-2023



Notes: Fossil fuels include coal, oil and natural gas. In 2023, together they accounted for 0.9 TWh of electricity generation. Electricity demand is not available for 2023. Both the electrification scenarios are expressed in terms on electricity demand.

Sources: IEA (2024), World Energy Balances (database); Swedish Energy Agency (2023), Scenarios for Sweden's energy system 2023.

Generation capacity

As part of its original 2019 National Energy and Climate Plan, Sweden outlined a target that 100% of its electricity production would come from renewable sources by 2040. More recently, under the Spring 2023 budget, the government revised the goal to 100% fossil-free electricity by 2040, to include nuclear power.

Meeting the expected growth in electricity loads will require roughly a doubling of electricity generation capacity from today's levels. The Swedish Energy Agency expects that in the near-term period of 2030-35, load growth will mostly be met by an

expansion of onshore wind and solar. In the longer term, offshore wind and new nuclear power are expected to play bigger roles.

Hydro

Hydropower forms the backbone of Sweden's electricity system. In an average year, hydro supplies around 45% of Sweden's electricity needs, though is more subject to annual variations than other generation sources owing to water inflow fluctuations. Notably, Sweden's hydro reservoirs can be used for energy storage, with a storage capacity equivalent to 25% of the country's yearly electricity consumption. Hydropower thus plays an important role both as a dispatchable power source and as a balancing resource for variable wind and solar output, which will become increasingly relevant in the coming years.

While the scope for new hydropower projects in Sweden is limited, companies are actively looking into ways to increase efficiencies and capacity at existing hydro sites. Over a 20-year period, Sweden began an environmental review process of all existing hydropower permits older than 40 years starting in February 2022. This process was paused in January 2023 to revisit the review conditions with an eye to maintaining and expanding the role of hydropower in Sweden. The review will also reconsider the previous target of limiting loss of hydropower production for environmental reasons to 2.3%, or 1.5 TWh, based on security of electricity supply considerations.

Sweden is also looking into ways to increase pumped hydro storage potential as the electricity system accommodates more variable renewable energy. Likewise, the TSO is undertaking grid expansion plans to direct more hydropower in northern Sweden to demand centres in the south.

Nuclear

The current government has placed a strong emphasis on nuclear power as the leading source of new large-scale generation capacity in the 2045 time frame, underpinned by the Tidö Agreement among coalition partners in parliament. The agreement committed SEK 400 billion (EUR 34.6 billion) in loan guarantees for the sector.

A nuclear roadmap from November 2023 announced plans to enable the construction of new nuclear capacity equivalent to two large-scale reactors with a total capacity of

2.5 GW by 2035 at the latest. The roadmap also sets a long-term ambition for a large nuclear buildout, approximately equivalent to ten new large-scale reactors (including possibly both large-scale and small modular reactors, amounting to roughly 12.5 GW) by 2045. It also noted the option of extending the operating life of existing nuclear reactors, which represents a lower cost proposition to keep more fossil-free generation in the system.

In January 2024, the government also reversed previous rules that capped the total number of reactors in the country at ten and that limited new reactor construction to existing sites, thereby removing key restrictions on new nuclear plant investments.

As in other advanced economies, high upfront costs and long development timelines have hindered progress for new nuclear builds. Moreover, in Sweden, the lack of new projects for decades means that the first movers on investment will bear higher costs before a domestic industry rebuilds. The private sector needs government-backed incentives to undertake investments, and getting the financing model right will be instrumental for Sweden to realise its ambitions.

To help support new nuclear investments, the government launched an inquiry that will assess the permitting process for nuclear plants to improve efficiency and shorten timelines, possibly through the introduction of a fast-track approval process. A separate investigation (in collaboration with the Ministry of Finance) was launched to determine the type of funding model that Sweden will deploy for new nuclear plants, with an eye to financial risk-sharing between the government and the private sector. The government has also appointed a national co-ordinator to support its efforts to expand nuclear power and implement the measures outlined in the roadmap.

The findings of the investigation into financing models were released in August 2024. The investigation looked at different models applied in recent years in Europe, including Czechia, Finland, France, Poland and the United Kingdom. It intends for Sweden's financing programme to support the first 4-6 GW of new generation capacity, or approximately 4 large-scale reactors. This means the support schemes would go beyond the government's 2035 target of 2.5 GW under the first phase of the nuclear roadmap, which likely represents a reasonable estimate of the number of projects needed to regain industry expertise. The report notes a benefit in using support models that the European Commission has already approved for state aid. Overall, the investigation recommended a risk-sharing model consisting of three main components: 1) state loans to lower the cost of capital; 2) a price-hedging mechanism

through a contract for difference with the government; and 3) a risk- and profit-sharing mechanism that ensures a minimum return on equity while avoiding excess profits.

Wind

Sweden has seen strong growth in wind power generation over the past decade and maintains a robust pipeline of new wind projects for the next few years. In fact, the government expects wind power to account for the bulk of new electricity generation capacity in the short term. Beyond the next few years, however, the pipeline for wind projects will taper considerably. The project pipeline is generally more robust in northern Sweden (where permitting is easier) compared to the south, despite good wind conditions in the south.

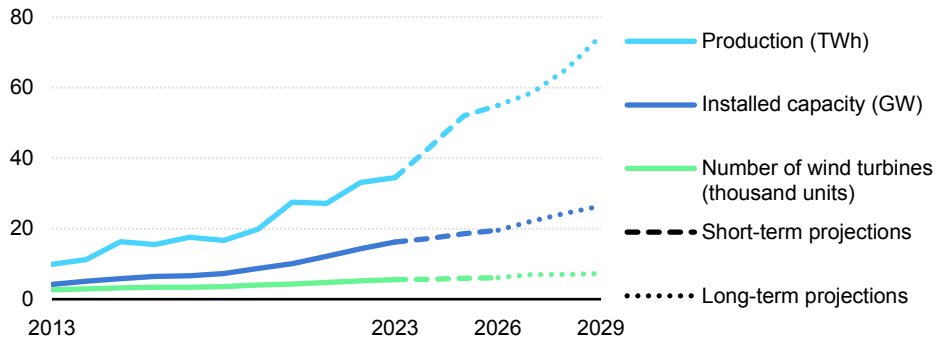
Sweden introduced an electricity certificate system for renewables in 2003. The programme granted renewable electricity producers a certificate, which could be sold in a free market to electricity consumers that had quota obligations for renewable electricity as a share of total electricity consumption (with exemptions for energy-intensive industries). Though the certificate system applied to all types of renewable generation, the biggest beneficiary was wind power. In 2020, Sweden decided to end the programme (run in unison with Norway since 2012) for new projects built after 2021 because the programme's targets had been met. As a result, the government no longer offers any subsidies to wind projects, and the current expansion is market-driven.

Today, onshore wind power benefits from low unit costs of production compared to other sources of generation. As such, it remains an economically advantageous choice for investors, even absent government incentives. The main challenge for new wind projects is permitting approvals, in particular local consent. Municipal approval is required, and municipal vetoes have foiled a number of projects in recent years. Moreover, vetoes can come at any point during a project's permitting process, creating uncertainty about project viability throughout the development timeline. Municipal opposition often stems from the lack of financial incentives from renewable projects, such as property taxes. For example, in Finland, wind developers pay a maximum 3.1% property tax to municipalities in which a wind farm is located. Elsewhere, Austria allows local municipalities to levy a property tax of between 0.1% and 0.2% on wind projects and Estonia imposes a land tax of between 0.1% and 0.25% that is fully paid to local governments in which projects are located. In Sweden, the property tax paid by wind power developers is directed to the state budget.

To help address the issue of local acceptance of wind projects, in 2022 the government appointed a special investigator to propose options for compensation to local communities. The inquiry issued recommendations in April 2023 and the government is now in the process of preparing proposals towards this end. Sweden could also look to other countries that have implemented community benefits programmes, such as Ireland, which established a community benefit fund into which project developers must pay EUR 2/MWh of electricity generated.

Unlike some of its neighbours, Sweden has had limited development of offshore wind to date. However, there is strong interest from investors and a long queue of grid connection applications, though several overlap in terms of sites and grid access. In total, 48 GW of offshore wind is awaiting approval, either from regional authorities (when closer to the shore) or the national government (when further out at sea), and another 56 GW is at an earlier stage in the process.

Wind development, historical and projected in Sweden, 2013-2029



Notes: 2024-26 projections based on ordered turbines and announced projects as of 19 April 2024. 2027-29 projections based on a scenario with an attractive market environment where all ordered turbines are delivered, all announced projects are realised, all presently authorised offshore projects are realised and 50% of presently authorised onshore projects are realised.

Source: Svensk Vindenergi (2024), Statistik och prognos – Q1 2024.

One impediment to development has been competing interests in Swedish waters of the Baltic Sea between energy developers and the Swedish Armed Forces. Risks of possible interference with military activities were the cause for rejection of over 3 000 turbine installations from 2017 to 2022. Fishing interests also exist in the region.

As a starting point, the Swedish Agency for Marine and Water Management already undertakes maritime spatial planning and was tasked by the government with updating plans to accommodate for more electricity demand.

Sweden could look to its neighbours, notably Denmark, for strategies to expand offshore wind and to balance competing offshore interests. Denmark's clear offshore wind strategies and targets, supported by centralised planning and implementing frameworks, have proven particularly successful at providing the wind industry clarity on the path forward. Comprehensive spatial planning and priority designation of sites would also help, as the United Kingdom does as part of its offshore wind auction process.

The Swedish government launched an investigation into permitting for offshore wind in May 2023 to assess the regulatory framework for supporting offshore wind development in Sweden's economic zone. Results from the inquiry are due in November 2024.

The process of grid connection also remains an important one for offshore wind developers. Under the Tidö Agreement, the government scrapped an earlier exemption offered to offshore wind project developers to pay for grid connections, which will increase costs for offshore wind. Svenska kraftnät is currently exploring options to facilitate offshore wind grid connections, including communicating preferred onshore connection points and available transmission capacity.

Solar

Compared to wind, solar power has experienced more limited growth, partly due to Sweden's relatively limited solar radiation, particularly in the winter months when electricity demand is the greatest. Nonetheless, the sector is poised for additional growth and is expected to be a key source of fossil-free generation in the years to come, particularly large-scale solar plus storage.

Though Sweden scrapped the renewable energy certification scheme, the government still offers incentives to homeowners for rooftop solar installations in the form of tax deductions. The "grön teknik" (green deduction) covers up to 20% of the cost of solar installations up to a maximum of SEK 50 000 (EUR 4 300) per person per year. Households can also apply for a renovation tax rebate of up to 9% of costs for solar panel installations. Rooftop solar installations, along with battery storage, experienced a surge in 2023, bolstered by the energy crisis, but are expected to slow

in 2024. Since 2015, micro-producers of solar electricity in Sweden can receive a tax credit on excess energy corresponding to 0.6 SEK/kWh.

In the long term, the government prefers that solar power be market-based and not dependent on subsidies. Moreover, given variability, the government sees storage as a critical security of supply component to complement solar power. Large-scale solar installations could also face similar local consent challenges and issues with competing interests as wind currently faces.

Electricity prices

Overall, Sweden has experienced increased price volatility in recent years compared to decades past. This partly coincides with the growing share of variable renewables in its electricity mix, which is expected to increase in the coming years.

The high degree of interconnectivity with the rest of Europe also means that Sweden is more exposed to importing energy price spikes from neighbouring countries, as was made acutely evident during the energy crisis in 2022-23. The issue of high electricity prices became a headline political issue during this period, though the government resisted applying price caps. Moreover, the rationale for interconnections came under public scrutiny due to high prices, despite the flexibility benefits they provide to the system. In fact, the risk of importing high prices was the rationale for the government to reject an application for a planned interconnector to Germany in June 2024.

The electricity price outlook for Sweden is an instrumental variable in its energy transition, as electricity becomes the cornerstone of the energy system. Notably for Swedish industry, electricity prices will be a key determinant of competitiveness. As Sweden's industries look to decarbonise, affordable electricity will be essential to realise plans for new facilities and technologies, including hydrogen. Moreover, plans

to site new industrial facilities in the north of Sweden, where prices are currently low, may not be sustainable as a few large projects can drive up demand, resulting in price spikes.

Beyond industry, keeping the cost of electricity down for all consumers will be essential to ensuring fairness and ongoing public support for the energy transition and preventing average households (especially low-income ones) from bearing the brunt of changes to the system that the energy transition brings.

Power balance and regional variations

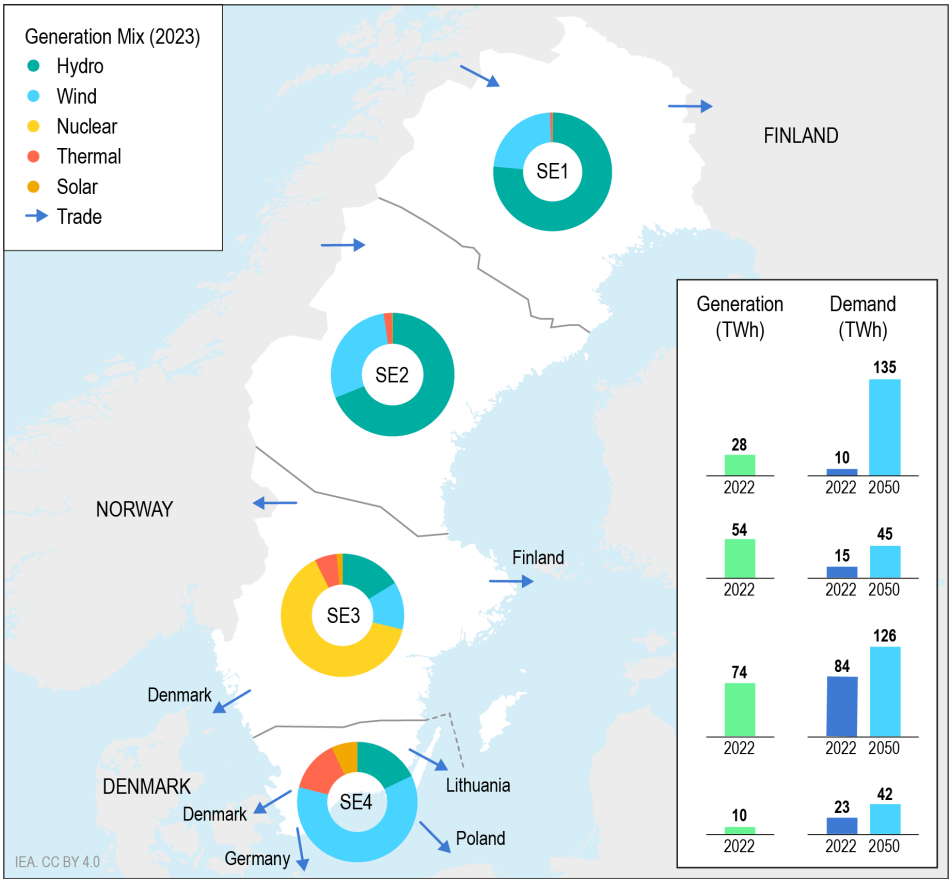
Even though growth in wind power has led to increased net electricity exports on an annualised basis, the south of Sweden is experiencing growing challenges with its power balance, raising the call on imports during peak consumption periods.

Moreover, regional disparities across the country's four power balancing regions (SE1-SE4, from north to south) have grown. Notably, prices in the south of Sweden – home to all current nuclear capacity and where the bulk of demand comes from – have, in recent years, been significantly higher than those in the north – where most hydro and wind resources are located. The recent energy crisis stemming from Russia's invasion of Ukraine have driven up electricity prices on the European continent and exacerbated regional price variances in Sweden. The largest price differential was recorded in August 2022, when the average price in SE4 was 305 SEK/kWh relative to just 18 SEK/kWh in SE1. Differentials were not as significant in 2023, however.

Insufficient transmission capacity from north to south has prevented directional flows to deficit regions that would otherwise have been motivated by price signals. The price signals have similarly not led to sufficient new investment in generation capacity in deficit areas. In fact, southern Sweden has among the highest power deficits in the European Union. Sweden is currently in the process of reviewing its pricing zones as part of an EU review of the division of electricity areas in Europe, to which Svenska kraftnät is due to submit recommendations in 2024.

In the coming years, the power balance in northern Sweden is also expected to shift as a number of large industrial facilities are planned to be sited there to take advantage of the low electricity prices. In fact, the TSO expects region SE1 to shift to a power deficit as early as 2035 in all its scenarios. This will reduce the electricity currently supplied to consumers in the south of Sweden from generation in the north.

Map of electricity bidding zones and respective generation (2022, 2023) and demand (2022, 2050) in Sweden



IEA. CC BY 4.0.

Sources: IEA analysis based on data from Swedish Energy Agency (2023), Development paths for electricity generation; Svenska kraftnät (2024), Electricity statistics; Svenska kraftnät (2024), The control room.

Grid expansion

Sweden's transmission grid will play a crucial role in realising its energy transition plans. Not only will the grid need to expand significantly to meet accelerating load growth from electrification, it will also be instrumental in addressing regional power imbalances and price discrepancies.

The TSO, Svenska kraftnät, notes four main drivers for transmission grid development in the next decade (2024-33): 1) reinvestment to service existing lines; 2) expansion to accommodate increased connection needs; 3) system reinforcement to expand coverage areas; and 4) market integration with neighbouring countries. To ensure multi-year planning for transmission capacity, the government has directed Svenska kraftnät to propose targets for increasing transmission capacity between balancing areas to 2030, 2035, 2040 and 2045. These targets are supposed to reflect societal requirements for electrification and the government's estimate that total demand will grow by at least 300 TWh by 2045.

However, sizeable uncertainties exist in the long-term forecasts, including the scale of industrial demand for electricity in the north, offshore wind development in the south, and the outlook for existing and new nuclear plants. Industrial plants and hydrogen production facilities, whose size and scale can create enormous demand from just one facility, are particularly challenging to incorporate into forecasts given uncertainties on which ones will move forward. The expansion and integration of EV charging infrastructure will also need to be co-ordinated with the development of local and regional network owners.

The current process for transmission lines can be quite lengthy, which does not align with the needs of a rapidly transitioning energy system. Svenska kraftnät estimates that the process from project conception to completion of a line can take around 15 years. The TSO is in the process of identifying solutions to halve the lead times for overhead lines by the end of 2024. A large part of this effort will be focused on starting internal work on permits and land access earlier in the overall process to allow several steps to be carried out simultaneously rather than sequentially. It similarly promotes a more co-ordinated approach among relevant authorities. However, other areas also require reform, including spatial planning and community engagement.

Svenska kraftnät is also currently involved in a government commission, together with the Swedish Energy Markets Inspectorate, Lantmäteriet (the Mapping, Cadastral and

Land Registration Authority) and county administrative boards, to identify new approaches to reducing lead times and to streamline the permitting process for grid projects.

Large-scale infrastructure development, such as utility-scale power plants and grid lines, can have a noticeable geographic footprint and can come into conflict with competing uses for land. This holds especially true as generation and grid capacity needs surge and required timescales for investment and construction accelerate. Therefore, planning for growth of the electricity system will take on more significance as energy transitions advance, with close co-operation across national, regional and municipal authorities.

Existing regulatory models for grid planning and investments might warrant reconsideration, especially in liberalised markets such as Sweden, where generation, transmission and distribution functions are all carried out by different parties. In particular, a clear vision from the government on the long-term direction of travel and requirements for the electricity system would help mobilise investments in the most appropriate areas. Compared to other countries, Sweden has an exclusively market-driven approach to system planning, particularly in terms of siting new generation and consumption facilities. Many other market-based economies include some degree of co-ordinated planning to support the development of areas more suitable for generation or demand, such as integrated system plans (e.g. Australia) or industrial development clusters (e.g. United Kingdom).

Beyond the transmission level, regional and local grid companies are required to release ten-year grid development plans every two years. The plans must include planned investments and flexibility requirements in line with forecasted demand growth. Increasingly, grid development plans for the transmission and distribution networks will need to be more co-ordinated and aligned as the overall system becomes more integrated and flexibility and digitalisation needs grow, notably demand response and distributed resources. Likewise, co-ordinated planning for electricity and hydrogen grid development will be needed, given the interconnectedness of the two systems. Sweden will also need to co-ordinate interconnection capacity, particularly with its SE1-SE2 regions and Finland and Norway, in a context where all countries will experience unprecedented electricity demand growth and expanded hydrogen infrastructure.

System flexibility

Rapid growth in electrification along with a greater role for variable renewable energy in the electricity system will warrant a greater emphasis on system flexibility. Sweden will need to significantly expand the role of flexibility resources and digital tools to support system stability and operational efficiency.

Demand will play a key role in bolstering system flexibility. To start, it will be important to ensure that efforts to electrify industry and transport are undertaken with due consideration of energy efficiency measures so that the additional call on power supply is contained.

Moreover, demand flexibility can play a key role in improving the power balance. Demand-side response (DSR) measures are still in their nascency in Sweden. Key enablers for DSR are price signals and access to information. The energy bill notes the lack of sufficient data and effective data management along with the lack of data communication standards. Similarly, Sweden does not have a framework for data aggregation that would facilitate the growth of data aggregation services to support flexibility solutions. Pilot projects for new compensation models for flexibility services, such as aggregation of home batteries for ancillary services or discounts on EV charging, are underway in certain locations (such as Stockholm Flex). The roll-out of time-differentiated tariffs, expected over the next two years, will also support more DSR for flexibility.

Sweden has the option to use both pumped hydro storage and battery storage solutions to balance its grid. Existing hydropower resources offer a good starting point for the system. However, given limited options for new hydro projects, future balancing needs based on the energy transition will require additional resources that could come from batteries.

Storage assets in Sweden can participate in frequency and ancillary services, which are currently the main revenue sources. Notably, the market for battery storage in Sweden improved with the introduction of the Fast Frequency Reserve market across the Nordic countries in 2020, which removed barriers to entry and improved the participation of fast-acting services. The decision by Nordic TSOs to switch from a one-hour imbalance settlement period to 15 minutes will further support the participation of battery storage.

Hydrogen plants can also play a role in providing system flexibility. Though not in use today, the TSO in its long-term power system scenarios expects hydrogen storage to play the largest flexibility role.

Moreover, Sweden has the potential to use thermal energy storage, mainly related to its DH systems, to introduce more flexibility into electricity supply from co-generation plants. For example, a previous oil storage facility in Västerås is being converted to store excess heat from the Mälarenergi co-generation plant during summer months for use in the winter, freeing up electricity production in winter months.

Digitalisation will also play an important flexibility function in the Swedish electricity system over the coming years. Sweden was one of the first countries in Europe to deploy smart meters based on regulation in 2003, with a target to roll out monthly metering for all small electricity customers and hourly metering for large consumers by 2009. The roll-out of first-generation meters was followed by a second roll-out of next-generation meters, which is still underway. The smart metering capabilities provide Sweden with the potential to use demand measures for flexibility more systematically than have been applied to date. Increased digitalisation will also need to be accompanied by due consideration of the increased risk of cyberattacks along the electricity supply chain.

Overall, Sweden will need to not only rebalance price variations across regions, but also ensure system-wide planning that considers long-term needs for generation, consumption, transmission and interconnectedness of sectors. A broad inquiry into Sweden's electricity market development and regulation is underway and due to report findings by 25 April 2025.

Recommendations

4. Undertake system-level analysis and planning to adequately prepare for increased electrification.

Sweden takes a market-led approach to electricity sector development. However, as it looks towards a doubling of electricity consumption in the coming decades, the scale of the challenge requires a more co-ordinated approach to system planning, led by the electricity TSO Svenska kraftnät. The government's 300 TWh planning target for electricity demand by 2045 is not underpinned by concrete planning for the sources

of generation, locational needs and grid infrastructure to support it. Without clarity on future energy infrastructure, companies are likely to postpone projects or develop them in suboptimal locations. The TSO's grid development plan is a solid starting point. The power system (including both the transmission and distribution levels) should be optimised to accommodate mass electrification, so mapping of grid connection needs and availability will help support project advancement (both generation and consumption). In particular, the government could direct the TSO and DSOs to identify and communicate geographic areas suitable for different generation types against load needs as well as flexibility needs across the system. It should likewise incorporate forthcoming changes to distribution grids, such as growth in behind-the-meter consumption and electric vehicle charging. Such system planning is not uncommon in other market-based economies, as it can provide clarity and help guide investments to areas where they are most needed (see also Recommendation 10).

5. Accelerate grid connections through an updated and more transparent selection process, along with promotion of flexibility mechanisms.

As in most countries facing large-scale electrification as part of energy transitions, Sweden is facing a surge in grid connection requests from generation facilities and large industrial users (as well as data centres). Many projects are geographically overlapping and not all projects will come to fruition. Therefore, a traditional approach to grid connections on a first-come, first-served basis is no longer appropriate. The government and Svenska kraftnät have recognised that reforms to the grid access process are needed. The TSO has already implemented some changes to offer grid access based on project maturity and is in the process of implementing additional reforms to limit reserved but unused grid capacity. All these steps are welcome developments and offer a good starting point. However, additional efforts are likely warranted to quickly unlock a pipeline of over 20 GW of capacity. Developers would likely accept some degree of partial grid access, which should be considered. The TSO could likewise place connection requirements on grid users to enhance flexibility and limit the need for additional infrastructure. Moreover, as the grid connection process shifts away from a first-come, first-served model, ensuring full transparency and predictability of the new selection process will be critical to preserving investor confidence. One important option is to incentivise more flexibility solutions to optimise the use of the existing grid, which will be underpinned by increased digitalisation. The regulator could allow flexibility-focused operating expenses and investments in

research, innovation and digitalisation to be recovered through tariffs rather than only new grid lines with long development timelines. At the same time, the government should promote the continued development and scaling up of successful local flexibility platforms. It should likewise remove barriers to participation from small users and aggregators and help expand the penetration of locational signals for grid users through differentiated grid tariffs.

6. Ensure a level playing field and technology-neutral approach across generation options and time horizons.

Sweden's growing electricity needs in line with electrification goals will necessitate a major buildout of new generation capacity in the coming years and decades. No single generation type will meet all these needs, highlighting the need for different generation sources spanning the time horizon to 2045. In this regard, the government's focus on new nuclear builds has its merits, and its extension of the electricity target to include all "fossil-free" generation sources is, in principle, welcome to avoid disadvantaging nuclear in the future energy mix. However, a singular policy focus on nuclear should not undermine the case for other forms of generation, especially where policy interventions to remove roadblocks may be needed. Notably, realistic timelines for new nuclear make it a more suitable option to meet longer term load needs, while other sources of generation offer shorter term capacity solutions, notably onshore and offshore wind. The government should ensure that its policy focus on nuclear does not impede strong growth potential in wind generation capacity. A perceived rivalry between nuclear and wind is counterproductive to the overarching objective to achieve a diversified and secure fossil-free electricity system, where all clean energy sources will have a role to play in achieving net zero targets.

7. Facilitate the permitting of new generation capacity, especially wind.

Wind projects are already economical to build without additional government support. The main impediment to wind projects is a municipal veto that is used unpredictably across the permitting process. In the current system, municipalities cannot directly benefit from revenues related to energy infrastructure projects. For example, property taxes paid by wind developers are channelled directly to the state budget. While most notably impacting wind projects today, future investments in transmission lines, solar

photovoltaics, hydrogen pipelines and nuclear power projects might also face the same local acceptance challenges. Options could include a policy change to direct local taxes to municipalities to minimise the exercise of municipal vetoes on energy-related infrastructure projects as well as the creation of community benefit funds paid for by project developers. Moreover, the government could also consider limiting the exercise of municipal vetoes to the early stages of a project's permitting process as currently a veto can come at any point during the development time frame (and without clear justification), including after preliminary approvals have already been granted. The creation of a "one-stop shop" for permitting, as required under the EU Renewable Energy Directive, would also support a more streamlined and systematic approach to permitting.

Likewise, the development of an offshore wind sector has been stifled by vetoes from competing interests, notably the Swedish Armed Forces. While national defence interests are undoubtedly critical, the government could support sectoral development by creating a forum for dialogue between all regional interests. Such dialogues should support finding a middle ground between additional electricity generation requirements and national security interests, with an eye towards issuing more conditional approvals that allow project advancement if certain conditions are met. Efforts in other countries to streamline stakeholder engagement, address competing interests through strategic spatial planning and priority zoning, and increase predictability around project approvals could offer lessons for the Swedish context.

8. Establish a framework for efficient licensing, project management and financing for nuclear new builds.

Both the industry and energy agencies acknowledge that in the mid- to long term, nuclear power, as a dispatchable baseload source, will be important to maintaining a stable and competitive decarbonised electricity system, which is expected to nearly double by 2045. The government's vision for this nuclear new-build programme is that it will be private sector-driven, while the state's role is to create the enabling conditions for it to materialise in an efficient, timely and competitive manner. It is essential that forthcoming financing model(s) and related policy decisions provide: 1) predictability and stability in licensing, public consultation and authorisation processes; 2) economic viability for all parties (ensuring competitive electricity prices, fair risks and benefits allocations); and 3) support a long-term national consensus on the role of nuclear power, in conjunction with other carbon-free sources, in achieving the

country's net zero ambitions in the most efficient and timely way. Such a framework is a prerequisite to ensure investment in new nuclear capacity in a timely fashion. To support this effort, financing and project management best practices should be identified among recent and ongoing new build projects in OECD countries. Importantly, Sweden should co-ordinate nuclear support programmes with broader electricity market design developments to ensure that these measures in aggregate make the overall system more efficient and flexible.

Hydrogen for decarbonising industry

Industrial decarbonisation

Sweden's export-oriented industrial sector accounts for around a third of the country's total GHG emissions and is a major contributor to the overall economy and jobs. The sector encompasses several sub-sectors, including automotive, telecom, chemicals and refining, life science, pulp and paper, cement, and steel and iron. Industries are spread across a number of geographical areas, but concentrated in a few, large clusters, notably the north (iron and steel) and west (oil and chemical refining). Most emissions from the sector are related to fossil fuels used in specific processes requiring high temperatures and are, therefore, harder to abate. Given their role in the economy, ensuring the competitiveness of Swedish industry through the transition is a top priority.

To support efforts by Sweden's economic sectors to decarbonise, the government-led initiative, Fossil Free Sweden, was established in 2015 to spearhead companies and other stakeholders in 22 sectors to develop decarbonisation roadmaps towards the goal of net zero emissions by 2045. The initiative offers a constructive approach to decarbonisation by aligning and co-ordinating government goals with industry plans.

Industrial processes in Sweden are focused on five key technology options for decarbonisation: 1) biomass; 2) electrification; 3) hydrogen; 4) CCS and BECCS; and 5) carbon capture and utilisation.

The EU ETS is the primary policy tool to drive industrial decarbonisation in Sweden, with a target for emissions reductions of 62% under the system from 2005 levels by 2030. Industry, however, receives a portion of its allowances for free based on a

benchmarking calculation to mitigate against carbon leakage concerns (to be phased down over time). This is complemented by the EU Renewable Energy Directive that establishes sectoral targets for the share of renewable energy in final energy consumption. For industry, it sets an indicative target of a 1.6% annual increase in the share of renewable energy, in addition to a binding target that at least 42% of hydrogen used in industry be sourced from renewable fuels of non-biological origin.

To support industrial decarbonisation, in addition to credit guarantees (SEK 80 billion in 2024) for green investments, in 2018 Sweden announced the creation of the Industrial Leap programme, which is part of the European Recovery and Resilience Facility and the Next Generation EU programme. The Industrial Leap programme is funded for SEK 1.46 billion (EUR 129 million) in 2024 to cover projects that run until 2031. To date it is estimated that SEK 6.4 billion in government funding has leveraged SEK 36 billion in private sector co-financing to support over 160 projects. It provides investment support for projects that reduce GHG emissions from process industry, negative CO_2 emissions and BECCS, and strategic projects that support net zero emissions at a societal level. It supports projects across all development stages, from industrial research to pilot projects and first-of-a-kind investments.

Sweden's iron and steel industry is a long-standing cornerstone of the Swedish economy. The sector contributes around 6 Mt CO_2-eq per year of GHG emissions (almost 13% of GHG emissions in 2021), with the vast majority (85%) coming from the conversion of iron ore using coal. As such, decarbonisation of steel is a top priority for industrial decarbonisation.

Based on a target for fossil-free steel production by 2045, the steel industry has developed a roadmap for decarbonisation. It includes measures to transition from coal to low emissions hydrogen for the direct reduction of iron ore, electrifying furnaces and using bio-coal to replace fossil fuels in some processes. Among these, the largest reductions would come from the switch to low emissions hydrogen – the industry's primary focus to realise decarbonisation plans.

Hydrogen

As highlighted in Sweden's 2024 energy bill, low-emission hydrogen (using fossil-free electricity generation) is seen to play a critical role in Sweden's future energy system and will be instrumental to phasing out fossil fuels from industry (and important for transport sector decarbonisation).

In March 2023, the government commissioned the Swedish Energy Agency to co-ordinate work on hydrogen in the country, in collaboration with other stakeholders in industry and society. The assignment is due to expire at the end of 2024, though the government is assessing whether to offer the agency an extension.

Sweden's hydrogen approach is currently rooted in a set of principles outlined in the long-term energy bill that are expected to guide the sector's development:

- Low emissions hydrogen should contribute to the transition away from fossil fuel energy systems and industrial processes.
- Hydrogen should focus on economically efficient applications that lack viable alternatives.
- Hydrogen production should be well integrated with Sweden's electricity and heating systems and support security of energy supply.
- Hydrogen infrastructure should be developed in ways that do not conflict with climate mitigation efforts and that do not drive up electricity prices to uncompetitive levels.

However, beyond a set of principles for the development of hydrogen, unlike some other countries with hydrogen plans, the Swedish government has not established targets for hydrogen production or electrolyser capacity. The rationale for this approach was to preserve a market-driven approach to hydrogen driven by industry demand and capabilities rather than supply targets set by the government. Moreover, the Swedish approach also recognises that hydrogen development will be heavily dominated by industrial decarbonisation efforts rather than oriented towards a larger industry that supports large-scale use in transport or for export.

Hydrogen strategies

Fossil Free Sweden worked with stakeholders in the sector to develop an industry-led hydrogen strategy in 2021, which offers recommendations and pathways for hydrogen development in the country. It is focused on the acceleration of hydrogen infrastructure and supply chains through the creation of cross-sectoral local and regional hydrogen clusters, or hydrogen valleys. The goal is to align with existing infrastructure such as ports as well as the location of existing industrial facilities that plan to use hydrogen.

The strategy notes that several projects are already at various stages of development for hydrogen production and use. These projects are estimated to result in

CO_2 reductions of 7.1 million tonnes annually by 2045, or 14% of Sweden's total emissions. At the same time, a planning goal of 8 GW of electrolyser capacity by 2045 is expected to require around 55 TWh of electricity. Lastly, the strategy highlights the ongoing role that research and development along with skills training (in industry and within government) will play as hydrogen is effectively introduced and expanded in the energy system.

The Swedish Energy Agency also released a proposed hydrogen strategy in 2021. Among other things, it included planning targets for 5 GW of electrolyser capacity by 2030 and an additional 10 GW by 2045 (for a total of 15 GW). It estimates that this level of electrolyser capacity would require around 60-126 TWh of annual electricity demand (relative to total electricity demand of around 126 TWh in 2022). This, in turn, could result in 3-6% reductions in CO_2 emissions by 2030 and 15-30% by 2045 (relative to 2021 levels). The strategy document also recommends an inquiry into policy instruments to narrow the cost gap between low emissions hydrogen and fossil hydrogen as well as the creation of a platform for dialogue on hydrogen development among key stakeholders. However, the government has not adopted the proposed strategy as its official policy.

Policy and regulation

From a regulatory perspective, Sweden does not have a dedicated regulatory framework for hydrogen in place. A set of regulations on hydrogen production and networks (as part of revisions to gas market regulations) was adopted at the EU level in June 2024, expected to be implemented in full in 2033. The new rules under the EU Hydrogen and Decarbonised Gas Package will outline parameters for national revenue regulations, third-party access, unbundling, network planning and cross-border hydrogen transit. The Swedish Energy Markets Inspectorate has been assigned responsibility for proposing implementation plans for most of the articles in the package, due by late June 2025. Additional measures to fully implement the package are still being considered.

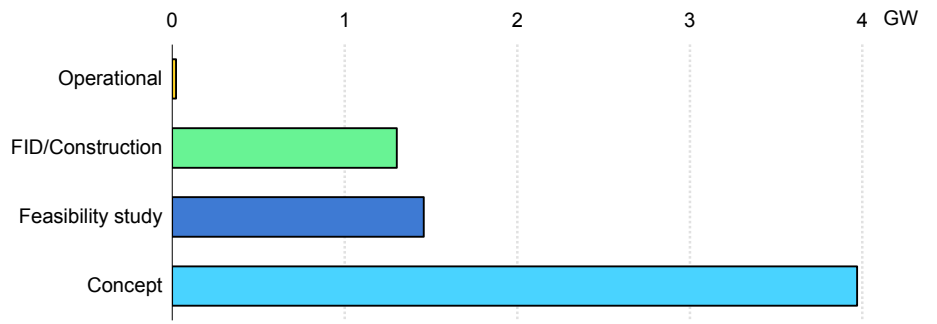
Although Sweden does not have a dedicated regulatory framework for hydrogen pipelines, this does not preclude pipeline projects from moving forward based on existing pipeline regulatory structures.

In terms of financial incentives, Sweden mainly allows development of the sector without major subsidies. However, the Industrial Leap project has funded hydrogen

initiatives, as has the Climate Leap programme, which supports local initiatives to reduce GHG emissions. Regional electrification pilots and EU support programmes such as the Innovation Fund also offer support to the sector.

The Swedish government plans to introduce an Energy Research Bill at the end of 2024, which will include a section dedicated to hydrogen.

Power-to-X production projects by status and capacity in Sweden until 2030



Notes: FID = final investment decision. For ease of comparison, estimated normalised hydrogen production capacity in MW H_2 output is included for all power-to-X projects.
Source: IEA (2024), Hydrogen Production and Infrastructure Projects Database.

International collaboration

Sweden participates in several international fora on hydrogen, including the IEA Technology Collaboration Programmes “Hydrogen” and “Advanced Fuel Cells” and the working group on renewables and hydrogen within the Nordic Council of Ministers. Sweden also has two hydrogen projects on the EU list of Projects of Common Interest and expects that project developers will apply for funding from the Connecting Europe Facility framework. Additional areas for international collaboration could be explored further, including around standards and regulations, especially in the EU context.

Current projects

Sweden can already be considered a global leader in hydrogen-based steel production, based on projects currently underway. Most projects are targeted in northern Sweden, where there is currently abundant, reliable, low emissions

electricity along with good quality iron ore resources. These early movers will help pave the way for additional projects (not only in steel), but growth also hinges on expanded hydrogen infrastructure and, most crucially, sustained access to low-cost, fossil-free electricity.

Hybrit/LKAB

Swedish companies SSAB (steel), LKAB (iron ore) and Vattenfall have a joint company Hybrit Development AB for hydrogen production to use for fossil-free steel production. The Hybrit project has also received support (SEK 3.1 billion, or EUR 267 million) through the government's Industrial Leap programme. The Hybrit project will convert iron ore from LKAB's mines to iron ore pellets using biofuels instead of fossil fuels. The pellets will then be reduced to CO_2-free sponge iron using low emissions hydrogen instead of coal and coke at an LKAB pilot plant in Gällivare. The pilot plant is targeted to produce 1-1.5 million tonnes of sponge-iron per year, which will then be smelted using an electric arc furnace (see below). The plant has already successfully produced pilot scale sponge iron.

SSAB

SSAB plans to build a fossil-free, mini-mill in Luleå (northern Sweden) using Hybrit technology to produce low emissions hydrogen for the direct reduction process. The mill, which is expected to start production in 2028 and reach full capacity a year later, will have a production capacity of 2.5 million tonnes per year of green steel. It will use a combination of fossil-free sponge iron from the Hybrit demonstration plant in Gällivare as well as recycled scrap. The company expects the full switch to hydrogen at the plant to reduce Sweden's national emissions by 7%.

Stegra (formerly H2 Green Steel)

Stegra, a new company established in 2020, is developing a large-scale (700-800 MW) electrolyser, supplied by fossil-free electricity, in Boden (northern Sweden) to produce the hydrogen necessary to manufacture 5 million tonnes of steel annually by 2030. The electrolysis facility will be integrated into the steel plant and is expected to begin operations in 2025. The hydrogen will mainly be used to reduce iron ore, thereby cutting CO_2 emissions by roughly 95% by avoiding coal use. Importantly, Stegra's funding model is partly based on offtake contracts that it has signed for its green steel.

The company signed a partnership with Fortum for the supply of fossil-free electricity to its operations under two power purchase agreements: 1) for 1.3 TWh to be supplied annually on an index basis for five years from 2026; and 2) a fixed-price purchase power agreement for up to nine years from 2027.

Electricity supply

A lynchpin of low-emission hydrogen production through electrolysis is fossil-free electricity. Today, conditions in northern Sweden are suitable for low-emission hydrogen production based on an abundance of low-cost hydropower in the region. However, to realise plans for fossil fuel steel production, not to mention decarbonising other industrial sectors, Sweden will experience a major demand surge for electricity. Not only will this require additional generation capacity, but also the associated grid buildout and connections to meet new demand. Moreover, a spike in electricity demand from even one, large green steel facility in northern Sweden could erase the region's surplus and undermine the investment case for additional investments.

Stegra and SSAB are already vying for available grid access in the north. Historically, grid access was granted on a first-come, first-served basis (as allocated by the DSOs). This approach was partly revised in December 2023 when TSO Svenska kraftnät incorporated a recommendation to the DSOs for new non-binding criteria that was meant to help more advanced projects secure grid connections faster. Based on the changes, Vattenfall allocated 500 MW of capacity to Hybrit and delayed access for the second phase of Stegra's project (the decision does not impact Stegra's first phase, which has already secured grid access). Currently, an estimated 20 GW of connections are queued for grid access in the region, and the decision has called into question the process for grid connections, including transparency around selection criteria and consistency in application by the DSOs. In response, the government tasked the Swedish Energy Markets Inspectorate to lead a reform effort of the regulatory regime for electricity supply and grid access in the north.

The Swedish Energy Agency's long-term scenarios forecast that hydrogen investments by industry could drive electricity demand by 22-100 TWh by 2050. Therefore, the considerable variance in estimates creates uncertainty around investments for both hydrogen and electricity.

The government also sees hydrogen playing an important role in balancing the electricity system based on flexible demand from electrolysers and hydrogen storage.

To achieve this, hydrogen infrastructure planning would need to be co-ordinated with planning for the electricity and heating systems, including clarifying roles and responsibilities for all parties (notably system operators). In some places, hydrogen pipelines that connect with power generation sites can also be used to supply industries with hydrogen instead of large electricity grid connections that supply electrolysers to industrial sites.

Pipeline infrastructure

Unlike many other EU countries, Sweden does not have an extensive existing natural gas pipeline network to repurpose for hydrogen, so hydrogen infrastructure will require new greenfield investments. Though the conversion of existing gas networks comes with its own set of challenges, new pipeline investments could face siting disputes and local opposition. In addition, uncertainties about exactly where demand will be located could also complicate infrastructure investments. To help address this issue, in June 2024 the government tasked the electricity TSO with co-planning electricity and hydrogen infrastructure in bidding zone SE2 (Norrbotten and Västerbotten counties) by August 2025.

Recommendations

9. Issue a hydrogen strategy that guides the establishment of rules and responsibilities for system development and operation.

Sweden has not developed a dedicated hydrogen strategy, though it has included guiding principles for hydrogen in its latest energy bill focused on the electricity system. The development of a hydrogen market would benefit from a more detailed strategy that clarifies the role hydrogen will play in the future energy system and the infrastructure required to support it. A hydrogen strategy does not necessarily need to include long-term supply targets for hydrogen or electrolyser capacity, but it is useful to outline what decisions the government will take when and based on which information. The government should also assess the costs and competitiveness implications of hydrogen projects and consider whether additional support mechanisms are needed. The clarification of a system planning entity for the hydrogen sector along with delineating roles and responsibilities for regulation and oversight of the sector is lacking, creating uncertainty for investors. Likewise, the

absence of a defined risk-sharing model and tariff structures for hydrogen infrastructure are also impeding investments. Currently, the regulatory framework for hydrogen is expected to be developed gradually, in line with the updated EU Gas Directive, by 2033. In the meanwhile, the regulation is planned to track market development rather than the other way around. In practice, however, it is unclear how that will work; it is unlikely that industrial companies will make the necessary, irreversible decarbonisation decisions without clarity on the regulatory framework for hydrogen. Such a regulatory framework can be incrementally optimised as projects are developed. It is also important to ensure from the outset that hydrogen projects and infrastructure do not face the same public acceptance challenges that wind projects currently face, highlighting a role for the government to clearly make a public case for hydrogen development as a core pillar of industrial competitiveness under a hydrogen strategy. The hydrogen strategy should also quantify the workforce and skills needed to realise its hydrogen ambitions.

10. Co-ordinate system planning across the hydrogen and electricity sectors.

It is clear that the main driver for hydrogen sector development will be the growth of low-carbon industries, notably the steel and iron industries. At the same time, industrial decarbonisation plans along with electrolysers for hydrogen production are expected to be the overwhelming driver for electricity demand growth on the pathway to net zero (up to 100 TWh is expected to come from hydrogen by 2045). Therefore, a joined-up planning approach across the electricity and hydrogen sectors (as well as natural gas, where it exists in the system) is justified, underpinned by detailed analysis on system needs and constraints. Hydrogen storage might increasingly also play an important role in electricity system balancing. The electricity, gas and potential hydrogen TSOs are among the key stakeholders to lead this analysis. The outcomes of the analysis could inform a system-wide planning process across all relevant sectors to ensure that the development of the hydrogen sector is aligned with that of overall energy system development, towards the achievement of net zero emissions. The government's June 2024 decision to task the electricity TSO with co-planning hydrogen and electricity infrastructure in northern Sweden is, therefore, a welcome step in this direction.

Annexes

Acknowledgements

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Acronyms and abbreviations

BECCS	bioenergy with carbon capture and storage
CCS	carbon capture and storage
DSO	distribution system operator
DSR	demand-side response
EED	Energy Efficiency Directive
ESR	Effort Sharing Regulation
ETS	Emissions Trading Scheme
EU	European Union
EV	electric vehicle
FFS	Fossil Free Sweden
GDP	gross domestic product
GHG	greenhouse gases
IEA	International Energy Agency
LNG	liquefied natural gas
LULUCF	land use, land-use change and forestry
NECP	National Energy and Climate Plan
STEM	science, technology, engineering and mathematics

TES	total energy supply
TFEC	total final energy consumption
TSO	transmission system operator

Units of measurement

bcm	billion cubic metres
EJ	exajoule
GW	gigawatt
kb/d	thousand barrels per day
Mt CO_2-eq	million tonnes of carbon dioxide equivalent
MW	megawatt
TJ	terajoule

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Government action plays a pivotal role in ensuring secure and sustainable energy transitions and combatting the climate crisis. Energy policy is critical not just for the energy sector but also for meeting environmental, economic and social goals. Governments need to respond to their country's specific needs, adapt to regional contexts and help address global challenges. In this context, the International Energy Agency (IEA) conducts Energy Policy Reviews to support governments in developing more impactful energy and climate policies.

This *Energy Policy Review* was prepared in partnership between the Government of Sweden and the IEA. It draws on the IEA's extensive knowledge and the inputs of expert peers from IEA member countries to assess Sweden's most pressing energy sector challenges and provide recommendations on how to address them, backed by international best practices. The report also highlights areas where Sweden's leadership can serve as an example in promoting secure clean energy transitions. It also promotes the exchange of best practices among countries to foster learning, build consensus and strengthen political will for a sustainable and affordable clean energy future.