Author Accepted Manuscript. Accepted for publication 3rd of February 2021.

Johansson B. (2021) Energy Governance in Sweden. In: Knodt M., Kemmerzell J. (eds) Handbook of Energy Governance in Europe. Springer, Cham. https://doi.org/10.1007/978-3-319-73526-9_30-1

ENERGY GOVERNANCE IN SWEDEN

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Abstract. Sweden is a sparsely populated country with significant hydro, bioenergy, and wind resources. Renewable energy sources currently account for more than 50% of total Swedish use and both electricity production and residential heating are virtually fossil-free. Swedish energy policy can be characterized by the perceived conflict between an ambitious climate policy and the competitiveness of the energy-intensive industries. Related to this, the future of nuclear power has played a key role in the Swedish energy discourse over the last 40 years. Energy governance through market solutions is widely embraced in Sweden and includes the use of economic policy instruments such as carbon and energy taxes, the EU Emissions Trading System, and renewable electricity certificates. Fully decarbonized electricity and heating sectors would appear to be within reach in the coming decade, although technical and institutional adaptations will be necessary to manage the expected continued expansion of variable electricity production. However, major challenges remain for decarbonization of the transport and industrial sectors in Sweden. In both sectors, electrification, together with the continued role of bioenergy, are regarded as key options for the future.

Keywords: Sweden, decarbonization, renewable energy, nuclear power, market liberalization, economic policy instruments

1. Introduction

Sweden's energy system has the highest share (55%) of renewable energy in the EU (European Commission, 2020). Sweden is characterized by an almost fossil-free electricity system and, most fossil fuels used for domestic heating have been replaced by biomass, electricity, and district heating. The broad diffusion of renewable energy reflects both the favorable geographic conditions and the implementation of policy initiatives. Sweden is a sparsely populated country with large renewable resources such as bioenergy (forests cover approximately 70% of the country), rivers that lend themselves to hydropower production, and vast areas of land that are suitable for wind energy exploitation.

The expansion of district heating, a large forest industry, and the early introduction (1991) of carbon taxation, have supported the increased use of biomass in the energy system. The forest industry accounts for approximately one-third of industrial energy demand and a significant part of this is covered by biofuels. Unlike many other European countries, both coal and natural gas play only a minor role in the Swedish energy mix and there are no domestic fossil-fuel resources. Currently, coal is primarily used in the steel industry, while natural gas is used regionally in south-western Sweden. Petroleum products are still significantly used, although mainly in the transport sector (Swedish Energy Agency, 2020b).

The nuclear power issue has dominated the Swedish energy discourse for the last 40 years and Vedung (2001) states that "nuclear power, not oil is the hub around which Swedish energy policy conflicts move". Consequently, energy policy has largely been regarded as being equivalent to electricity policy. After a rapid nuclear expansion during the 1970s, driven by expectations of growing electricity demand and a desire to reduce oil dependence, following a referendum in 1980, the Swedish parliament decided to halt the expansion after already commissioned plants had been built. It was then decided that a step-by-step decommissioning of nuclear power plants should be conducted with an end date in 2010. Since this time, this decision has regularly been challenged and, in 2018, nuclear power still accounted for approximately 40% (Swedish Energy Agency, 2020b) of the electricity supply. There is currently no end date and some political parties support building new nuclear plants while the owners of some of the plants have decided to shut them down because of reduced profitability.

Sweden has largely embraced the market paradigm and pursued opening up the electricity and gas markets, even though the state has continued to own one of the major power companies, Vattenfall AB, a company that has also been active outside Sweden with acquisitions in Germany, Poland, and The Netherlands. The Swedish electricity market is closely integrated with the other Nordic countries through the power marketplace, Nordpool, and is also interconnected with other neighboring countries.

There is a general acceptance of the government's role in directing the energy system in an environmentally benign way. In Sweden, there is an overarching governance principle of "steering by environmental objectives" (Hildingsson & Johansson, 2016) although the markets play a significant role in achieving these objectives. Cost efficiency plays a prominent role in defining how policies should be designed (Hildingsson, 2014) and Swedish policy largely relies on economic policy instruments such as carbon taxes, Renewable Energy Certificates (REC), and the European Emission Trading System (EU ETS).

Sweden is regarded as being at the forefront of climate ambitions (Sarasini, 2009; Zannakis, 2015) and has implemented several ambitious policies and set a national target for becoming a country with no net GHG emissions by 2045. Within the EU, Sweden belongs to a group of countries that have argued for more ambitious climate policies, while being less concerned about issues such as energy dependence, etc. Also, Sweden has usually readily implemented new EU regulations (Nilsson, 2011). However, one area of conflict relates to bioenergy, in which Sweden and Finland have a more positive attitude towards the opportunity to combine the utilization of biomass with sustainable forestry than many other countries have (Baylan and Tiilikainen 2018).

For competitive reasons, the industrial sector has been protected from the most stringent climate policies through, for example, substantial tax deductions. Although taxation levels for road transport are significant and there are other support schemes as well, these initiatives have not been enough to ensure sufficient reductions in greenhouse gases (GHG) in this sector, as efficiency improvements have been partially counterbalanced by increased demand for road transport. For the future, industry and transport are arguably the most challenging sectors concerning energy-related greenhouse gas reductions.

This chapter aims to provide an overview of Swedish energy governance with a focus on how it contributes to a low carbon transition. The chapter starts with a brief description of the historic development of the energy system and the current energy mix. The main energy policy discourses and actors are presented. Key Swedish policy objectives and instruments are then described followed by an analysis of the current and projected outcomes and the challenges of achieving a low carbon energy system.

2. The General State of Energy Governance in Sweden

2.1 Legacies of Swedish Energy Governance

From its early days, the Swedish electricity system was characterized by the huge significance of hydropower. Interest in nuclear power started in the 1950s when the country was also considering developing nuclear weapons for its armed forces. The decision to invest in nuclear energy was based on the conviction that it would be in the interests of the nation to use the assets of natural uranium, advanced reactor technology, and the expertise on nuclear physics that the country had at its disposal (Anshelm, 2009). Increased electricity demand and opposition to the continued exploitation of rivers for hydropower by the end of the 1960s required new sources of electricity to be found. During the 1970s, as oil replacement was high on the agenda, nuclear power appeared to be the most natural replacement for oil in the electricity system. At the end of the 1960s, criticism of nuclear power started to emerge. This intensified during the 1970s and contributed to a change of government in 1976 (Hakkarainen & Fjaestad, 2012). A referendum in 1980 following the Three Mile Island accident led to a parliamentary decision to decommission nuclear power plants, although nuclear power continued to expand with the last reactor taken in operation in 1985. The combination of a nuclear share of electricity production that was close to 50%, existing decommission plans and high climate ambitions have created a policy nexus around which much Swedish energy policy has revolved.

The development of district heating, starting in the 1950s, has also been an important structuring factor for the Swedish energy system. The district heating infrastructure was initially developed by municipalities to produce combined heat and power (CHP). Interest in CHP diminished with the expansion of nuclear power and low electricity prices but re-emerged during the 1990s following new support schemes (Di Lucia & Ericsson, 2014; Higa, Cunha, & Silveira, 2020). Other forms of motivation for district heating were to reduce oil dependence in individual buildings and local air pollution (Ericsson & Werner, 2016). In the early stages, district heating was dominated by fossil fuels, but from 1990, an expansion in biomass made district heating systems an integral part of the Swedish bioenergy system. In 2018, approximately 60% of heat demand for residential buildings and offices was supplied by district heating (Swedish Energy Agency, 2020b).

Before fossil fuels started to dominate the energy system, traditional energy sources such as wood fuel dominated the Swedish energy supply (Kander & Stern, 2014). Following the oil crisis in 1973, a renewed interest in this “domestic and renewable” resource emerged. This interest grew even stronger in the 1990s as a part of increasing climate policy ambitions. The forest industry infrastructure and district heating systems facilitated a rapid replacement of fossil fuels with biomass and related emission reductions (Ericsson, Huttunen, Nilsson, & Svenningsson, 2004).

The state and energy-intensive industries have enjoyed a special relationship and the perception of these industries’ key role in Sweden is expressed in the often-used term “basic industry” (Hildingsson, Kronsell, & Khan, 2019; Johansson et al., 2017). The need to prioritize this industry has been pursued in the form of a perceived common interest between industrial owners and trade unions. The connection between trade unions and the long-governing Social Democratic Party has strengthened this view and has gained importance through the corporative governance traditions that are present in at least some of the areas of Swedish policy (Kronsell, Khan, & Hildingsson, 2019). This has led to a strong prioritization of competitiveness in these sectors and has allowed them to resist stringent climate policies (Hildingsson & Khan, 2015; Hildingsson et al., 2019). However, there are now indications that this is changing, with greater commitment to transition from the energy-intensive industries in recent years (Roger Hildingsson et al., 2019).

Energy policy emerged as a policy field in its own right after the oil crisis 1973 when Swedish dependence on imported oil became apparent to most people (Kaijser, 2001). In order to increase energy security, Sweden has pursued a diversification strand with regard to both energy balance and choice of supplier and has also highlighted policies for energy conservation (Kaijser & Högselius, 2019). The acceptance of governmental policies in the environmental field and the use of environmental taxes as a policy instrument is also relatively high. However, since the 1980s there has been a general trend towards deregulation and privatization in Sweden that has also been reflected in developments in the Swedish electricity and district heating markets.

2.2 Composition of the energy mix

Final energy use in Sweden has been relatively stable between 1970 and 2020 (Figure 1). However, total energy use has increased significantly, and this is mainly attributable to energy losses in nuclear power plants. The composition of the energy mix has also changed significantly (Figure 2). Oil consumption has more than halved and is now almost exclusively used in the transport sector. The share of renewable energy has increased significantly and in 2018 accounted for around 55% of Swedish energy use (Swedish Energy Agency, 2020a). Also, the role of nuclear power has increased since its introduction in the mid-1970s. Coal/coke and natural gas account for only 4% and 2%, respectively (Swedish Energy Agency, 2020b).

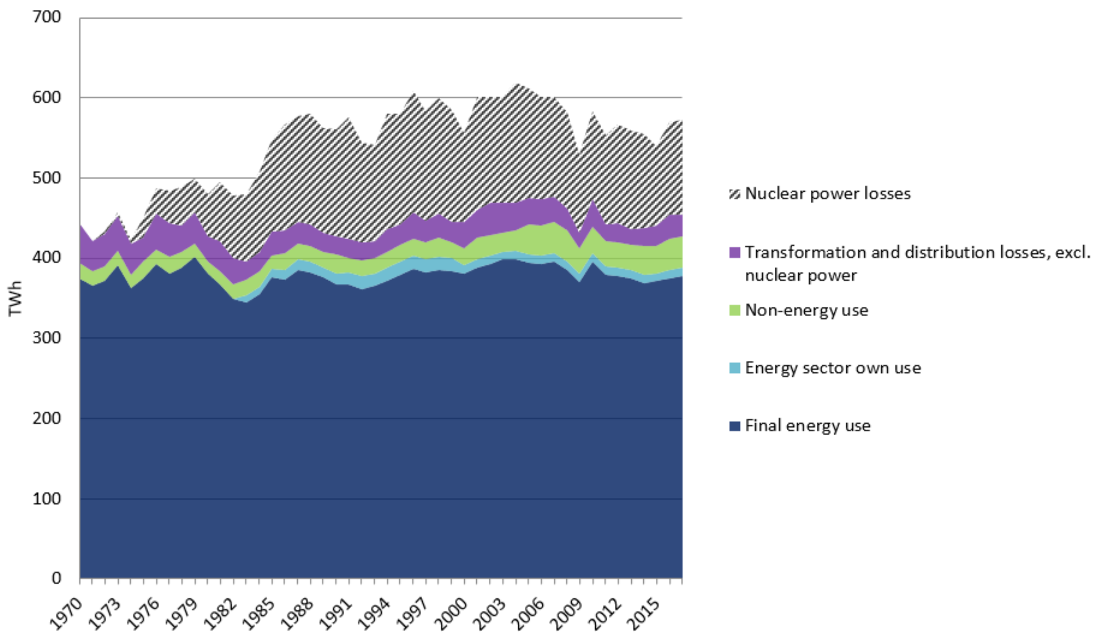

Figure 1. Total energy use, by final energy, losses, etc. (Swedish Energy Agency, 2019a).

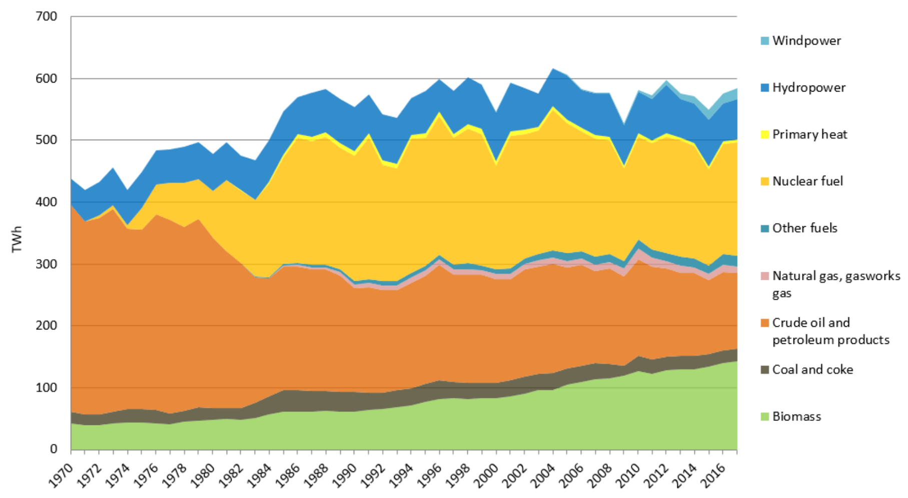

Figure 2. Total energy supply by commodity (Swedish Energy Agency, 2019a).

Both electricity demand and production have remained relatively stable since the mid-1980s and have long been dominated by hydro and nuclear power complemented by electricity from CHP produced in district heating systems and the industrial sector, Figure 3. In 2018, nuclear power accounted for 41% of Sweden's electricity production. The production of fuel-based electricity in condensing plants is virtually non-existent, except for back-up purposes. The last decade has seen significant growth in wind power largely due to the existing REC system, see Chapter 3. The increase in renewable electricity production combined with a rather stable demand has led to an annual electricity surplus of 10–15% that enables the net export of electricity to neighboring countries (on an hourly basis, Sweden is sometimes a net importer and sometimes net exporter depending on the actual supply and demand conditions). The residential and service sectors use more than 50% of electricity, followed by the industrial sector, which accounts for almost 35% of electricity. A significant share of electricity demand (14%) is used for domestic heating (Swedish Energy Agency, 2020b). This is largely a legacy of the surplus electricity in the 1980s due to the rapid expansion of nuclear power plants and dedicated oil replacement policies at the time.

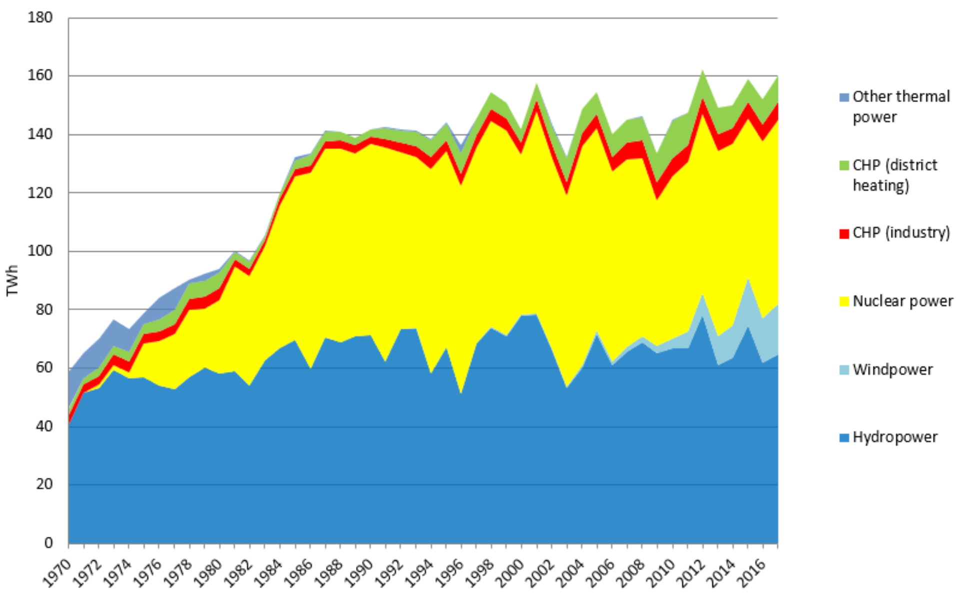

Figure 3. Electricity production by source. Source: (Swedish Energy Agency, 2019a)

Oil products still dominate energy use in the transport sector although biofuels have grown significantly in recent decades. In 2018, renewable energy (biofuels and electricity) accounted for 23% of the energy demand for domestic transport (Swedish Energy Agency, 2020a). If calculated in accordance with the Renewable Energy Directive in which fuels from certain types of residues are multiplied by two and electricity from renewable energy used for rail transport and road transport is multiplied by factors of 2.5 and 5, respectively, the share is nearly 30%. The biofuels mainly comprise FAME (fatty acid methyl esters), HVO (hydrogenated vegetable oils), ethanol, and biogas. Most of these biofuels are currently produced abroad or are based on non-domestic feedstocks (Swedish Energy Agency, 2020b) from around the world, despite there being vast bioresources in Sweden. This is primarily due to higher domestic production costs and a lack of production facilities to meet the rapid increase in demand.

Industrial final energy use has remained relatively stable for decades and is dominated by three energy-intensive sectors: paper and pulp (51% of total energy use), iron, steel and metalworks (16%), and the chemical industry (9%) (Swedish Energy Agency, 2020b). Industrial energy is dominated by biomass (39%) and electricity (35%) while the remaining use of coal in Sweden is in the iron and steel industry, a sector that currently accounts for more than 10% of Sweden's GHG emissions. Oil, previously a dominating energy source in the sector, currently accounts for around 7% of industrial energy supply.

Energy use in the residential and service sectors has decreased by approximately 10% since 1970, despite the significant expansion of heated areas (Swedish Energy Agency, 2020b). This has largely been a result of targeted energy efficiency initiatives that started with the oil crisis in the 1970s. (Since 1995, specific energy use (MJ/m2) has been reduced by approximately 20% (Swedish Energy Agency, 2020b)) During this period, district heating almost quadrupled and, combined with the expansion of electricity (including electric heat pumps) and modern small-scale biomass heating, the direct use of fossil fuels for heating purposes has virtually ceased.

This is underscored by developments in district heating systems in which fossil fuels have been largely replaced. Currently, the district heating supply is dominated by wood fuels, municipal waste incineration, electric heat pumps, and industrial waste heat. The fossil content in waste accounts for more than one-half of the remaining GHG emission in Swedish district heating systems and approximately 5% of total Swedish GHG emissions.

Swedish biomass use has more than doubled since 1990, see Figure 4. The biomass used in stationary applications is currently dominated by industrial by-products (mainly pulping liquors and other industrial by-products), although a minor proportion of logs is also used for small-scale heating. As previously mentioned, there is significant use of liquid biofuels in the transport sector.

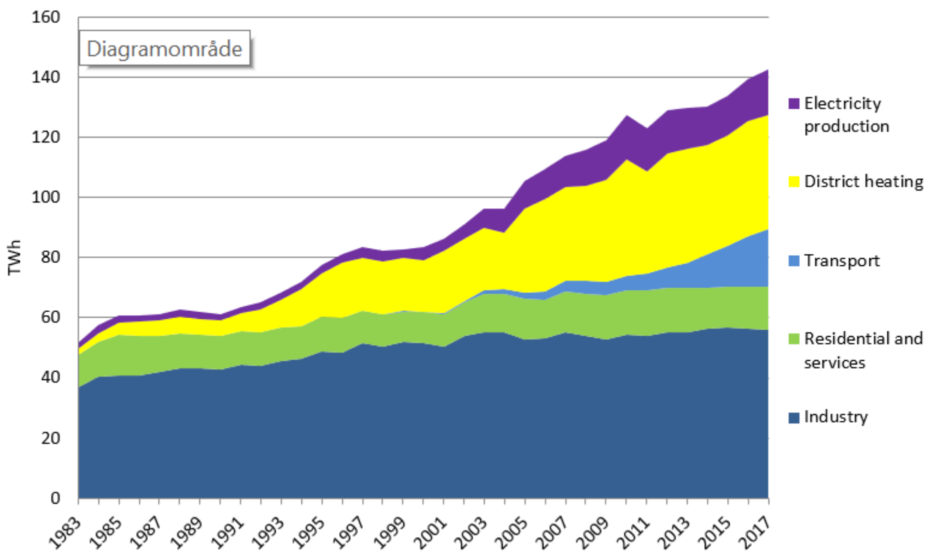

Figure 4. Use of biomass per sector. Source: (Swedish Energy Agency, 2019a)

2.3 Discourse on energy issues

Sweden's discourse on energy issues has largely been characterized by the tension between a rather broadly rooted high environmental ambition and the concerns about industrial competitiveness with the associated need to provide the industrial sector with low energy prices.

The issue of nuclear power has dominated the Swedish energy discourse over the last 45 years. In the discussion associated with the previously mentioned nuclear referendum of 1980, the risks of nuclear power were contrasted to a lack of confidence in the capacity of renewable energy to supply the required electricity. In the referendum, the voters had three options that all stated that nuclear power should be phased out. However, two options were regarded as being pro-nuclear as they accepted that the already commissioned new reactors could be used, while one option was more obviously against nuclear power and required the rapid decommissioning of nuclear power plants (Edberg & Tarasova, 2016; Hakkarainen & Fjaestad, 2012). Even though after the referendum the Swedish parliament decided that nuclear power plants should be decommissioned by 2010, very little happened. The start of the phase-out was conditional upon a reduction in nuclear power being fully compensated by energy conservation and new renewable capacity and it was not until 1999 that the first reactor was shut down. In 2010 the existing regulations prohibiting nuclear power were removed, but with decreasing electricity prices and fierce market competition the economic prerequisites for new nuclear power were simply not there. The most recent comprehensive parliamentary energy decision from 2018 (Swedish Government, 2018) is ambiguous in terms of the decommissioning of nuclear power plants. It states that the electricity system should be 100% renewable by 2045 while simultaneously arguing that this should not be seen as an end date for nuclear power (Swedish Government, 2018). This ambiguous approach is probably explained by the fact that the decision was based on a compromise including both governmental and oppositional parties. This compromise has already been challenged. While the power companies have decided to shut down several reactors in 2020 and 2021, industrial lobby groups and pro-nuclear political parties (the Liberal party, the Christian Democrats, the conservative Moderate party and the right-wing populist Sweden Democrats) argue that nuclear power is needed in a system that has increasing amounts of variable renewable electricity production and expected growth in electricity demand due to the electrification of industry and transport.

High climate ambitions have broad support in most political parties. However, there are significant differences concerning the timing, exact mitigation levels, and methods of achieving the targets, for example, the role that the markets should play compared to public spending schemes and the level of focus on domestic mitigation measures compared to Swedish investments in mitigation abroad. Roger Hildingsson (2014) has identified a discursive struggle between a dominating neoliberal climate policy narrative and a competing decarbonization narrative that provides an alternative notion of low carbon transitions. The neoliberal narrative primarily focuses on emission reductions and identifies market failures as being the main problem, which could be addressed by the internalization of external costs using market mechanisms. The decarbonization narrative sees the need for broader energy system transformations and the need to remove multiple barriers and implementation deficits. In order to achieve this, a broad portfolio of policies is regarded as being necessary.

Swedish low-carbon transition policies have often been motivated by the desire to lead by example to act as a role model in the international arena. The transition has also been motivated by using concepts such as ecological modernization and the existence of win-win combinations (Sarasini, 2009). Zannakis (2015) similarly noted that motivations for Sweden to be an early mover were based on two storylines in which the first storyline highlighted the competitive advantage of early action and the second storyline, emphasizing ecological justice as a more altruistic motivation. However, these positive storylines have regularly been challenged by a storyline that highlights the fact that early mitigation means unnecessary sacrifice, arguing that Sweden should not commit to more than necessary.

A recent example reflects some of the disputes above. These emerged in connection with an application from the petroleum company Preem for a license to expand the capacity of one of its refineries. Those actors who were against granting the company a license argued that new fossil fuel capacity should be prohibited to meet the 1.5 °C aspirational target of the Paris Agreement.

Those who were in favor argued that prohibiting the expansion would only lead to production elsewhere in less efficient production plants and that prohibition would be unnecessary as refineries were already regulated by the EU ETS. Before the government managed to take a final stand on the issue, in September 2020, Preem withdrew its application on commercial grounds.

The increasing role of markets in the energy sector is widely embraced in Sweden. This was reflected in the relatively early deregulation of the electricity market. This process started in the 1980s and led to new legislation in 1996 for a more deregulated electricity market. According to Högselius and Kaijser (2010), the point of departure was the new ideological climate that has been present in Sweden since the early 1980s, which emphasized competition as being a positive force for economic efficiency in providing infrastructure service and in the public sector in general. Although the benefits for the various market actors were not evident, they regarded the change as inevitable and, in different ways, prepared themselves for the change. According to M. Nilsson (2011), the market reform and the framing of the electricity sector as a deregulated market in Sweden have now become deeply institutionalized.

The concern for energy security was the main reason why energy policy emerged as a separate policy field in the 1970s although it was later absent from the key energy discourse for an extended period because the national energy system was regarded as being robust and the external supply of petroleum was thought to be secured through relatively stable international markets. However, security of supply has grown in importance in recent years following the expansion of variable electricity production and concern is being expressed that the closure of nuclear power and CHP plants due to lack of profitability will increase the risk of capacity shortages in parts of Sweden and negative impact on other electric qualities such as frequency stability and reactive power. The discussion regarding whether renewable energy can supply power as inexpensively as nuclear power is also still ongoing. Recently, the lack of local production and distribution capacity has emerged as a central issue in the energy discourse, in which it is argued that this prevents regional development if expanding industries are not given access to the grid or that the electrification of transport is hindered (A collection of debate articles that provide a good picture of this discourse can be found at Sydsvenskan (2020) and Svenska Dagbladet (2020)).

Wind power development was rather slow until the introduction of the REC system (see below). The expansion sparked a debate about the potential tension between the desire for more renewable energy, driven by high climate ambitions, and local environmental protection and other interests, for example, from the armed forces (See Liljenfeldt (2015); Söderholm, Ek, and

Pettersson (2007), Lindgren, Johansson, Malmlöf, and Lindvall (2013)). Partially as a consequence of this, much of the production has been established in Northern Sweden in which there are fewer conflicting interests due to the less dense population, even though protection of the landscape and reindeer herding still cause conflict.

Swedish energy policy has been dominated by a strong belief in technological solutions and the role of innovation in solving energy challenges. Several non-governmental organizations (NGOs) and political parties have argued that this is not enough and that more significant societal changes, including behavioral changes, are necessary. For example, many politicians, researchers, and industry actors are now convinced that the electrification of transport will be the solution to mitigating the climate impact of transportation, whereas other actors argue that transport planning that takes reduced demand into account is necessary to manage the challenges.

2.4. Political institutions and actors

The Swedish administrative model is characterized by relatively small ministries and large governmental agencies that have a relatively high degree of autonomy in relation to the government (Hall, 2016). Over the years, energy as a policy field has been assigned to different ministries such as the Ministry of Industry, the Ministry of Environment and Energy, the Ministry of Enterprise, and now, the Ministry of Infrastructure. Regardless of ministerial location, energy policy is also heavily influenced by the interests of the Ministry of Finance. The sector is affected by several forms of legislation such as the Electricity Act, the Environmental Code, the Energy Taxation Law, the Planning and Building Act, etc.

The Swedish Energy Agency is broadly responsible for monitoring and developing energy policies, as well as for statistics, advice, and research funding. It also administers policy instruments such as the REC system and various other support schemes. The Swedish Energy Markets Inspectorate (EMI) is the main regulator of the electricity and gas markets in Sweden and monitors the functioning of these markets and supervises price setting for monopolistic distribution services. The Swedish Radiation Safety Authority is responsible for nuclear safety and has the mandate to stop reactors if threats to reactor safety and security are identified. Finally, Svenska Kraftnät is the authority responsible for the Swedish transmission system. It is the system operator for Sweden with overall responsibility for keeping the balance between supply and demand. This includes developing new transmission infrastructure and ensuring a reserve production capacity when the market is unable to do so. In addition to these direct energy-related agencies, energy policy is influenced by other agencies such as the Swedish

Environmental Protection Agency and the Swedish National Board of Housing, Building, and Planning.

Typical for the Swedish political system is the use of commissions of inquiries to develop policy proposals in different fields and to anchor policy proposals in different segments of society (Petersson, 2016). This could be in the form of either individual investigators or broad parliamentary commissions regarding the more strategic decisions. The commissions often use experts and special advisors who represent ministries and public agencies with the relevant responsibilities and different stakeholders representing, for example, enterprises or NGOs. The proposals from the committees undergo a mandatory referral procedure in which different societal actors have the opportunity to submit their comments before the government sends the bill to parliament for decision. The work of both the parliamentary Energy Commission (2017) and the Cross-Party Committee on Environmental Objectives (2016) has been influential in identifying important policy goals and compromises for Swedish energy policy.

A new type of actor with potential impact on energy policy is the Climate Policy Council, comprising a group of senior scientists tasked with scrutinizing government policy and verifying whether such policy is in line with the Swedish Climate Act, which has been in force in Sweden since 2017 (Swedish Code of Statutes, 2017) The introduction of this organization into the Swedish policy arena was clearly inspired by the Committee on Climate Change in the UK (cf. Schoenefeld and Rayner (2019)).

Local authorities (municipalities) in Sweden have a considerable degree of autonomy including taxation rights but also broad responsibilities that are determined through national legislation (Feltenius, 2016). Their impact on energy systems is manifold. First, they are important end-users through their ownership of a large stock of buildings used for schools, elderly care, etc. Many municipalities also own housing companies. Second, some municipalities own energy companies that are responsible for district heating and electricity production and distribution. Third, the authorities have a so-called local planning monopoly and can decide on the proper use of land including the location of businesses, residential, and shopping areas, with a major impact on transportation demand and the development opportunities for public transport. Their influence on the location of wind power plants has also been a decisive factor through their comprehensive planning and their right to veto new wind power plants, although this right to veto is currently (2020) under scrutiny (Lauf, Ek, Gawel, Lehmann, & Söderholm, 2020; Liljenfeldt, 2015). Many national subsidy programs also target municipalities and fund local energy projects (Baker & Eckerberg, 2007; Lundqvist & Kasa, 2017).

Self-governing authorities on the regional level (Regions) are responsible for public transport, and important actors for driving the decarbonization in this field (Aldenius, 2018; Aldenius & Khan, 2017). In parallel, regional administrations of the central government (County Administrative Boards) also play a role in regional planning and are responsible for coordinating and managing regional initiatives in the field of crisis management, and in developing and implementing regional energy and climate strategies.

The interaction between public and private actors is partially through legislation but there is also institutionalized collaboration through participation in public committees, remitting procedures, and in various collaborative groups. For several decades, dialogue and collaboration have characterized the relationship between state and industry in Sweden (Roger Hildingsson et al., 2019; K. Söderholm & Söderholm, 2020). The inclusion of stakeholders in two public inquiries by the Energy Commission and the Cross-Party Committee on Environmental Objectives (CCEO) is an example of a more formal form of collaboration. In their interview study, Kronsell et al. (2019) noted that the CCEO was referred to as a good example of a policy deliberation that established the joint view that decarbonization was possible without compromising the economic viability of the industrial sector. However, the authors note that environmental and social movements have been given a marginal role in these examples of policy deliberation (Kronsell et al., 2019). In addition to controlled formal and organized consultations, there are increasingly more ad hoc, spontaneous and informal forms of interaction in policy processes in which ideas are exchanged and input is given to the policy process (Kronsell et al., 2019).

3. Coordination, instruments, and drivers of the Swedish energy transition

3.1. Drivers of the energy transition

The most important driver of the ongoing transitions in Sweden is the high climate ambitions both nationally and within the EU. Many policymakers and researchers regard Sweden as being a frontrunner in environmental policy, although this role has also been challenged by others (Hysing, 2014). However, the general level of support for a stringent climate policy has been quite broad and stable and, consequently, Sweden has often set more stringent targets than required by international obligations, implemented a broad range of policy instruments (see below) and been an advocate for strict international commitments.

In Sweden, technological research and development has been seen as an engine of change in Swedish energy policy (Bergquist & Söderholm, 2015). Technology improvements and cost reduction in wind and solar power, mainly resulting from global developments, have accelerated the transition to more renewable electricity. Also, green groups and wind power lobby groups have driven the government to increase its ambition for renewable electricity expansion, and it has consequently adapted its policy instruments. For example, the targets for the Electricity Certificate System (see below) have step by step become more ambitious since its introduction in 2003, most recently in 2017 (Swedish Government, 2017).

The interest in bioenergy has been supported by the existence of an important forest industry, modern forestry, and district heating systems. They have collectively provided the infrastructure, logistics, and expertise that made it possible to react to the implemented policy instruments, particularly the carbon taxation (Ericsson et al., 2004). However, support has not been without challenges as there were previous concerns that an increased bioenergy demand would increase the competition for bioresources traditionally used for pulp and paper (Higa et al., 2020), as well as concerns about its compatibility with the preservation of biodiversity.

3.2. Strategies, instruments, and coordinating mechanisms

Swedish energy policy, just like EU policy (Knodt & Ringel, 2020), aims to combine ecological sustainability, competitiveness, and security of supply (Swedish Government, 2018). The strategy for a low-carbon energy transition has been reframed several times since the first climate target was introduced in 1988, with continuously increasing ambitions. In recent years, a perspective that focuses on identifying the most efficient areas for mitigation has turned to a broader decarbonization narrative that recognizes that all sectors must achieve near-zero emissions. However, the primacy of cost efficiency in much of the policy discourse has meant that sectoral targets have been avoided, except for a specific focus on a fossil-free transport sector. Parallel to dedicated climate strategies, strategies on infrastructure, a circular economy, and bio-economy have also been introduced with direct and indirect implications for energy. In 2017, the Swedish parliament decided on a new institutional setting for the energy transition through a Climate Act that established a framework for future climate policies that regulate the government and its agencies and introduced an independent evaluation body (cf. above).

The climate restrictions for the energy system are based on both EU and national targets, see Table 1. The Swedish Climate Act has a fixed target for achieving net-zero emissions by 2045 that cover all sectors of society. On its way to achieving this target, there are regulated milestones for sectors outside the EU ETS. In addition, there is a sectoral target for transportation for 2030, which requires a 70% reduction in GHG emissions compared to 2010. The EU has also determined legally binding targets for sectors that are not covered by the EU ETS through its Effort Sharing Regulation (ESR) (European Union, 2018).

Table 1. National climate targets and EU obligations for Sweden. (Swedish Climate Policy Council (2020), European Union (2018))

	Swedish national climate targets. Changes in GHG emissions compared to 1990, if not otherwise stated	Swedish obligations according to the EU's effort-sharing obligations. GHG emissions in sectors outside the EU ETS compared to 2005 levels
2020	Sectors outside EU ETS -40% compared to 1990. A maximum of 13 percentage points of the reductions through flexible mechanisms	-17%
2030	Sectors outside the EU ETS -63%. A maximum of 8 percentage points of the reductions through additional measures Domestic transport – 70% compared to 2010	-40%
2040	Sectors outside the EU ETS -75%. A maximum of 2 percentage points of the reductions through additional measures	
2045	Net-zero emissions (including the EU ETS). A minimum of 85% domestic reductions. The remainder can be achieved through additional measures.	

Additional measures include net sequestration in forests, verified emission reductions through Swedish investments abroad, and carbon capture and storage from the combustion of biomass (bio-CCS).

The most recent broad energy policy decision (primarily dealing with electricity) state that the electricity system should be based on 100% renewable energy by 2045. In addition, the energy decision set a target for a 50% increase of energy efficiency by 2030 compared to 2005, measured as energy supply in relation to GNP. A national target has been set for the share of renewable energy in 2020 (50%) but no national target for renewable energy for the entire energy system has been set for later years.

A number of policy instruments is used to reach these targets, and a selection of the most prominent ones is presented in Table 2 and further discussed below.

Table 2. A selection of key energy and climate policy instruments in Sweden, following the typology of this handbook. As described in text, the policy instruments do not apply to all the actors in the respective sector in the same way due to specific design features.

	Regulative instruments	Incentive-based instruments	Internalizing instruments	Soft governance
Cross-sectoral instruments	Environmental Code Planning and Building Act	Cross sectoral funding schemes (LIP, KLIMP, Climate Stride)	Energy and carbon taxes EU ETS	RD&D Regional Planning
Electricity supply	Electricity Market Directive Electricity Act	Renewable electricity certificates Investment grants for solar electricity Tax deductions for small-scale electricity production	Waste incineration tax	Fossil Free Sweden public-private collaboration
Industry		" Industrial Stride"-funding scheme		Fossil Free Sweden public-private collaboration
Transportation	Emission requirements for new vehicles Emissions reduction obligations for diesel and petrol Biofuel supply obligations for major filling stations	Support schemes for vehicles with environmental technology	CO_2 differentiated vehicle tax Tax on air travel	Urban environment agreements Infrastructure planning Public procurement
Household and service sector	Building regulation EU Eco design directive			Energy and Climate Advisory Services Voluntary agreements Energy declarations Public procurement

3.2.1. Cross-sectoral policy instruments

General economic policy instruments have been a key part of Swedish energy and climate policy for several decades. Fuel taxes were introduced as early as 1924 for transportation fuels and during the 1950s for energy used for other purposes. However, it was primarily from 1991, when the carbon and sulfur taxes, as well as nitrogen oxide charges, were introduced as part of a major tax reform (Skovgaard, Ferrari, & Knaggård, 2019; Sterner, 1994), that they came to be more clearly regarded as a policy instrument rather than a source of financial revenue.

The standard level of carbon taxation has more than quadrupled since its introduction and is currently the highest in the world. However, for a fair cross-national comparison, it is necessary to study how the carbon tax interacts with other taxes. E.g., the taxation on transportation fuels is not higher in Sweden than in many other European countries, although the part specifically called carbon tax is higher. In 2019, the level was equivalent to approximately 120 EUR/tonne CO2 (SEK 1.18/kg) (Swedish Government, 2020b)). Energy tax levels vary among the different fossil fuels with the highest levels applied to transportation fuels. However, these standard levels only apply to a fraction of energy use (heating, transport, and certain parts of the industrial sector), and several exemptions and deductions are in place, see Table 3. For example, no carbon tax is paid for fossil fuels used in metallurgical processes, electricity production, aviation or industrial facilities in the EU ETS. Previously, agriculture and industry outside the EU ETS had reduced carbon tax levels but these tax deductions have been removed on a stepwise basis (Skoovgaard, Hildingsson, & Johanssson, 2019). There are currently proposals to also abolish the energy tax deductions for these sectors as part of a tax reform switching the tax burden from labor to environment. (Swedish Ministry of Finance, 2020).

Table 3. Carbon and energy tax deductions for various operations. The information reflects the levels in November 2020.

	Carbon tax deduction Percentage reductions from standard levels	Deductions on fuel energy taxes Percentage reductions from standard levels
Fuels used for other purposes than motor fuel or heat production.	100	100
Fuels used in industry within the EU ETS	100	70
Fuels used in industry outside the EU ETS	0	70

Heat produced in CHP within the EU ETS	9	0
Fuels used for aviation, shipping and rail transport	100	100

The general tax level on electricity consumption is relatively high but there are minor tax deductions for consumers in certain rural areas and major tax deductions for energy-intensive industries (these lower levels are set by the EU's minimum tax levels and are less than 2% of the general levels). Recently, data centers have been granted the same low tax levels. The tax loss relating to this measure was compensated by higher electricity taxes on households and services. In addition to energy and carbon taxes, VAT is applied to energy. In 2019, taxes (incl. VAT) contributed to approximately 60% of the consumer price of petrol and 40% of the electricity costs for domestic electricity consumers with electricity use of 20,000 kWh/year (Swedish Energy Agency, 2020a; Swedish Energy Markets Inspectorate, 2020b). Several studies have identified carbon taxes as being important for both fuel replacement (particularly the expansion of biomass) and energy efficiency in Sweden (see e.g. Johansson (2000); Nilsson et al. (2004)).

Since 2005, Sweden has participated in the EU ETS and the emissions regulated by the system were equivalent to slightly less than 40% of Swedish domestic GHG emissions (Swedish Environmental Protection Agency, 2018). As the introduction of the EU ETS has been accompanied by significant exemptions from carbon taxes in many sectors, it has provided few additional incentives for emission reductions. Since heating plants that use biomass have been allocated emission allowances without having to report their emissions, the total allocation of emissions allowances to Swedish installations has been approximately 10% higher than the reported emissions (Swedish Environmental Protection Agency, 2019).

In recent decades, broad economic subsidies directed at municipalities and other actors have been implemented, including the Local Investment Programme (LIP) 1998–2002, the Climate Investment Programmes (KLIMP) 2003–2012, and, since, 2015, the Climate Stride (Klimatklivet). The Climate Stride supports fuel conversion projects, public systems for EV charging, filling stations for alternative fuels, biogas plants, etc. (Swedish Environmental Protection Agency, 2020). The goal of these programs has been to generate initiatives and engagement in municipalities and industries, and they have often included parallel goals such as sustainable development, job creation, etc. (Baker & Eckerberg, 2007). There have also been several more subsidy programs directed at specific technologies, fuels, or sectors, some of which will be described below in detail.

Over the years, support for energy RD&D has also been regarded as an important policy instrument. The Swedish Energy Research Programme has changed its direction and focus multiple times since it was established in 1975, following changes in national policy priorities (Haegermark, 2001). Energy research existed before 1975 and both government and industry research made important contributions to power transmission and hydro and nuclear power technologies. Many forms of collaboration between government and private industry have evolved during the program. Haegermark (2001) noted that although the main objective of the program has always been energy policy, support for Swedish energy and environment-related industries has been a significant secondary goal. This has not changed over the last two decades. The most recent government bill on energy research(Swedish Government, 2016) identified five key areas to which research should contribute: i) an energy system that is fully based on renewable energy, ii) a flexible and robust energy system, iii) a resource-efficient society, iv) innovation for job creation and climate mitigation, and v) integration of different parts of the energy system (Swedish Government, 2016). Between 2017 and 2020, approximately SEK 1,600 million/year (160 MEUR/year) (Swedish Government, 2020b) was directed towards energy research.

Electricity and heat production units, refineries, and large energy users, including industrial facilities, are all regulated by the environmental code as "environmentally hazardous activities". They require permits that regulate both pollution and resource conservation. However, under the EU directive (European Union, 2010) it is not permitted to regulate GHG emission levels or the volumes of fossil fuels used for plants within the EU ETS regarding GHGs.

3.2.2. Electricity

The electricity sector in Sweden is regulated in accordance with the EU electricity market directive with a separation between energy producers and distributors and a free choice of electricity suppliers combined with local and regional distribution monopolies. The Swedish Electricity Act (Swedish Code of Statutes, 1997) includes regulated fees that distributors must pay consumers if disruptions to the power supply last longer than 12 hours. In addition, the price that distributors can charge consumers is regulated and monitored by the Swedish Energy Markets Inspectorate. On several occasions, the Swedish EMI has limited the prices set by the distribution companies, although this has been successfully legally challenged by many utility companies (Swedish Energy Markets Inspectorate, 2016).

The development of the transmission system is governed by the Swedish TSO (Transmission System Operator), Svenska Kraftnät, which is permitted to cover its costs through transmission charges. According to government directives to Svenska Kraftnät, investments in new transmission infrastructure should be based on socio-economic cost-benefit assessments (Swedish Code of Statutes, 2007). However, this approach has been criticized for leading to underinvestment in infrastructure compared to what is needed for the future.

The expansion of renewable electricity is primarily driven by the REC system that was introduced in 2003. It replaced previous subsidy systems such as investment grants and production subsidies. It comprises a quota obligation for electricity suppliers who must procure electricity certificates corresponding to a certain percentage (in 2020 it was 26.5%) of their electricity supplies. Supplies to energy-intensive industries are exempted. Since 2012, there has been a joint REC system for Sweden and Norway although the quota obligations differ between the countries, depending on policy ambitions.

In principle, all types of renewable electricity are eligible for certificates, except for large-scale hydropower plants (1500 kW) built before 2002. Also, one year later, peat, which is not classified as renewable energy, was included in the system as a result of intense lobbying on the part of the peat industry. A renewable power plant can receive certificates for 15 years of operation. In the last decade, the total costs for onshore wind power production have fallen rapidly, making them competitive at current electricity price levels. This has driven down the certificate price to a very low level and the set targets have been achieved ahead of the schedule. In November 2020, a decision was made by the Swedish parliament to phase out the system (Swedish Government, 2020a). With a few exceptions, further expansion of renewable electricity will mainly rely on market forces and the price-driving effects of the EU ETS.

One of the motivations for the REC system was cost-effectiveness in the sense that it would lead to the prioritization of renewable electricity options with the lowest costs. At the start, this primarily referred to biomass-based electricity and, more recently, onshore wind power plants. Other options, such as solar and offshore wind power, cannot compete without additional support. Some researchers and policymakers have regarded this as a general problem for REC systems as it would hinder technological development, see e.g. Bergek and Jacobsson (2010). To allow for more costly options such as offshore wind power and solar energy, over the years, different Swedish governments have complemented the REC system with different forms of investment grants. Apart from that, small-scale plants received indirect subsidies as electricity tax is not applied to electricity produced for self-consumption, and through tax deductions when small-scale producers sell electricity to the grid. Overall, these initiatives have led to a rapid expansion of small-scale solar electricity production in recent years, albeit from low initial levels.

3.2.2 Transportation

Achieving a low carbon transport system requires a combination of new and improved technologies and measures that affect means of transport and transport demand, *per se*. A broad range of policy instruments has been applied to this sector. High fuel taxes have been an important driver for limiting energy use in the transport sector in Sweden, affecting both transport demand and vehicle energy efficiency. In addition, vehicle efficiency improvements driven by EU directives regulate the average energy efficiency on an EU level (European Union, 2009).

Other drivers for more low-polluting vehicles in Sweden have been vehicle taxes differentiated according to their level of CO_2 emissions. Since 2018, a bonus-malus system has been in place that combines higher taxation for high-emission vehicles (malus) and financial support for "environmental vehicles" (bonus). This system applies to vehicles that are newer than three years. After this time, car owners pay a vehicle tax that is differentiated depending on the estimated CO_2 emissions. The bonus-malus system is expected to balance taxes and subsidies whereas the vehicle tax provides revenues to the state budget. Preferential taxes for company cars have also been adopted to support environmentally-friendly vehicles. There have also been subsidies for electric buses (Swedish Code of Statutes, 2016) and a system for subsidies for improved urban environments (Swedish Code of Statutes, 2015).

The share of biofuels in the transport sector has increased largely due to tax exemptions. These exemptions have regularly been scrutinized by the EU to verify whether they comply with state aid rules. This has made the system less predictable. In order to partially avoid this problem, a new system of emission reduction obligations has been introduced. These obligations mandate reduced emissions from fossil transport fuels. This is achieved through blending with renewable fuels. Current obligations are equivalent to an emission reduction of 4.2% for petrol and 21% for diesel. In autumn 2020, the government proposed increasing reduction levels reaching an equivalent to a 28% reduction for petrol and a 66% reduction for diesel by 2030 (Swedish Government, 2020c). The government has also proposed the introduction of a reduction obligation for aviation fuels (Swedish Government, 2020d). Single or high blend fuels such as biogas and E85 continue to receive tax exemptions. In order to make biofuels more widely available, a requirement for large filling stations to provide at least one type of renewable fuel was implemented in 2009. The ambition to develop a fossil-free transport sector is also reflected in the government inquiry that was appointed in 2020 and tasked with proposing a date for when fossil transport fuels would be phased out and analyzing the conditions for prohibiting the sale of new fossil-fuel vehicles (Swedish Government, 2019).

In 2018 a tax on flights was introduced following a broad political discussion. It was regarded as a second-best option as the preferred option of a fuel tax was not deemed compatible with the IATA's (International Air Transport Association) agreements (Aviation Tax Inquiry, 2016). Thus, the tax has received a certain amount of criticism for not targeting GHG emissions accurately enough, thereby rendering it inefficient. It would also, according to the critique, risk driving international flights from Sweden to neighboring countries where similar taxes do not exist. However, proponents of the reform argued that there was a need for air travel to be treated in the same way as other transport options and even argued for significantly higher tax levels. Thus far, there has been no long-term evaluation of the effect of this taxation.

3.2.3 Industry

The industrial sector has in different ways been protected against policy instruments that could threaten its competitiveness. As previously mentioned, taxes on fuels and electricity for the industrial sector have generally been significantly lower than for other consumers and some uses (for example, industrial processes) have been totally tax free. Similarly, the allocation rules in the EU ETS have protected sectors that are vulnerable to international competition. In addition, the obligation to procure REC has not applied for electricity supplied to energy-intensive industries. For the industrial sector, the REC system has been beneficial so far as it has driven electricity prices down (Åhman, Wiertzema, & Arens, 2020) while some industries, such as the pulp and paper industry, have been able to increase their production of renewable electricity, receiving support through the REC system (Ericsson, Nilsson, & Nilsson, 2011).

The Swedish government has also chosen to prioritize various voluntary agreements and collaborative approaches (Stenqvist & Nilsson, 2012). Most recently, a public-private initiative for developing low-carbon road maps has received significant attention (Fossil Free Sweden, 2020). The road maps were developed through roundtable discussions between different stakeholders in order to resolve conflicts, find constructive ways forward, and common ground for policy propositions. In the road maps, designated responsibilities have been distributed to the industrial sectors and the government, respectively.

Future-looking technologies have been supported through different schemes, most recently the so-called "Industrial Stride program". An often-highlighted example is HYBRIT, a collaboration between the state-owned mining company LKAB, the state-owned electricity utility

Vattenfall and the main steel producer SSAB, aimed at developing a process for carbon-free steel. A pilot plant recently opened and was supported by significant state funding (approximately 50 MEUR (Swedish Energy Agency, 2018)).

Having said that, the industrial sector is and has been historically driven towards achieving lower environmental impact through environmental regulations that require the use of the best available technology (BAT) and resource conservation. This system which, in its modern form has been in place since 1969, has been particularly successful in mitigating local and regional pollutants without excessive mitigation costs. Söderholm, Bergquist, and Söderholm (2019) argue that important factors for this are firm flexibility in terms of compliance measures, industry-wide R&D cooperation, knowledge transfer between public R&D support and technology adoption choices at the company level, as well as the use of extended compliance periods for permit experimentation and high regulatory expertise.

3.2.4 Buildings

The residential sector has long been the focus of emission reduction strategies. As early as the oil crisis of the 1970s, robust initiatives for energy conservation were introduced and several instruments for energy efficiency improvements were used with a focus on building codes, subsidies, and information activities. (Kiss, McCormick, Neij, & Mundaca, 2010). CO_2 taxes have also contributed to more efficient energy use and have influenced the choice of heating systems. Other instruments such as networking initiatives, technology procurement, and voluntary standards have also been used (Kiss et al., 2010).

For several years, the expansion of district heating systems was supported by local and national policies, including various investment grants (Di Lucia & Ericsson, 2014). Carbon and energy taxes have supported the expansion of non-fossil fuels both in district heating systems and in individual boilers. The expansion of heat pumps also accelerated in the early 2000s (L. J. Nilsson, Åhman, & Nordqvist, 2005). The expansion of small-scale biomass combustion driven by increased oil prices created concern regarding the risk of local pollution from individual wood boilers. This concern has led to regulations on small-scale bioenergy requiring the use of state-of-the-art technology, which also provided incentives for increased use of wood pellets instead of wood logs.

3.3. Swedish national energy governance and EU

Sweden has a generally positive approach to multilateral institutions and free trade. Sweden plays an active role in UNFCCC and is a strong proponent of ambitious policies. Swedish activities within the UNFCCC are, however, strongly coordinated with the EU's priorities. Much of Swedish Energy Policy is determined by common EU rules. Sweden joined the EU in 1995 and belongs to the Northern/Western Group in EU energy policy that values sustainability relatively higher than security of supply compared to the Southern/Eastern countries (Knodt & Ringel, 2020). Sweden has been swift and compliant to align domestic policies with EU requirements and, even before it joined the EU, was relatively coordinated with European energy policy (Nilsson, 2011). However, the country is a strong defender of independence regarding financial policy and has therefore been reluctant to adopt a common taxation system and earmark incomes from the EU ETS. However, this independence is somewhat restricted as the use of different forms of national tax exemption, support schemes, and investment grants must be aligned with competition and state aid rules.

4. Outcomes, challenges and prospects

4.1. Developments towards European and national targets

Swedish domestic GHG emissions decreased by 27% between 1990 and 2018. The emissions in the sectors outside the EU ETS are in line with both the domestic and the EU targets for 2020 (Swedish Climate Policy Council, 2020). The expansion of renewable energy has been significant in recent decades and the EU target for 2020 of 49%, as well as the domestic target of 50% renewable energy, have been met by a considerable margin. The EU target for renewable transportation fuels of 10% by 2020 will also be exceeded.

Forecasts for 2030 indicate further increases in the renewable share of both total and transport energy demand (Swedish Government, 2020b). Compared to the long-term climate targets, the forecasts are less positive and the Swedish Climate Policy Council (2020) has concluded that neither the overall Swedish targets nor the target for the Swedish transport sector will be met without major additional policy initiatives.

4.2. Towards a power sector based on renewable energy

The ongoing development towards a carbon-free power sector is expected to continue and the forecasts show only minor contributions of fossil carbon from the combustion of waste gases from steel production, the fossil carbon fraction in waste incineration, and production in reserve plants. However, there are challenges regarding the expected increase in electricity demand due to the electrification of the industrial and transport sectors and transport (e.g. producing fossil-free steel through electrification would require electricity equivalent to more than 10% of current

Swedish electricity demand (Kushnir, Hansen, Vogl, & Åhman, 2020)), new data centers, etc. In recent "high electrification" scenarios from the Swedish Energy Agency, electricity demand could increase by as much as 40% by 2050 compared to current levels (Swedish Energy Agency, 2019b). This could be compared with various reference scenarios that have seen increases of less than 10% over the same period.

Another issue that has been one of the main priorities in recent years is the need to improve the capacity of both the transmission and the distribution grid. Thus far, tardy and complicated planning and permitting processes have slowed down the process of expanding this capacity (SWECO, 2019). The need to identify solutions to these problems has become even more urgent due to the new production patterns resulting from the closure of nuclear power plants and the expansion of wind power plants, primarily in Northern Sweden (Svenska Kraftnät, 2017). Overall, this has created a new discussion regarding the need for new institutional settings and new and more efficient planning approaches that would provide incentives for grid expansion, flexible demand solutions, as well as balancing technologies such as gas turbines, batteries, and hydrogen. (SWECO, 2019; Swedish Energy Markets Inspectorate, 2020a; Svenska Kraftnät, 2017).

4.3. The future role of bioenergy

Bioenergy's key role and long tradition in the Swedish energy system are grounds for assuming that it could contribute even more to climate-neutral solutions for both energy and materials in the future. This expectation has led to questions regarding the degree to which the resources will suffice for all these demands and, if not, regarding where they could be used most efficiently. The potential conflict between biomass utilization and nature conservation and biodiversity is also an important issue. Swedish research has a long tradition of studying the interaction between bioenergy use and other environmental impacts and has identified methods that minimize negative side-effects of bioenergy use and has also identified important synergies in which biomass, particularly from agricultural land, could contribute to improved environmental conditions (Cintas et al., 2016; de Jong, Akselsson, Egnell, Löfgren, & Olsson, 2017; Englund et al., 2020). Recent estimates indicate that biomass supply from Swedish agriculture and forest land could increase significantly in the future (Börjesson, 2016) but the domestic demand will depend on the degree of electrification and energy efficiency improvements in the industrial and transport sectors (Börjesson, Hansson, & Berndes, 2017). The current situation in which most of the biomass used for transportation fuels is imported also illustrates that domestic demand is not necessarily covered by domestic supply but depends on different market conditions and policies implemented both domestically and abroad.

4.4. The main challenges of energy transition in energy-intensive industries and the transport sector

Swedish industrial GHG emissions have been reduced by approximately 20% since 1990. Good examples of emission mitigation can be found, for example, in the paper and pulp industry, which has managed to reduce CO_2 emissions by 85% from 1973 to 2011(Söderholm & Söderholm, 2020). In this respect, the sector has significantly benefited from the availability of internal renewable energy that could be used to replace oil (Bergquist & Söderholm, 2015). In other sectors, similar opportunities have been lacking and the decarbonization of the industrial sector has long been regarded as a challenge. This applies to the steel sector, which is responsible for around 10% of Swedish emissions, but also to the cement and chemical industries. Since the mid-2010s, the perspective of the respective industries has changed from a defensive approach in which the industry must be protected to the understanding that in a zero-emission future, all sectors must contribute to decarbonization (Fossil Free Sweden, 2020; Hildingsson et al., 2019). However, although domestic initiatives are important for initiating technological change, to achieve a full transition, the Swedish industrial sector is heavily dependent on developments on both an EU and a global level.

While the implementation of high carbon prices appears to be difficult as long as multiple competitors are active in countries that have less ambitious climate policies, EU state aid regulations are regarded as an obstacle to direct support for mitigation measures and technological development (Johansson, Nilsson, & Åhman, 2018; Åhman, Nilsson, & Johansson, 2016), even though state support for R&D projects such as the previously mentioned HYBRIT has proved to be in line with these regulations. In addition, carbon border adjustments on the EU level, which is part of an on-going discussion, as well as a more consumption-driven demand for low carbon materials can influence the creation of the necessary conditions for technological change.

A broad range of policy instruments have been implemented in the transport sector and have affected vehicle efficiency, fuel choices, and transport demand positively. However, as economic resources have grown over time, they have partially been used on bigger and heavier vehicles, partially counteracted efficiency gains, and enabled an increase in national passenger and freight transport and rapid growth in international aviation. Freight transport and aviation have been less strictly regulated than domestic passenger transport (in terms of internalizing external costs) out of consideration for the competitiveness of Swedish businesses and lax international aviation regulations. Although a future challenge will be to plan for a more transport-efficient society, there is much optimism for the electrification of transport, both passenger and freight vehicles, even though this electrification would require significant investments in infrastructure.

4.5 Concluding remarks

Since the 1970s, Sweden's energy policies have developed from a strong focus on oil replacement to an ambition to meet stringent climate objectives. Swedish energy policies are also heavily integrated with policy developments in the EU, which Sweden joined in 1995. Swedish policies have largely been successful regarding the decarbonization of electricity and heating systems and expansion of the use of renewable energy. However, major challenges remain in the industrial and transport sectors. In these sectors, the technological solutions have been less obvious and concern about retaining the competitiveness in the industrial sector has restricted the implementation of sufficiently strong policy instruments. For transportation, several policy instruments have existed simultaneously. However, increasing transport demands have largely mitigated the effects of more efficient vehicles and there will be a need for renewable transportation fuels and broader transport policy initiatives. Both sectors show high expectations for electrification based on the continued expansion of renewable energy. The role of nuclear power remains high on the policy agenda, regardless of the parliamentary decision made 40 years ago that nuclear power should be phased out and private operators decided to shut down several reactors due to low profitability. This, together with the rapid expansion of variable electricity production and the expectation of the broad electrification of society, has placed security of supply high on the policy agenda, with a number of actors expressing concern that deficiencies in the electricity system's supply, distribution, and balancing capacities will prevent both decarbonization and economic development.

5. Acknowledgments

This author thanks the Swedish Energy Agency for financial support. This text has been written within the research projects "The politics of economic policy instruments- between idea and practice" and "The political dimensions of electricity distribution in a future electrified and climate neutral energy system". The author is also grateful for valuable comments on previous versions of this paper from Jamil Khan, Karin Ericsson, Roger Hildingsson, Jens Portinson Hylander, Andre Månberger, Lars J Nilsson, Hannes Sonnsjö and Per Svenningsson.

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