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THE ENERGY TRANSITION IN SWEDEN

Michel CRUCIANI

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In these jobs, he followed the liberalization of the gas and electricity industry in the United States and in Europe, as well as the rise of environmental concerns, leading to the adoption of climate policies, a new role for nuclear energy and the promotion of renewable energy.

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Abstract

Sweden has the distinction of having started several major changes to its energy supply at an early stage. The country has no fossil reserves, and so was importing increasing volumes of oil products in the years following World War II. Yet it rapidly perceived the geopolitical risks generated by such oil dependency, and so developed its nuclear capacity, enabling it to reduce quickly the role of oil in its economy after the shocks of the 1970s.

Sweden has also managed to exploit its natural resources. Until the 2000s, hydropower was able to enter the market without public assistance. By contrast, wood could not have gained its current market share without a policy combining public aid for investment and penalties for competing energies. The severe economic crisis which hit the country between 1991 and 1993 led such penalties being converted into taxes, notably a tax on CO2 emissions that came into force in 1991. This helped Sweden reconstruct its tax system, to finance its social model. The challenge highlighted the country's ability to generate consensus policy guidelines.

One of these guidelines was to react immediately after initial warnings about climate change. Sweden first strengthened its energy efficiency policy, structuring field actions through a national agency backed up by partner organizations in local communities to help consumers – individuals or industries – technically and economically. Sweden then adopted an unusual instrument to promote renewable electricity, namely its system of green certificates. Implemented in 2003, this system has spurred the development of the cheapest sources of renewable energy, two-thirds coming from onshore wind and one third from biomass. The cost of this support still remains remarkably moderate today.

At the end of 2014, Sweden thus only used fossil fuels to provide 30% of its primary energy supplies, while renewables accounted for 52% of final energy consumption. Energy consumption per capita remains high, but relative to GDP it is exactly equal to the average for Western Europe (EU 15). Regarding emissions of greenhouse gases, the country had the lowest carbon footprint in 2013 within the EU15, both in terms of GDP and per capita use. Moreover, while environmental taxes raise the price of gas for industry substantially, they do not affect fuel prices overly. Nor do taxes prevent electricity prices from being among the cheapest in Europe, both for industry and for households.

The current situation seems to be excellent. As a result, Sweden's political leaders have chosen to keep its underlying foundations and to carry out only moderate changes. Thus, while stating their preference for renewable energy, the major political parties have found common ground to reduce tax pressures on nuclear power, since 2014. In June 2016, the Parliamentary majority and opposition parties signed an agreement to modernize Sweden's fleet of reactors, thus further demonstrating their sense of compromise. This solution is designed to limit the rise in electricity costs and to lengthen the period available for alternative energy sources to reach maturity. In addition, the agreement extends the provisions promoting renewable power, but it also emphasizes the importance of managing the demand for capacity as well as the efficient use of electricity, giving consumers of power an active role, be they industrial or domestic users.

In short, Sweden seems to have taken measure of the difficulties faced by some European countries which are already engaged in the energy transition and is trying to avoid them. Its political actors have been careful not to adopt excessively restrictive short-term goals and are content with general guidelines: they are betting on innovation to move forward. In this regard, Sweden has a major advantage, alongside the efforts made for several years, favouring research and development in a very structured way. The recent agreement consolidates these efforts.

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Introduction

Sweden regularly receives praise for its energy model, considered reliable, competitive, and low in greenhouse gas emissions. Two recent reports devoted to this country by the International Energy Agency have applauded measures taken over the last twenty years to strengthen the security of supply and reduce the impact of the energy system on the environment, while applying a very liberal regulatory framework.

For its part, IFRI has therefore wanted to analyze the Swedish energy system, and identify what distinguishes it or is similar to existing models in other European countries. The approach begins by tracing the path of Sweden's energy policy, starting with a brief history followed by a deeper look at the provisions that have led to the current framework. The information collected accordingly is presented in the first part of this report. The second part details results obtained concerning the main features that have characterized Sweden's energy transition: energy efficiency, renewable energy, emissions of greenhouse gases, not to mention an economic overview, focusing on energy prices. Finally, the third part provides some comments, examines possible developments in the coming years and tries to draw some lessons for countries that have initiated their own energy transition.

Although the study covers all energies, the following pages focus particularly on electricity. This form of energy occupies an exceptionally important place in Sweden's energy balance. In addition, it is the subject of special attention by the national government and the EU authorities, because electricity is expected to play a major role in facilitating the energy transition in all European countries. It therefore seemed appropriate to look more at the electricity situation in Sweden.

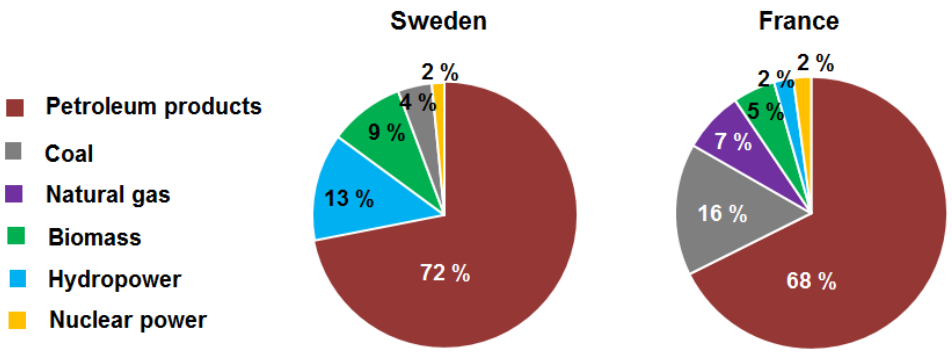
The study was conducted independently of previous reports on the country. With a few exceptions, it is based on data available from Swedish institutions, or from European sources, for purposes of comparison (the latter only provide accurate information about Sweden since its accession to the European Union, in 1995). In principle, this independent research is not influenced by previous work in the information and analysis it presents, which are based on processing accessible data. Such an approach is mainly of interest in the debate it may generate, and IFRI hopes that a broader discussion will arise out of this study.

An Overview of Sweden's Energy Sector

The First Steps

Sweden has only insignificant reserves of coal, oil or natural gas. But it has extensive forest coverage and a good hydrography. After World War II, electricity consumption increased rapidly, leading to a multiplication of dams on its rivers. Faced with a protest movement that emerged to preserve unexploited rivers, power companies turned to coal and especially to fuel oil. During the 1960s, imports of petroleum products rose sharply. In 1973, petroleum products still featured prominently in Sweden's primary energy balance. As shown in Graph 1, this situation was also found in France, another country without large fossil resources.

Graph 1: Sweden's primary energy balance in 1973



Source: Sweden, Energimyndigheten 2015a; France: CGDD 2011.

The risk to security of supplies that such external dependence entailed was then perceived, and the policy response was to use nuclear energy. This aspiration was strengthened by the global oil shock in 1973. By 1986, nuclear power had become the first source of energy in Sweden's primary balance, a position it still holds today. Between 1970 and 1990, the share of petroleum products in the final energy balance almost halved (from 21 to 12 Mtoe), whereas electricity consumption doubled. As total final energy consumption during this period remained stable, the share of

electricity in the energy balance increased from 15% in 1970 to 33% in 1990, and has never fallen below 30% since then. It is the highest level found in the European Union (EU 28).[1]

At the end of the 1980s, Sweden's economic situation was deteriorating: budget deficits, a declining trade balance, rising unemployment, slower growth ... until it entered a recession between 1990 and 1993. This crisis threatened the Swedish social model, often described as based on a Welfare State. To save its foundations, Sweden's political parties, employer organizations and unions agreed on major reforms aimed at making the country economically competitive.[2] These reforms affected the energy sector which was also hit by a new concern that was reconciled with Sweden's economic choices, namely the reduction of greenhouse gas emissions. Thus, four broad policy options have permeated the period beginning in the 1990s:

- As with other sectors, a liberalization policy was implemented for the gas and electricity sectors.
- The overhaul of the tax system was extended to energy taxation, with the introduction of a tax on CO2 emissions.
- The development of renewable energy and energy efficiency efforts have benefited from specific provisions that are regularly reinforced.
- The desire to preserve energy supplies at a moderate cost to industry led to the continued operation of Sweden's nuclear power stations and not to their early closure.

These four broad policy options are detailed below.

They have led to petroleum products to being targeted by new policies, although their relative decline after 1990 (down from 37% of final consumption in 1990 to 25% in 2014) mainly occurred in favour of bioenergy, which is consumed directly or distributed by district heating. Bioenergy saw its share in direct use rise from 15% to 22%, between 1990 and 2014; to supply heating networks, it jumped from 13% to 62% in the

1. Eurostat 2016a.
2. Since 1938, relations between the LO trade union and the SAF employers' association have been based on the Saltsjöbaden agreement, ensuring social peace accompanied by a very strong obligation of social partners to negotiate and a narrowing of the pay range. These arrangements were destabilized for a while by the crisis of the early 1990s, but the social partners managed to sign a new agreement in 1997, called Industrialvtalet, which has adapted the scope of bargaining to the constraints of a more liberal economy. (Source: JF Vidal, 2010).

same period.[3] Taking nuclear power into account, this means that 69% of primary energy comes from sources which do not emit CO2.

The Turning Point of the 1990s

The liberalization of the electricity marke[4]

In the face of the economic crisis which struck the country as of 1990, governments with Moderate and then Social Democratic majorities started pursuing a policy of economic liberalization. In the energy sector, Sweden was ahead of the European directives implementing market principles for electricity and gas from 1996 onwards. This transformation went smoothly, thanks to the quality of consultations between the government, business leaders and union employees.

Since 1996, an independent agency, usually referred to by the acronym Ei (for Energimarknadsinspektionen), has been responsible for market supervision. Ei oversees especially the organization managing the transmission grid, Svenska Kraftnät (SvK), whose capital is wholly owned by the State. Ei also sets a cap on the earnings of 162 local distributors, calculated in relationship to planned investment over periods of four years. This takes into account a capital cost of 6.5%. Despite liberalization, electricity production remains concentrated: in 2014, the national company Vattenfall provided nearly 50% of supplies, and two other companies supplied a further 25% (the German group E.ON, which had acquired the former Sydkraft, and the Finnish Fortum Group which is state-owned).

The geography of the Nordic countries, running from North to South, led them to build interconnections early on, from East to West. The Norwegian and Swedish transport network operators (respectively Statnett and SvK) decided in 1996 to create a common market place, Nord Pool. It was soon extended to Finland and Denmark, and more recently to the Baltic countries. The lack of transmission lines between regions in certain circumstances has led to the establishment of zones with distinct prices: at the end of 2015, their number had risen to 15, including the Baltic countries which had recently been connected to the Nordic countries by

3. Energimyndigheten 2015b. Swedish statistics aggregate solid biomass, biogas and biofuels under the label “bioenergy”. For heating, solid biomass is largely predominant, with 9 million toe consumed in 2014. Total biogas output was only 0.15 Mtoe that year, and part of this production was used for transport. The renewable fraction of household waste is sometimes recorded as bioenergy, or sometimes separately. Its contribution in 2014 was 0.9 Mtoe. (Source: Eurobserv'ER 2015)
4. Energimarknadsinspektionen 2014.

submarine cables (the corresponding maps are included as Annexes 1 and 2). The national regulatory agencies have monitored these connections, by establishing a common organization called North Reg, able to exercise control over the entire Nordic region.

So while Sweden has a total electricity generation capacity of 35.5 GW, major Swedish consumers which are able to buy on the wholesale market have access to a fleet of power plants producing 102 GW (in Denmark, Finland, Norway and Sweden), with approximately 45% of production being traded on a spot market. Nord Pool has divided the operations into two separate markets, Elspot for "day ahead" transactions (the next 24 hours) and Elbas for intraday trade. These two markets only cover physical deliveries; financial platforms (for futures and options) were sold to NASDAQ OMX Commodities in 2008. Nord Pool has joined the Price Coupling of Regions (PCR) initiative, conducted by the major electricity exchanges, in order to establish a single algorithm for allocating capacity across the EU, called Euphemia.

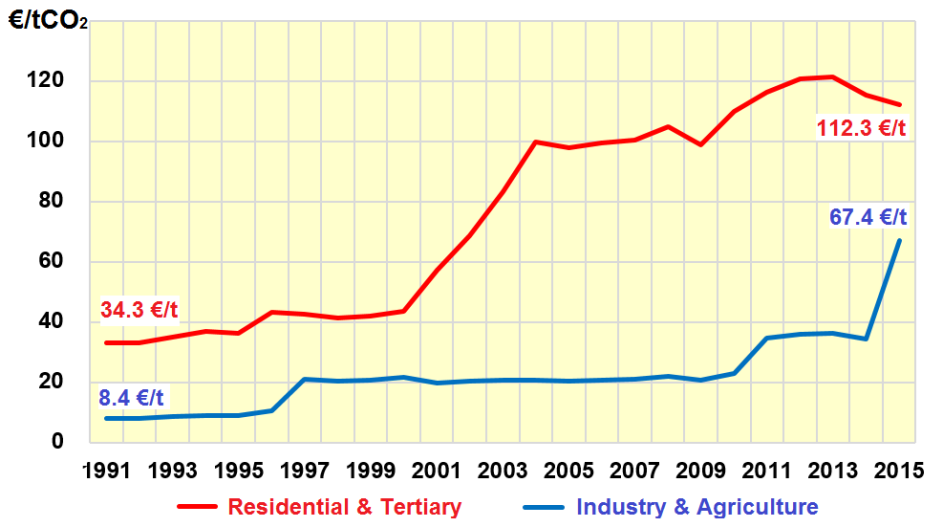
Taxing energy

Sweden applied a tax on the consumption of oil products as of 1924. This tax was gradually extended to all other forms of energy, with rates varying by energy type and use (for heating or transport). This tax includes a reduced rate, or exemption, for industry and agriculture. In 1991, as part of a general program to reduce tax burdens, the government led by Carl Bildt (center right) lowered taxes on labour and income. The loss of revenue was partially offset by an increase in taxes on energy. First, the government extended VAT to energy consumption, hitherto spared, and applied taxes on emissions including sulphur compounds (SOx) and nitrates (NOx). Secondly, the government decreased the overall energy tax but introduced a tax on CO2 emissions. This included a low rate for some sectors and very low taxes for energy-intensive industries. Both taxes are levied at source, on sales by producers, importers or wholesalers.[5]

These taxes have experienced a series of increases over the years. In 1991, the tax on CO2 emissions was €33.40/t for residential and tertiary sectors, and €8.40/t for industry and agriculture (excluding energy-intensive sectors). In 2015, the tax level averaged €117/t in the residential and tertiary sectors; while industry and agriculture paid €67.40/t. Graph 2 shows the evolution of the carbon tax from 1991 to 2015, and Table 1 reconstructs the tax amounts for 2015: the small changes are due to minor exchange rate movements between the Swedish krona and the euro.

5. IEEP 2014 & Ministry of Finances, 2010.

Graph2: The evolution of carbon taxes from 1991 to 2015



Source: H. Hammar 2011 & NAO 2012.

Table 1: Taxes on CO_2 and on energy in 2015

		Energy Tax		CO2 Tax		Total	
		Residential and Tertiary	Industry and Agriculture	Residential and Tertiary	Industry and Agriculture	Residential and Tertiary	Industry and Agriculture
HEATING							
Heating oil	€/litre	0.08	0.025	0.31	0.18	0.39	0.205
Coal	€/tonne	64.13	19.28	278.83	167.3	342.96	186.58
Natural gas	€/m3	0.09	0.03	0.24	0.14	0.33	0.17
Electricity (*)	€/MWh	31.32	0.53	0	0	31.32	0.53
Bioenergy		0	0	0	0	0	0
TRANSPORT							
Gasoline	€/litre	0.33	0.33	0.26	0.16	0.59	0.49
Diesel	€/litre	0.18	0.18	0.31	0.18	0.49	0.36
Natural gas		0	0	0	0	0	0
Bioenergy		0	0	0	0	0	0
ELECTRICITY							
Electricity (*)	€/MWh	31.32	0.53	0	0	31.32	0.53

(*) Rate applied in Southern Sweden

Source: Swedish National Audit Office, Climate related taxes, 2012; Ministry of Enterprise, Energy and Communications, Report to the European Commission, Plan for implementation of Article 7 of the Energy Efficiency Directive, 5 December 2013; Eurostat, Euro/ECU exchange rates - annual data [ert_bil_eur_a], annual average.

Other taxes hit the energy sector and the government modulates their levels to influence choices by economic agents. Thus, the tax on the thermal power from nuclear power plants rose from an average amount of €0.19/MWh in 1993 to €6.79/MWh in 2014.[6] In the transport sector, the principal charge is akin to an annual "stamp": it is not applied to buyers of plug-in electric or hybrid vehicles and has a reduced rate for vehicles powered by natural gas or burning a mixture that contains more than 80%

6. Naturvardsverket 2016 & Energimyndigheten 2015c.

biofuel. Moreover, this type of fuel also remains exempt from the energy tax and the tax on carbon emissions.

Policy in favour of energy efficiency and renewable energy

As of 1990, Sweden has attached particular importance to the development of renewable energy and especially energy efficiency. Public policies have respected the specificities of the country, which combine freedom of initiative, incentives through grants, involvement of local authorities, as well as the influence of prices, which are in turn affected by various taxes. A pragmatic approach allows for progress within a flexible regulatory framework.

The notable provisions were adopted early in the period. These included the overhaul of taxation and measures to promote energy efficiency, but which were adopted without targets. It was only in 2009 that the Parliament (the Riksdag), led by a center-right alliance, adopted a comprehensive set of objectives. The new majority since 2014, which brings together the Social Democratic Party and Sweden's Green Party, has kept them unchanged. They can be summarized as:

- 50% renewable energy by 2020,
- 10% renewable energy in the transport sector by 2020, the car fleet should be free from fossil fuel use by 2030,
- a 20% improvement of energy efficiency by 2020,
- a 40% reduction in greenhouse gas emissions by 2020 (relative to 1990), in the sector outside the European Emission Trading Scheme (ETS). By 2050, Sweden will have no net emissions of greenhouse gases in the atmosphere.[7]

Policies relating to energy efficiency

Launched in the 1970s, energy conservation efforts were strongly reinforced after 1990. Created in 1998, the Swedish Energy Agency has 14 regional offices, providing local information, advice and grants to officials in charge of energy efficiency in Sweden's 21 counties and 290 municipalities. These officials pass on the grants to companies or individuals, and ensure compliance with the rules governing such aid.[8]

7. Regeringkansliet 2009. This goal was set for 2045, in the political agreement of 10 June 2016.
8. Ministry of Enterprise, Energy and Communications 2013.

Specific actions have targeted large industrial energy consumers, organized as of 2004 in the PFE program (*Programmet för energieffektivisering i energiintensiv industri*); in return for their commitment to policy, these "energy intensive" businesses were exempted from the energy tax until 2008, or even to 2017 in some cases. Since 2010, all companies consuming more than 500 MWh per year can receive aid covering 50% of the costs of their energy audit. For households, subsidies related to renovation can run to €11,000 per housing unit. [9]

Policies on renewable energy

In the early 1990s, the Swedish authorities adopted two measures that have significantly changed the energy balance. The first was the creation of a tax on CO2 emissions, with wood and some waste being exempted. This tax is described above. The second measure provided grants to local authorities for work on heating networks powered by bioenergy, and individuals who agreed to connect their homes to these networks (up to 30% of total expenditures). Thanks to these two measures, district heating has penetrated 245 communes and accounts for 50% of the country's heating needs. In 2008, bioenergy accounted for about 71% of these supplies.[10]

This combination of taxes and subsidies then promoted the production of biofuels from the 2000s onwards. By the end of 2014, Sweden ranked fifth in the EU for the consumption of bioethanol and sixth for biodiesel consumption. The country is in first place for the use of biomethane fuel, alone accounting for 67% of the biogas fuel consumption in the EU.[11]

However, up until 2002, this combination had failed to stimulate the production of electricity from renewable sources in new sectors (wind power, micro-hydro, etc.). In May 2003, the Parliament therefore approved an ordinance establishing a system of green certificates. Under this system, electricity producers receive a certificate for every MWh produced from an eligible energy source (old dams are not included), which they can sell on specifically-dedicated exchanges. Every year, electricity suppliers must then submit a number of certificates proportional to their sales to a competent authority; they can acquire these certificates on these exchanges. In principle, the value of the certificates is equal to the difference between the electricity price set in the market (Nord Pool) and

9. J.-E. Nilsson, 2011.
10. NREAP 2010. Peat is sometimes included with bioenergy in Swedish statistics, though European rules do not allow it to be qualified as renewable.
11. EurObserv'ER 2015. Biomethane results from the purification of biogas to remove certain impurities.

production costs in the new energy sectors. The allocation of certificates lasts 15 years per installation. The obligation of suppliers represented 7.5% of their sales in 2003; it increased gradually but not linearly to 18% in 2010 and should reach 20% in 2020. Since 2012, Norway and Sweden, which apply the same system, allow suppliers to submit certificates acquired in either country. Between 2003 and 2012, renewable electricity output increased by 13.3 TWh: under the agreement between the two countries, Norway and Sweden have a common goal of achieving 26.4 TWh output by 2020.[12]

Nuclear power policy

Sweden was one of the pioneering countries in the use of nuclear energy, with the completion of its first experimental reactor in 1954. The launch of modern commercial reactors began in 1972; in total, 12 units were put into service through 1985.

In the early years of nuclear power, Swedish public opinion was mostly benevolent towards this source of energy, but mistrust was never far. Successive governments have given strong guarantees, first in terms of the safety of facilities, based on the actions of the national nuclear safety authority, the SSM; then in 1977, in terms of radioactive waste management, by obliging operators to outsource this task to a specially-dedicated company, SKB.[13]

Public scepticism about nuclear power emerged following the accident at the Three Mile Island power plant (in Harrisburg, Pennsylvania) in 1979. This accident did not cause any casualties or damage to the environment, and radioactive emanations were kept within the reactor's containment structure. Nevertheless, the accident raised strong emotions in Sweden. In March 1980, during a national referendum, 58% of voters wanted Sweden's nuclear plants be closed progressively as renewable energy developed, and subject to demand (39% voted for immediate closure), while no new nuclear power stations were to be authorized.

The referendum had no constitutional value, but all political parties had pledged to take account of its outcome. This they did in 1991, after the Chernobyl accident, when the Swedish Parliament voted to set a deadline for the nuclear power plant fleet to stop operating in 2010. However, in December 1995, a public commission on energy concluded that alternative

12. NVE 2013.
13. SSM: Strålsäkerhetsmyndigheten, and SKB: Svensk Kärnbränslehantering AB.

supplies would not be sufficient at that date. Moreover, the economic recession that hit the country in 1992 and 1993 showed the importance of low-cost electricity for the Swedish industry, in which several branches remain heavy electricity consumers. A new law was passed in June 1997. It repealed all deadlines, but imposed the closure of the Barsebäck plant, which had attracted violent opposition in Denmark since its launch: Denmark is generally hostile to nuclear energy and its capital is located just 20 km from Barsebäck. The first unit of this facility ceased operating in November 1999 and the second unit stopped in May 2005. Sydkraft, the operator which had come under ownership of the German group E.ON, received an indemnity of nearly €600 million for the closure of each unit, and a handover of about 30% of the capital investment in the Ringhals nuclear power plant by its owner Vattenfall, to prevent the latter from holding a dominant position on the Swedish market.

Sweden has moreover estimated that the loss of production at Barsebäck will oblige it to build gas-fired plants. In 2002, the country obtained adjustments to its commitment under the Kyoto Protocol, as other European countries agreed to reduce their CO2 emissions more than expected. Sweden could thus increase its own emissions, while the EU's planned total remained unchanged.

After the 1997 vote, Sweden's nuclear operators understood that it would be difficult to build new reactors. They therefore grasped every opportunity within the existing legal framework to increase the production at each site by gradually replacing old equipment with new components to expand available power capacity, under supervision of the national nuclear safety authority, SSM. In total, these increases reached nearly 1,600 MW, exceeding the capacity of the closed facility at Barsebäck. The table in Annex 3 shows Sweden's fleet of nuclear plants with enhanced power, as of early 2016.

The scepticism of part of the population concerning nuclear power has not affected national provisions for the storage of spent fuel. SKB was able to open an interim storage facility (CLAB) near the Oskarshamn power plant, and undertake the development of a final landfill site near the Forsmark power station, without encountering any significant opposition. This final storage site should be operational in 2020. The corresponding expenses are covered by a fund for nuclear waste (*Kärnavfallsfonden*), which is independent of operators, but which they fund through a tax on each MWh produced by their reactors. The SSM proposes tax levels which the government then fixes by regulation.

In 2009, the center-right majority led by Mr. Fredrik Reinfeldt opened the possibility of replacing each old reactor by a newer model,

provided it is built on a site already in operation and that the total number of units in operation remains equal to ten. The text adopted by Parliament also called for the ratification of the Paris Convention of 2004, which raises the liability of operators to €1.2 billion for accidents, but this resolution has not been implemented to date. A political changeover in 2014 brought to power an alliance between the Social Democratic Party and the Green Party. The new government raised the levy on nuclear waste to €4.30/MWh for the period 2015-2017, and increased the tax on the thermal power nuclear reactors by 17%, as of 1 August 2015: the tax rate then exceeded €7/MWh. With taxes as high as this and market prices which are significantly depressed, renovating older reactors, which will soon be necessary, seems no longer profitable. Such work does indeed look to be very costly given the new safety requirements presented by the SSM in October 2014, and which is mandatory as of 2020. In February 2016, the OKG group thus announced the closure of Unit 1 at the Oskarshamn power plant in 2017, and that it will not restart Unit 2 which had been shut down for maintenance. For its part, the Vattenfall Group has looked at the final shutdown of Units 1 and 2 at Ringhals in 2019 and 2020. In total, nearly 2,800 MW in capacity might be removed by 2020, about 7% of Sweden's installed capacity and 12% of its annual electricity output.

Concerns raised by these prospects, prompted the Prime Minister Stefan Löfven to reconsider his policy. Having reshuffled his team substantially on 25 May 2016, he entered into negotiations both within his coalition and with the opposition parties. These negotiations led to an agreement on 10 June 2016 by which the country will strive towards the goal of 100% renewable energy by 2040. But there is no fixed term applied to the use of nuclear energy. The agreement confirms the provisions approved in 2009, notably the possibility of building new reactors to replace old ones, and the agreement also provides for the abolition of the tax on the thermal power of reactors within two years. The shortfall in State revenues will be offset by an increase in the energy tax borne by residential consumers.[14] The agreement was approved by five parties, which obtained 72% of the vote in the last elections, and 74% of elected officials.

14. Regeriengskansliet 2016.

The Present Situation

The Energy Balance

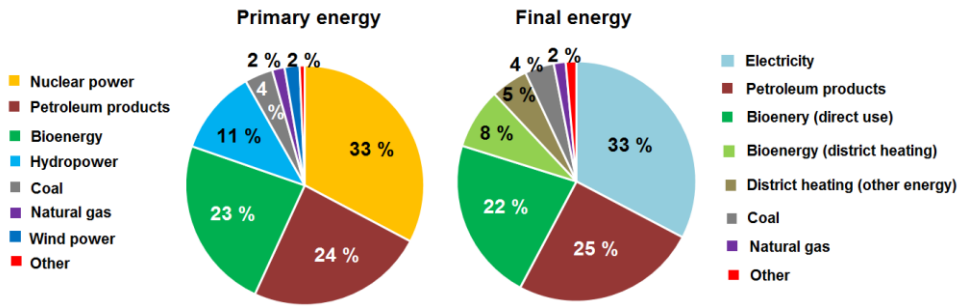
Supply

In 2014, the primary energy balance in Sweden was characterized by three factors:

- Fossil fuels accounted for only 31% of the total balance, compared to more than 72% for the whole of the EU. Petroleum products provided only 24% of these resources (34% for the EU).
- Sweden led the EU in the role played by renewable energy, with 36% of the primary balance (equal with Latvia); on average, renewables contributed less than 13% in the EU 28.
- Nuclear power (33%) was far more important than the European average (14%); France alone relied more on nuclear energy (45%).[15]

Graph 3 illustrates these features; renewable sources are broken down into bioenergy (23%), hydropower (11%) and wind power (2%).

Graph 3: Energy balances in Sweden in 2014



Source: Energimyndigheten 2015a and Energimyndigheten 2015d.

Graph 3 shows up another Swedish singularity: the marginal role assigned to natural gas, which in 2014 accounted for only 2% of the primary balance. Sweden thus ranks 24th among the gas consuming

15. Eurostat 2016a.

countries of the EU, behind Luxembourg. The gas transport network only has 620 km of pipeline. Only 30 communes are connected, which are all located in the southwest of the country; Stockholm is not supplied with gas.

Despite the small size of the domestic market, the need to diversify supplies and benefit from advantageous spot market prices led to the construction of Sweden's first LNG terminal in Nynäshamn, which opened in 2011. Sweden has another specificity: 9.4% of the final consumption of gas is used for transportation, compared to 1.3% on average in the EU.[16] The liquefied natural gas (LNG) is to be used for transport, especially to fuel coastal ships. A second regasification terminal is under construction at Lysekil: unlike the first, this terminal could be connected to the network.

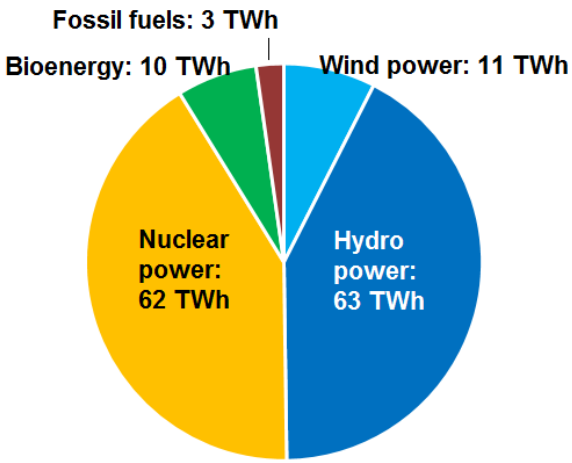
The processing of primary energy resources into final energies leads to further Swedish specificities:

- Over 33% of final consumption is in the form of electricity, compared to less than 22% for the average European level, a level found broadly in the EU's large countries: slightly less for Germany, Italy and the United Kingdom (about 21%), slightly more for Spain and France (25%).
- Bioenergy for end use exceeds 30% of the Swedish balance, while the figure is less than 15% throughout the EU (solid biomass and biogas for heating and biofuels for mobility).
- Fossil fuels only play a minor role in the production of electricity, less than 2% in Sweden, compared to an average of 45% in the EU.[17]

For final energies, electricity generation has an outstanding configuration, which appears strikingly in Graph 4. Renewable energy (56.3%) and nuclear power (41.4%) mean that nearly 98% of Sweden's electricity production comes from sources not emitting greenhouse gases.

16. Eurostat 2016b.
17. Commission Européenne 2015b and Eurostat 2016b.

Graph 4: Electricity generation by source in 2014

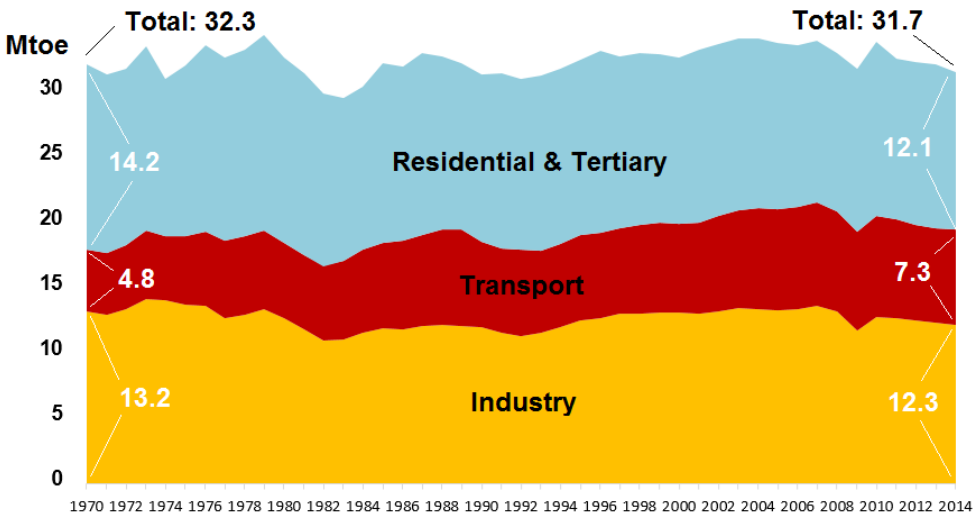


Source: Energimyndigheten 2015c.

Demand

Final consumption remained remarkably stable from 1970 to 2014, decreasing by 1.8% over the period. The falls observed in the residential & tertiary and industry sectors were almost fully offset by the increase in the transport sector.

Graph 5: Final consumption by sector



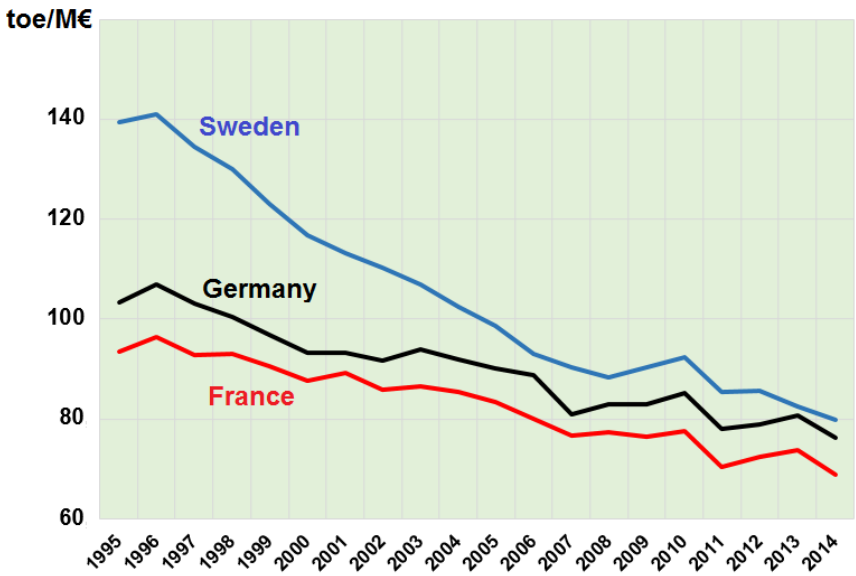
Source: Energimyndigheten 2015e.

It should be noted that Sweden's population increased by 9.4% between 1995 and 2014, from 8.8 million to 9.6 million. Thus, final consumption per capita fell by 16.5% over twenty years, from 4 toe to 3.2 toe per year. Over a longer period (1973-2014), France's population

increased substantially more (23.2%) and has successfully reduced unit demand by 8% (from 2.7 toe to 2.6 toe per year per person).[18]

Since the accession of Sweden to the EU in 1995, homogenous data for measuring gross domestic product (GDP) has been available. It can be noted that Sweden continues to be highly energy intensive, both in terms of primary resources, using 123 toe per million euro (€M), and in its final consumption, with 74.3 toe/€M. Sweden's energy intensity has nevertheless fallen sharply since 1995, due to the sustained GDP growth (2.6% per year on average), while energy consumption has remained stable. With substantially lower economic growth (1.6% per year), France has not recorded a comparable decline. Germany is in an intermediate position, as shown in Graph 6.[19]

Graph 6: Energy intensity (final energy)



Source: Eurostat 2016a et Eurostat 2016e.

The three countries today have relatively similar energy intensities, despite distinct paths, with Sweden having experienced markedly different developments to France and Germany, and more generally the other 14 countries that made up the EU on its entry. Table 2 illustrates this difference.

18. Eurostat 2016a, Eurostat 2016d et CGDD 2015.
19 Eurostat 2016a et Eurostat 2016e.

Table 2: A comparison of situations from 1995 to 2014 (final energy)

	1995		2014		Variation	
	GDP per capita	Energy intensity	GDP per capita	Energy intensity	GDP per capita	Energy intensity
	€ 2010	toe/€M	€ 2010	toe/€M	%	%
EU 15	24 200	100.3	30 000	74.3	+ 24%	- 26%
Germany	26 400	103.3	33 800	76.3	+ 28%	- 26%
France	25 800	93.5	31 100	68.8	+ 21%	- 26%
Sweden	28 500	139.4	40 300	74.3	+ 41%	- 47%

Source: Eurostat 2016a et Eurostat 2016f.

Greenhouse Gas Emissions

According to Swedish data, emissions of greenhouse gas were 71.9 MtCO2e (million metric tonnes of carbon dioxide equivalents) in 1990, and decreased to 54.4 MtCO2e in 2014, a fall of 24%. Standardized European data were interrupted in 2013, but they confirm that Sweden has achieved a greater reduction than the average of the 15 Western European countries, which have reduced their emissions by 16.8% (1990-2013).[20] Given the economic growth highlighted above, the reduction relative to GDP has been even more dramatic: emissions dropped from 294 to 146 tCO2e/€M. In 2013, the Swedish economy had the lowest carbon footprint of the EU, whose average was 345 tCO2e/€M. Germany was slightly above the average (353 tCO2e/€M); France was in the third best position (238 tCO2e/€M), behind Denmark (224 tCO2e/€M).

Sweden's performance is also reflected in its ranking in per capita emissions: in 2013, the average Swedish citizen emitted 5.8 tCO2e/year, or half the greenhouse gases emitted in neighbouring Germany (11.6 tCO2e/year), and significantly less than in Denmark (9.7 tCO2e/year), in Britain (9 tCO2e/year), in France (7.5 tCO2e/year) or than the European average (8.8 tCO2e/year, EU 28).

The data used here do not take into account changes in land and forest use.[21] As most European countries, Sweden has recorded an extension of wooded or natural areas, which play a role as carbon sinks. It was feared that the massive use of biomass may have weakened this phenomenon, but it has remained stable. Swedish green areas absorbed

20. Naturvardsverket 2016b and Eurostat 2016g. Emissions excluding changes in soil use and international transport.
21. LULUCF – *Land use & Land use change and forestry*.

40.9 MtCO2e in 1990 and 41.6 in 2013. Only France did better in the EU, soils having retained 46.7 MtCO2e in 2013 (37.6 million tCO2e in 1990). [22]

Sweden has therefore easily met its commitments under the Kyoto Protocol, taken after an agreement within the EU that allowed Sweden to increase its emissions between 2008 and 2012 by 4% above their 1990 level. The average emissions recorded in these five years were about 15% lower compared with 1990. [23] Sweden also seems well on track to meet the obligation established by the EU in 2009, of reducing its emissions in the sector not covered by the EU ETS by 17%, between 2005 and 2020. According to the latest progress report by the European Commission, Sweden's current path should enable it to achieve a 28% cut.[24]

Renewable Energy

We saw in Chapter 1 that the combination of taxes on CO2 emissions and subsidies for heat networks has spurred the development of bioenergy after 1990. Its place in Sweden's primary energy balance rose from 11% in 1990 to 23% in 2014, rising with a near-linear slope, and reaching 11.2 Mtoe in 2014 (out of a total primary consumption of 47.7 Mtoe).

In the early years, bioenergy consisted primarily of wood and black liquor, a byproduct of paper pulp manufacturing, which is an important industry in Sweden. In the 2000s, a series of tax measures has also given an advantage to biofuels and biomethane: a VAT rebate, and exemption from taxes on energy and CO2 emissions, incentive premiums to buy vehicles, etc. Since 2006, the law has required petrol/gasoline stations to install at least one pump for an alternative fuel. The impact of these measures has been amplified by local initiatives: exemptions from congestion charges, special traffic lanes, free parking, as well as the purchase of "clean" vehicles for municipal services. The Swedish car manufacturers (Volvo and Saab) adapted their products immediately, including so-called "flex fuel" cars capable of running with a mixture of up to 85% bioethanol. At the end of 2014, the primary sources of bioenergy were as follows:

22. Eurostat 2016a, Eurostat 2016e and Eurostat 2016f.
23. Naturvardsverket 2016b.
24. European Union 2009 and European Commission 2015a.

Table 3: Bioenergy at the end of 2014

	Mtep
Wood	5.3
Black liquor	3.7
Biofuels	1.2
Biogas	0.1
Organic components of household waste	0.8
Total	11.2

Source: Energimyndigheten 2015f.

About half of all wood is sold in the modern form of *wood chips* or *pellets*, making it easier to store and transport, in bulk or in bags, and also improving combustion. In 2014, wood dominated supplies for heat networks, representing 62% of energy consumed, compared to 9.2% for fossil fuels. These networks used electric boilers up until the mid-1990s, providing 15% of heating in 1990. But this technology has now been replaced by heat pumps (8.5% of demand in 2014) or heat recovery in buildings, subways, etc. (7.5% of resources in 2014). Some of the wood is used to produce electricity: 9.1 TWh in 2014. All power plants consuming wood in Sweden operate in cogeneration, also producing heat.

The taxes on energy and on CO2 emissions, along with local subsidies, were sufficient to allow wood to dislodge fossil fuels for providing heat, within a decade.[25] However, this approach alone has appeared unsuitable for the production of electricity. The green certificate system, which came into force in 2003, targeted electricity especially, as only electricity suppliers were obliged to collect annually a number of certificates proportional to their sales. This measure gives electricity producers the freedom to choose their renewable sources of energy. In practice, the construction of new dams appears extremely difficult, given that laws protect not yet equipped waterways, while cogeneration is only profitable by exploiting heat. However, the real needs which could be met by this sector are approaching saturation.

The new legal framework has therefore mainly benefited wind power. Between 2002 and 2014, the fleet of hydropower stations remained unchanged; the thermal capacity increased by 572 MW; and wind power capacity grew by more than 5,000 MW.[26]

25. To be precise, it should be recalled that Sweden let its currency depreciate by 21% between 1992 and 1993, leading to higher prices for fossil fuels which are all imported.
26. Energimyndigheten 2015j.

The green certificate system is neutral vis-à-vis technology; in all cases, the revenue the producer gets is the sum of the electricity price and the price of the certificate. As a result, the system favours the cheapest sector. According to Swedish Wind Energy (Svensk Vindenergi, i.e. the trade association of wind power producers), the constraint that electricity suppliers back 20% of their sales with green certificates by 2020 has stimulated many projects. For onshore wind power, by the end of 2015 the Association listed more than 6,600 MW in confirmed projects, and a further 12,000 MW under investigation. As for offshore wind power, output of almost 2,300 MW has been confirmed, and 3,450 MW is planned.[27] Aside exceptions, power facilities in service before 2003 do not receive a green certificate.

However, expectations remain insufficient to stimulate the production of electricity from sources such as biogas or photovoltaic solar panels. Biogas has found support among local authorities, which have stimulated its development through grants, and are seeking to use output in the form of transport fuel, particularly for captive vehicle fleets. In late 2011, more than 1,500 buses were running largely on biomethane (purified biogas) in Sweden, with 250 in Stockholm. The green certificate system is poorly suited to solar power, because it leads to prohibitive transaction costs for small installations. The falling cost of components has nevertheless allowed this sector to take off. Solar power capacity is still modest: 79 MWp were in service at the end of 2014, equal to 0.06% of Sweden's electricity generation. But, it is growing fast. It is estimated that only 8% of this production has requested the corresponding green certificates. The first projects were funded by local cooperatives, with earnings coming mainly from sale contracts with municipal companies.[28]

Economic Issues

In Sweden, as in all OECD countries, the import prices of fossil fuels – coal, oil and gas – are set internationally, worldwide for the first two, in the European region for the third. The government cannot influence their evolution, although its tax policy affects prices for the end customer. Policies promoting renewables come on top of the effects of tax choices.

At the end of 2015, the price of natural gas for industrial use in Sweden was the second highest in the EU, along with the price in Finland, for all levels of consumption (from 300 MWh/year to 1.1 TWh/year). This was not a result of the tax system, because the price before taxes was

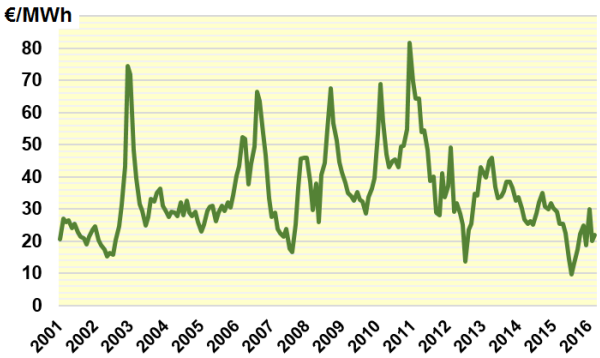
27. Svensk Vindenergi 2016.
28. Baltic Biogas Bus 2012, AIE 2014 & Svensk Solenergi 2016.

already among the highest. In 2015, a Swedish industrial company within the average consumption band (I3, or 3,000 to 30,000 MWh/year) paid the about €35/MWh for gas, while the wood price was less than €20/MWh (excluding taxes). Admittedly, this price relates to woodchips which require storage space and entail much higher handling costs than gas. But, the cost advantage still seems substantial, especially as wood is exempt from the carbon tax.[29]

The bulk of Swedish imports of petroleum products are used for transport. The European Energy Portal indicates that in 2016 the price of unleaded gasoline is €0.371/litre excluding taxes. This is below the European average (€0.425/litre, for the EU 28). After Sweden's energy tax, carbon tax and VAT (Europe's highest at 25%), the price of gasoline is €1.267/litre, which is higher than the EU average (€1.177/litre). The price of diesel, excluding taxes, paid by Swedish owners of diesel vehicles is higher than the European average, respectively €0.455 and average €0.436/litre. After taxes and VAT, the diesel price is the third most expensive in Europe, behind the UK and Italy. In the case of transport fuels, the conditions of supply and VAT are therefore as important to the final price as the energy tax and the carbon tax.[30]

Regarding electricity, Swedish industrial consumers benefit from prices which are among the lowest and often the lowest in Europe, both before and after tax. For electricity-intensive consumers, which can buy on the wholesale market, however, prices vary significantly depending on the season and on precipitation, which affect hydropower generation. Indeed, in the four countries constituting the Nord Pool, the fleet of hydraulic power stations represents nearly 50% of all installed capacity (Graph 7).

Graph 7: Spot price fluctuations on Nord Pool and the composition of the power station fleet



	MW
Hydro power	50 184
Thermal	27 243
Nuclear	12 283
Wind power	9 653
Solar power	606
Total	103 313

Source : Nord Pool 2016 et Nord Reg 2014.

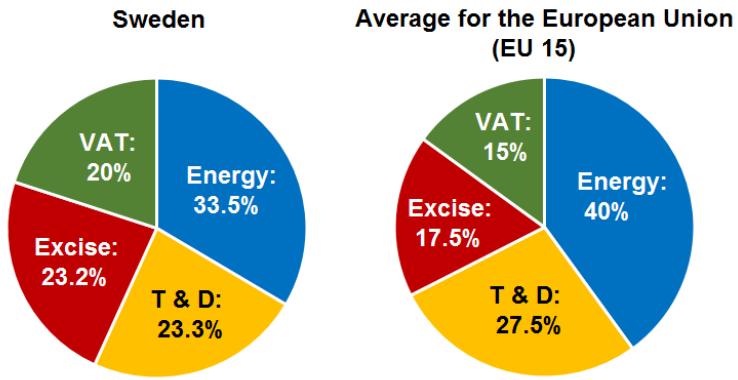
29. Eurostat 2016g, and Energimyndigheten 2016.
30. Europe Energy Portal 2016.

The Nord Pool market has experienced a downward trend since 2012.

For the small domestic consumer, electricity costs €187 per MWh, putting Sweden in fifth place behind France (€168) and the Netherlands (€183), but well ahead of the United Kingdom (€218), Italy (€243), Germany (€295), Denmark (€304 €), etc.[31] However, this is an average, aggregating a variety of situations, as Swedish suppliers offer a wide range of prices. These may be with or without a fixed premium, variable or guaranteed for one, two or three years, and modulated according to actual annual consumption.[32] Although all consumers in Sweden have been equipped with electronic meters, electricity suppliers do not yet offer prices that are modulated according to time of use.[33]

These prices include all levies and taxes: in Sweden, they include energy tax, the cost of green certificates and of course VAT. The energy tax can be estimated at €31/MWh for 2015. The cost of green certificates is not yet known for 2015, but it has never exceeded €5/MWh since 2003 (a cost relating to all MWhs consumed). By way of comparison, the share attributable to renewable energy is expected to be €15.10/MWh in France and €63.50/MWh in Germany, in 2016.[34] Nevertheless, although one kWh of electricity in Sweden hardly includes carbon tax, since the share of fossil fuels in electricity production is small, it carries a very high level of overall taxes (excise + VAT) as shown in Graph 8.

Graph 8: Breakdown of consumers' electricity bills



Source : Commission Europeenne 2014 et Nord Reg 2014.

T & D: Transmission & Distribution. The term "Excise" here includes all taxes and charges which are proportional to consumption yet independent of energy prices.

31 The DC band in the European classification is an annual consumption of 2.5 MWh to 5 MWh per year.
32. Eurostat 2016g and Statistiska centralbyran 2016a.
33. Energimarknadsinspektionen 2014.
34 Energimyndigheten 2014, BMWi 2015, CRE 2015

Outlook and Lessons

The Search for New Answers

For twenty years, Sweden has had a remarkable economic performance, while having successfully stabilized its energy consumption, reducing its emissions of greenhouse gases and increasing the share of renewable energy in its energy balance. All indicators suggest that this trend will continue until 2020. But can it last until 2030 and beyond?

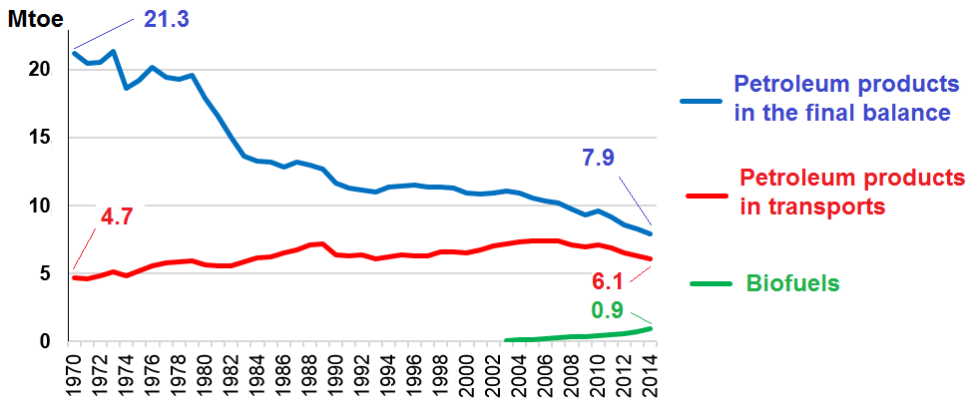
Reducing greenhouse gas emissions further

We have seen that fossil fuels only made up 30% of Sweden's primary balance 2014: about 24% from oil, 2% from gas, and 4% from coal.

First, it needs to be noted that coal consumption has in no way diminished in 35 years, rising slightly from 1.22 Mtoe in 1970 to 1.25 Mtoe in 2014. Coal is used mainly in industry, which accounted for 68% of demand in 2014. The use of coal in sectors such as steel and cement is hard to replace. Unless production is relocated offshore, emissions from coal are therefore likely to fall little in the short term. Sweden is also in fact among the countries looking at CO2 capture and storage (known as Carbon Capture and Sequestration or CCS), either nationally within the SwedStoreCO2 program, or within the regional NORDICCS network, involving countries bordering the Baltic Sea.

The consumption of petroleum products has dropped sharply since 1970, from 29 Mtoe that year to 11.5 Mtoe in 2014. The bulk of the available petroleum volume today is divided between industry, where it is partly used as a raw material for petrochemicals, and especially in the transport sector, where gasoline and diesel still provide 84% of needs. Petroleum products are no longer used in the heating market. But, after becoming more important in transport (rising from 4.7 Mtoe in 1970 to 7.4 Mtoe in 2007), they have only slowly yielded ground to biofuels, natural gas or electricity, as petroleum products still contribute 6.1 Mtoe to transport, as shown in Graph 9.

Graph 9: Transport in the total energy balance



Source: Energimyndigheten 2015d and Energimyndigheten 2015g.

Sweden seems to have exceeded the 2020 target, which involved using at least 10% of non-fossil fuels in the transport sector. In 2014, biofuels already provided 13% of transport energy and electricity 3%. The objective the government has set for 2030, namely having a transport sector which does not use fossil fuels, seems much more difficult to achieve. As in the past, the measures taken to achieve this goal combine penalties and subsidies. Among the penalties, the Minister for Climate and the Environment (in office since October 2014) has announced an increase in the fuel tax and the creation of a tax applicable to all heavy goods vehicles to compensate for the wear caused to roads (*Vägslitage skatt*).[35]

Among the subsidies, the government strengthened support for facilities with biomethane pumps and electric charging stations. In addition to biofuels, the public authorities have strongly encouraged the spread of electric vehicles: from 2012 to 2015, €4,600 was granted for the purchase of any rechargeable electric or hybrid car. Their market share may of course grow significantly by 2030: electric cars accounted for 4.9% of new registrations in 2015, and rechargeable hybrids another 9.3%. However, given the current state of technology, electric drive will only slowly penetrate transport by truck or bus: commercial vehicles caused 33% of emissions of greenhouse gases in the transport sector, in 2014.[36]

Natural gas also requires a mention, because despite its small share in the energy supply of the country, it can replace some uses of petroleum products, especially when used as vehicle fuel, with much lower CO2 emissions per kilometre: emissions may be 16% lower compared to diesel

35. The Minister, Ms Asa Romson, resigned on 9 May 2016.
36. Energimyndigheten 2015g and BIL Sweden 2016.

and 20% for gasoline. The development of the gas market in Sweden would certainly be an intermediate solution to achieving lower emissions, but it would not lead to their disappearance. [37]

In addition to this overview, the Swedish Environment Agency (Naturvardsverket) has indicated that Sweden reduced its emissions by 30%, during the period 1993-2013. But, this was achieved by transferring some of its consumption to imported products, whose production led to an increase of emissions estimated at 50%. This trend can be found throughout the EU, as its manufacturing equipment changes over time. [38]

Increasing the share of renewables further

According to European statistics, over 52% of energy consumption in Sweden in 2013 came from renewable sources, so that Sweden leads the rest of Europe by far (being clearly ahead of Finland and Latvia which are tied in second place with 37%). The objective assigned to Sweden by the 2009 EU Directive was 49% in 2020, and the country set its own objective of 50% in 2009: both goals have already been overtaken.[39] According to the agreement reached between the five main political parties and signed on 10 June 2016, Sweden will strive to achieve 100% renewable energy by 2040.

At present no scenarios exist for the efforts needed to reduce consumption and to deploy new energy sources to meet this goal. Nevertheless, it seems likely that future obstacles will be comparable to those which arose in fulfilling the commitments for 2009. In this context, the government predicted that 25 TWh of electricity output would benefit from green certificates in 2020. Under the agreement of 10 June 2016, this quantity will increase to 43 TWh by 2030. According to the latest available inventory, production covered by the green certificates scheme amounted to 15.4 TWh in 2013. Projections to date suggest that forcing sellers of electricity to ensure that 20% of their sales by 2020 are covered by green certificates would lead to an output of 25 TWh.[40] Yet four uncertainties remain:

The limits to resources

The green certificate system has attracted new bioenergy resources into power generation. In one of its scenarios, the Energy Agency estimates that bioenergy could provide a further 2.4 Mtoe by 2030 (in addition to 11.2

37. AFGNV 2016.
38. Naturvardsverket 2016c.
39. Commission Européenne 2015c.
40. Energimyndigheten 2014.

Mtoe produced in 2014). But, this figure includes all uses (electricity, heat and biofuels), and it also includes peat and waste. Though extensive, Sweden's biomass reserves are not inexhaustible: it has already been suggested that fast-growing trees should be used preferably for reforestation, to expand wood output at the expense of natural biodiversity. Greater demand has economic consequences: between 1993 and 2013, the price of wood pellets and chips doubled. Also, in an open economy like Sweden, some consumers are importing these products, which are traded internationally as ordinary commodities, with prices which are sometimes cheaper than local supplies. In 2011, imports accounted for 8.5% of national consumption of this type of wood. [41]

Moreover, the European Commission has announced that solid biomass would soon be subject to comparable environmental evaluation which exists for biofuels since 2009. To be classified as "renewable", they must meet very strict specifications, which eliminate products that required too much energy in the initial stages of collection, processing, routing. For this study, no simulations were found indicating whether Swedish timber production would be threatened by this future standard, but this cannot be excluded.[42]

Regarding wind energy, Sweden has considerable potential capacity. In 2009, a study by the European Environment Agency put the country ahead of all European countries for terrestrial wind resources, with a theoretical generation capability of 4,560 TWh, followed by France (4,524 TWh), Finland (4,511 TWh), and the UK (4,409 TWh). This volume is more than 30 times the consumption of 2014, and was calculated for 2030. It incorporates expected cost reductions due to learning effects throughout the entire industrial process. Only sites with a harmonized generation cost equal to or less than €65/MWh were selected.[43]

This study assumes flawless social acceptance of wind power. But it is in fact facing organized opposition, with the creation of an association which in 2009 already had 15,000 members, motivated by landscape preservation and the fight against local disturbances caused by wind turbines (Föreningen Svenskt Landskapsskydd). However, Sweden's specific culture of dialogue has encouraged the emergence of a consensus, in the form of a map of areas where residents tolerate the establishment of wind farms. Available production in these areas is set to reach 20 TWh

41. Energimyndigheten 2015h and Skogsstyrelsen 2016b.
42. Commission Européenne 2016.
43. AEE 2009. Energy likely to be producible in 2030 (4,560 TWh) is equivalent to the sum of output judged as "competitive" and "probably competitive", on page 48.

onshore and 10 TWh at sea in 2020. This is very far from the theoretical evaluations of the European Environment Agency.[44]

Consequences for electricity prices

By choosing the green certificate mechanism which stimulates competition between the various technologies, Sweden has so far tapped the least expensive renewable sources in terms of bioenergy and onshore wind, at the best placed sites. The result appears remarkable, given that public support is limited to €23.50/MWh for onshore wind power (the value of a green certificate in 2013), compared to €40.20/MWh in France, from €49 to €67.50/MWh in Germany, and more than €54.20/MWh in the UK. The full returns to Swedish operators are obtained by adding to this support the price of the sale of electricity: given that the average price on the spot market (Nord Pool) was €38.10/MWh in 2013, electricity from wind earned €23.5 + €38.1 = €61.6/MWh. This level lies at the bottom of the range of costs estimated by international agencies.[45]

The low production cost of Swedish wind power is probably due to the reasonable returns demanded by capital providers, who benefit from a strong regulatory framework and so face a modest risk premium. This situation could change. Prices on the Nord Pool market have been falling since 2013 (see Graph 7). These price falls have been accompanied by declining costs of green certificates, as shown in Graph 10. The price of green certificates in turn depends on several parameters that are affected by high variability, including: rainfall, wind patterns, the level of electricity demand, etc. If uncertainties about the price of electricity are added to these hazards, then the risk premium will likely increase, especially as future returns on investment will be less assured given that the best sites are already equipped. Furthermore, the transition to offshore wind power cannot be envisaged without a significant increase in the price of green certificates. Indirect confirmation of this can be found in the study of the European Environment Agency mentioned above, which estimates that no offshore wind farm will reach the threshold of competitiveness by 2030.

44. Regeringkansliet 2009.
45. CEER 2015, Nord Pool 2016 and IRENA 2015.

Graph 10: The evolution of the price of green certificates

Source: SKM 2016.

Any increase in the price of green certificates will affect sales. The government has one lever to maintain electricity prices low for final consumers, namely reducing the energy tax, whose direct impact on consumer bills was explained at the end of Chapter 2. Doing this would reduce tax revenues, as this tax generated €2.2 billion for the government in 2014.[46] A cut in the rate of VAT would also be possible, with the same consequences for the national budget. However, the political agreement of 10 June 2016 in fact provides for an increase in the energy tax levied on residential consumption.

Consequences on the existing fleet of power stations

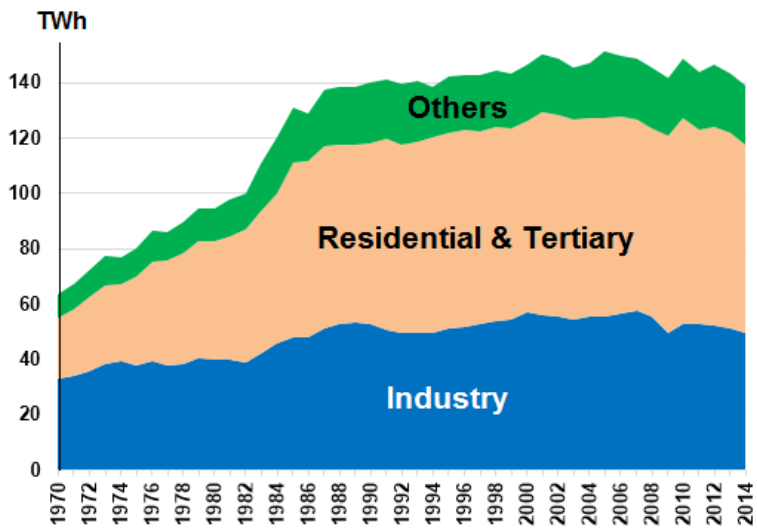
Across Europe, the rising volumes of renewable electricity which benefit from extra remuneration threaten "historical" producers whose revenues only come from the market. In Sweden, these are large hydro and nuclear power plants. The biomass units commissioned before 2003 are also vulnerable. They generally do not have access to green certificates, but all operate in cogeneration, and revenues from the sale of heat mitigate the impact of competition on their electricity sales.

As mentioned in Chapter 1 (section 4), E.ON and Vattenfall had considered the closure of four nuclear units in the near future, as their maintenance costs seemed too high given the economic and tax conditions

46. Statistiska centralbyran 2016b.

prevailing until 2016. The framework agreement of 10 June 2016 has postponed this possibility, and implicitly confirms that the loss of production caused by such closures cannot be offset in the short term by an equivalent reduction in electricity consumption. The latter has remained very stable since 1990, at around 144 TWh per year, of which nearly 40% on average is accounted for by the industrial sector, as Sweden has retained a powerful industrial sector, generating almost 19% of GDP (a higher share than in Italy, Spain, the United Kingdom or France). Electricity is also still used for residential heating in areas not served by district heating networks, very often using heat pumps (over 1.4 million heat pumps were in operation in Sweden in 2014). Graph 11 shows the demand for electricity: the fluctuations generally reflect temperature variations from one year to the next. [47] The political agreement of 10 June 2016 now focuses energy efficiency efforts on the consumption of electricity and emphasizes the development of their flexibility. This agreement thus confirms the principle that a reduction in demand coupled with greater flexibility will shape the development of renewable sources. In the meantime, Sweden will not be able to end its "nuclear interlude".

Graph 11: The evolution of electricity consumption



Source: Energimyndigheten 2015i.

Moreover, electricity bills for all consumers could rise significantly in case of premature withdrawals from nuclear units. On the one hand, financial support for alternative facilities would carry costs, passed on by

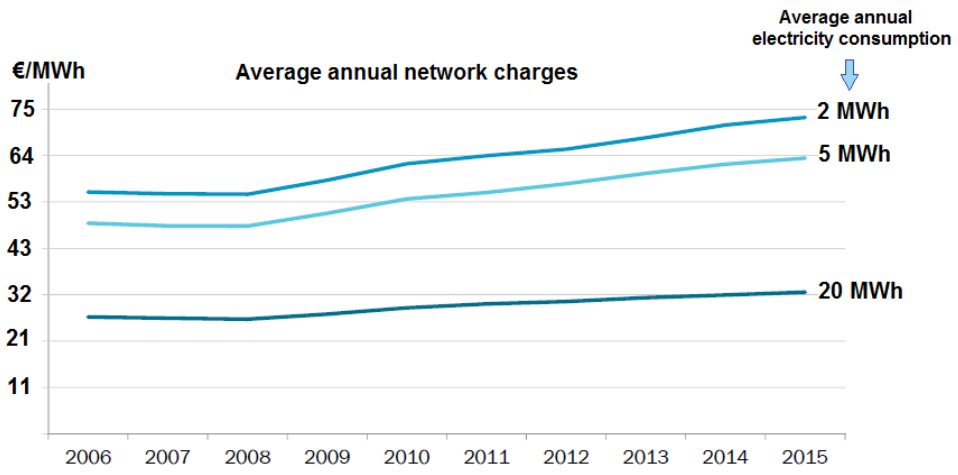
47. Energimyndigheten 2015i and Eurobserv'ER 2015.

the channel of the green certificates. On the other hand, if the operating life of certain nuclear reactors is shortened, it would be appropriate to increase the tax for the final management of spent fuel, as this tax would cover a smaller number of MWh than expected in initial cost estimates. Such a higher tax would further diminish the competitiveness of the remaining nuclear power plants... and risk hastening additional closures.

The outlook for networks

The development of new renewable energy sources requires, in Sweden as elsewhere, the extension and reinforcement of the grid. This results in an increase of transmission costs in electricity bills. In its latest report the National Regulatory Agency (Energimarknads-Inspektionen) lamented that this increase would affect small residential consumers more than large users, as shown in Graph 12.

Graph 12: The rise in power transmission costs for residential consumers



Source: Energimarknadsinspektionen 2014.

But Sweden has also been solicited for reinforcements that would benefit the EU more widely, by facilitating access for all operators to its water reserves. They could provide precious backup output for intermittent power generation. In all its scenarios, the e-Highway 2050 project calls for a consolidation of the North-South axis through the country, and its extension by an underwater, high-capacity connection with Germany.

In the shorter term, the Nordic market will be better connected with neighbouring markets resulting from the construction of new power lines with neighbouring regions, running from Denmark, Finland, Norway, and of course Sweden to the Baltic countries, Germany, Poland, the United

Kingdom, etc. These new routes figure prominently in the list of projects in the 10-year development plan of European networks for power transport.

Strengthening interconnections tends to unify prices which currently vary significantly in different markets. In the countries of the continental zone, from France to Poland, wholesale prices have fallen. Lignite and coal-fired power stations have overcapacity due to the current influx of renewable energy which has flooded the market with electricity with low marginal generation costs, particularly in Germany. But this price is still higher than the Nord Pool market price. A convergence of wholesale prices throughout the EU is expected to cause an increase in Nord Pool prices. This will surely not be good news for Sweden, whose industry currently benefits from the lowest price (excluding all taxes) in Europe, both in winter (despite low hydro production) and in summer. Swedish industry would therefore see its competitive margins shrink.[48]

Lessons for the Whole of the European Union

Sweden is one of the four most prosperous EU countries, in terms of income per person. The country has a per capita energy consumption which is about 50% higher than the European average (EU 28 - final energy). But, Sweden's heating needs are 67% greater (measured in degree-days).[49] Despite a highly structured policy for controlling consumption, Sweden's energy intensity remains high, particularly because of the share of industry in GDP.[50] However, Sweden prides itself in having a remarkably low carbon footprint, both per capita and per unit of GDP, due to its primary energy mix which is based to almost 70% on non-emitting sources (nuclear power and renewables, mainly bioenergy, hydropower and more recently wind energy). Several features of Sweden's energy policy have contributed to these good results and can provide useful lessons.

48. ENTSO-E 2014, Commission Européenne 2015d.
49. Eurostat 2016i and Eurostat 2016j.
50. Ratio of final consumption to GDP, measured in toe/€M.

Taxing CO_2 emissions

Sweden's bioenergy took off thanks to two provisions improving their competitiveness with fossil fuels: the introduction of a tax on CO2 emissions and public support for district heating. The Swedish experience on CO2 taxation prompts three observations:

- First, it should be noted that the tax did not penalize the economy neither in terms of growth nor employment.
- It can also be observed that the energy-intensive companies have benefited from accompanying measures in the form of support for energy efficiency and a lower tax rate. The low rate on large companies created perverse effects during the first years of the tax's application: paper companies made profits by consuming fossil fuels for their own needs, carrying a modest tax, and selling black liquor (a by-product of their activity considered as a renewable energy) to boiler plants of heating networks, which were paying the full tax rate.
- Finally it must also be noted that the carbon tax has not had any decisive effect on the transport sector. Although a higher rate applies to fuels, it has not led to much higher prices than found elsewhere in Europe.

In short, the tax on CO2 emissions in Sweden is seen as a tool to diversify government revenues, since it was introduced with the aim of keeping the overall tax burden constant (or somewhat smaller). The tax would not have succeeded in redirecting consumption without complementary policies, and its limits are firstly in the need to preserve the competitiveness of sectors facing international competition, and in areas in where there are no real satisfactory alternatives, as transportation or some industries (steel and cement). Indeed, the overall rate of all environmental taxation in Sweden is still low: it represents only 2.2% of GDP, so Sweden ranks in 20th place in Europe, behind Denmark, Italy, the United Kingdom, etc. Total charges on energy, which include the tax on CO2 emissions, put Sweden in 10th position, with an implied rate of €220/toe in 2014, lower than the European average (EU 28) of €234/toe.[51]

51. Eurostat 2016l. The implicit rate is calculated dividing the total amount of earnings by a country's final energy consumption.

Provisions favouring renewable energy

Two initial remarks need to be made. First, Sweden has water resources and forest cover well above the European average, having Europe's largest forest resources.[52] Second, the country had developed hydropower before the liberalization of the electricity sector, at a time when the ownership of a territorial monopoly facilitated access to financing. Subsequently, Sweden could also develop the use of biomass for heating, by using local grants which existed prior to EU guidelines governing such support strictly today.

As regards with new renewable energy, Sweden no longer benefits from these favourable conditions and faces the same difficulties as other European countries in supporting the growth of renewables. Therefore, as has been mentioned above, Sweden has kept its system of green certificates to this end. The system is often criticized because the uncertainty surrounding earnings leads investors to increase their risk premiums, so that facilities on average cost more than installations built under the system of guaranteed purchase prices (feed-in tariff). However, Sweden has succeeded until now in applying this system in such a way that it is one of the least expensive in the EU. The reason for this probably lies not in the principle of the system but in its terms: excellent visibility (until 2035), permission to "bank" certificates in order to monetize them at the most appropriate moments, and a subtle management of obligations imposed on suppliers. In addition to these specific provisions, the Sweden's overall legal framework inspires confidence among economic agents. It is based on regulatory stability, a solid currency, effective dispute resolution bodies, etc.

These advantages however do not isolate Sweden from risks arising in neighbouring countries which hinder investment. Low price levels seem firmly anchored in European wholesale markets, due to overcapacity caused by the massive spread of renewable sources (about 45% of consumption if the EU meets the target set for 2030). Under these conditions, and probably for the next decade, direct sales on the market alone will not be enough to pay investors. This holds not only for conventional energy, but also for renewable energy which require substantial capital, such as wind or hydropower, whose component costs are only falling slowly (only the cost of solar panels is decreasing at a rate comparable to that of prices on the electricity markets, but Sweden's solar potential remains limited). Consequently, financial support supplementing market earnings will remain indispensable permanently. It will likely also

52. FAO 2010.

be required by the facilities reaching the end of their technical life cycle, such as wind turbines, dams and wood-based heating systems, all of which then need major component parts to be replaced.

Research and development efforts

All the difficulties pointed out here which affect Sweden, as well as other European countries, could be mitigated by technological breakthroughs. These include: electricity storage, CO2 capture and storage, the production of advanced biofuels and of course the reduction of energy consumption.

Sweden has grasped the importance of innovation to carry out its energy transition better than any other European country. For several years, Sweden has been among the European countries which have spent the most money for research, demonstration and development. In 2014, Sweden headed the list of European countries in spending per capita (measured in purchasing power parity), while in 2012, the most recent year of available data, it was second in the world behind Switzerland, but ahead of Japan, the United States, South Korea and China (in terms of per capita spending in euros).[53] The country files a considerable number of patents each year.

Sweden's R&D efforts are very structured. The Swedish Energy Agency identifies priorities for research, which are then translated into projects developed by the Swedish Research Council and the Swedish Governmental Agency for Innovation Systems (VINNOVA). The latter serves as a relay for European R&D programs. Parliament evaluates these arrangements every four years and votes necessary appropriations for the following four years. The projects generally receive mixed funding, combining the two Agencies, universities and interested companies. This helps facilitate the actual implementation of industrial pilot projects and reduces the dissemination time of new advances. Between 2003 and 2011, the bulk of spending targeted energy efficiency (in industry, buildings and especially transport) and renewable energy (including biofuels and solid biomass).

53. Eurostat 2016m.

Conclusion

Sweden's current good results in terms of energy do not appear to come from a very specific policy, a sort of single key to success, leading to a highly enviable position. Instead, the country seems to manifest a collective ability to make quick policy shifts, first to reduce its dependence on petroleum products by developing nuclear energy, and later to boost the use of bioenergy. It can also be noted that Sweden applies steady and persistent efforts, by pursuing long-term actions firstly in favour of energy efficiency, and secondly for renewable energy.

Sweden's present environmental performance would not have been achieved without favourable natural resources – hydro and biomass resources – and its current economic performance would likely be lower without the political consensus that has prevailed until now concerning its fleet of nuclear power stations and the management of radioactive waste. In these areas, the Swedish model offers few solutions to countries that are less well-endowed by nature, less tolerant of nuclear power, and less able to formulate agreement between all political forces on policy responses that are acceptable to a large majority of citizens. However, the Swedish model does provide a general source of inspiration in terms of its coherence in introducing a CO2 tax to help steer certain investments. These are backed by local government intervention practices, including technical assistance and grants to supplement private initiatives. The great pragmatism of Sweden's ongoing energy management should also be mentioned, as it translates goals into indicators of simple functions and uses selected tools skilfully, such as green certificates.

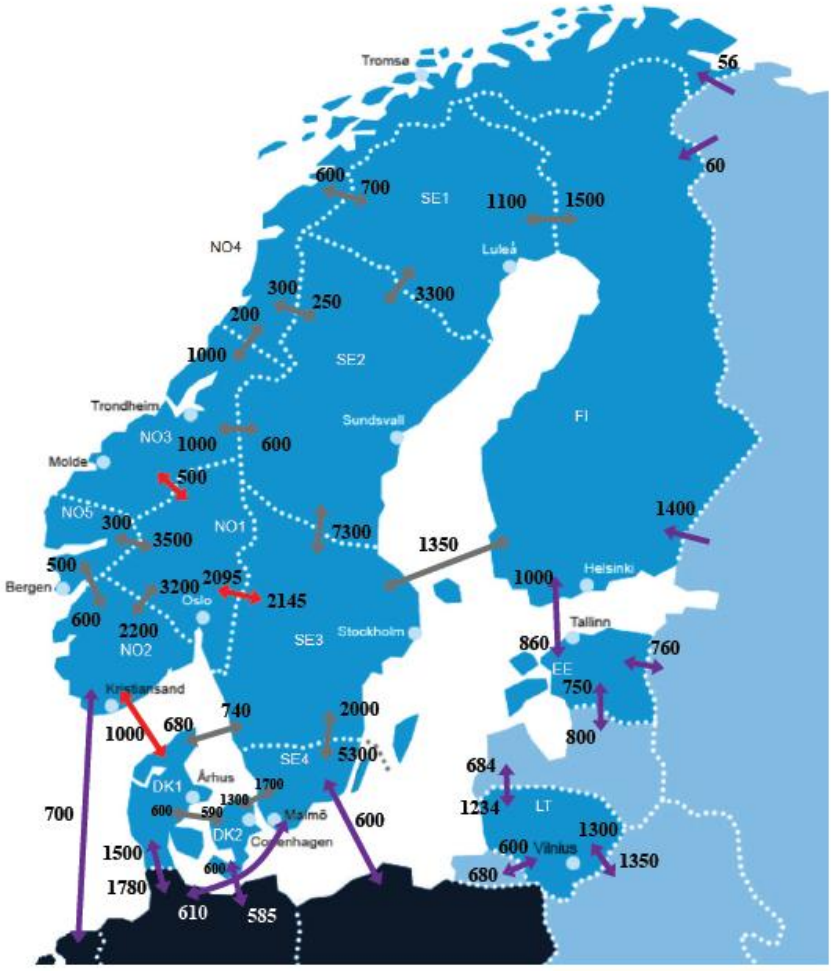
These lessons are emerging while questions are also rising about the future of the Swedish model. There are concerns mainly about electricity. To be sure, the agreement in favour of nuclear energy provides a guarantee of stability. But, cheap renewable energy resources could run out and the increased integration of the Nordic market into a large European electricity market could erode its competitive advantages. More generally, Sweden is now experiencing concerns common to all advanced countries which are already well into their energy transition. New advances in energy efficiency are proving to be slow (transport) and expensive (buildings). At the same time, high penetration levels of intermittent power sources require considerable investment, for generation (offshore wind, for example), networks (local or long distance) and load monitoring (possible storage).

Like other European countries, Sweden is therefore now confronted with the difficulty of bearing these investments without weakening its economic actors, in the face of global competition.

These are common problems, but Sweden is tackling them from a position of strength because its political leaders have been able to agree on a framework, thus avoiding costly, precipitated action. Above all, the country is preparing itself better than others in the energy transition by its emphasis on research and innovation, an area in which Sweden is a real European model.

Annexes

Annex 1: Electricity price zones within Nord Pool



Source: Nord Reg 2014.

Four countries – Finland, Estonia, Latvia and Lithuania – each make up a single area. Denmark is divided into two zones, Sweden into four, and Norway into five zones.

This breakdown is explained by the configurations of networks, shown in Annex 2. When transmission capacity between two zones is sufficient, prices will equalise depending on demand.

Annex 2: The electricity transmission network among Nord Pool members

Source: Energimarknadsinspektionen 2014.

Annex 3: Sweden's fleet of nuclear power stations in 2016

Sweden became interested very early in nuclear energy, with the establishment of a research center (AB Atomenergi) in 1947, where a first experimental reactor began operating in 1954. In 1964, Atomenergi and a public electricity company (Vattenfall) inaugurated a commercial heavy water reactor in Ågesta. It provided a small amount of power (65 MWth and 10 MWe) supplying electricity and heat to Stockholm. It operated for 10 years.

For their part, the private company Sydkraft and the construction firm ASEA designed a light water reactor, without purchasing a foreign licence. The first reactor based on this entirely Swedish model came into service in 1972 in Oskarshamn. It was a boiling water reactor (BWR) of 460 MWe, and is operated by the OKG Consortium, which has launched two further reactors on the same site. Sydkraft continued using BWR technology for two power units at Barsebäck. Its competitor Vattenfall also adopted light water technology, but wanted to diversify its technologies at the same time. Therefore, at the Ringhals site, Vattenfall ordered boiling water technology from ASEA, and three units of pressurised water (PWR) technology from Westinghouse. Subsequently, Sydkraft and Vattenfall decided to build and operate jointly the power station at Forsmark, which has three BWR units.

Since being launched, most units have benefited from improvements to increase their nominal power.

The following table gives key information about Sweden's fleet of nuclear power plants, with upgraded capacity until early 2016.

Reactor	Operator	Type	Power (MWe)	Entry into service	End
Ågesta	Vattenfall	HWR	10	1964	1974
Oskarshamn 1	OKG	BWR	473	1972	2017
Oskarshamn 2	OKG	BWR	638	1974	2015
Oskarshamn 3	OKG	BWR	1400	1985	2045
Barsebäck 1	OKG	BWR	600	1975	1999
Barsebäck 2	OKG	BWR	600	1977	2005
Ringhals 1	Vattenfall & Sydkraft	BWR	878	1976	2019
Ringhals 2	Vattenfall & Sydkraft	PWR	807	1975	2020
Ringhals 3	Vattenfall & Sydkraft	PWR	1062	1981	2041
Ringhals 4	Vattenfall & Sydkraft	PWR	938	1983	2043
Forsmark 1	Vattenfall	BWR	984	1980	2040
Forsmark 2	Vattenfall	BWR	1120	1981	2041
Forsmark 3	Vattenfall	BWR	1187	1985	2045

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