IEA Bioenergy
Technology Collaboration Programme

Implementation of bioenergy in Sweden - 2021 update

Country Reports

IEA Bioenergy: 10 2021

This report was prepared from the 2021 IEA World Energy Balances and Renewables Information, combined with data and information provided by the IEA Bioenergy Executive Committee and Task members[1]. Reference is also made to FAOstat and Eurostat data as well as data from national statistics. All individual country reports were reviewed by the national delegates to the IEA Bioenergy Executive Committee, who have approved the content. General background on the approach and definitions can be found in the central introductory report for all country reports.

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HIGHLIGHTS

- Renewables make up 41% of Sweden's *total energy supply* in 2019. The renewable energy share in *final energy consumption* is 58%[2]. Around 60% of renewable energy is from biomass.
- Sweden has a low population density and a high forest area per capita, so it has a high domestic potential of solid biomass. Most of its bioenergy (80%) comes from solid biomass.
- The main application of bioenergy in Sweden is in renewable heat, both in direct heating (predominantly in industry) and in district heating. Almost 70% of fuels/heat provision in Sweden (*excluding heat pumps / electric heating*) is through biomass.
- The Swedish power system is dominated by nuclear power and hydropower (both at 39% of electricity generation), with a relevant share of 8% through bioelectricity (produced through CHP), a growing share of wind energy (now 12%), and a very low share of fossil fuels (1%). 15% of power produced in Sweden is exported to neighbour countries.
- Liquid biofuels in transport reached high levels in recent years, particularly biodiesel (FAME and HVO) which represents almost 30% of diesel fuel sold. A relatively high share of biofuels (or feedstocks to produce them) is imported.

[1] While data for 2020 are starting to become available at national level, it was decided to consider trends up to 2019 for good comparability and benchmarking between the different IEA Bioenergy member countries. Care should also be taken when using 2020 data for analysing trends as these data are distorted by the COVID19 Pandemic.

[2] One significant reason for the large difference between the share of renewables in supply and consumption is the heat produced in nuclear power plants, which is not utilized.

COUNTRY PROFILE

Population and land use

Sweden is situated in Northern Europe and is member of the European Union. It has a total land area of 407 thousand km² and a population of 10.3 million people, which represents a low population density of 25 persons per km².

Most of Sweden has a temperate climate, despite its northern latitude. Around 70% of the land area is forest land. Only 7% is agricultural land, predominantly arable land, mostly situated in the south of Sweden.

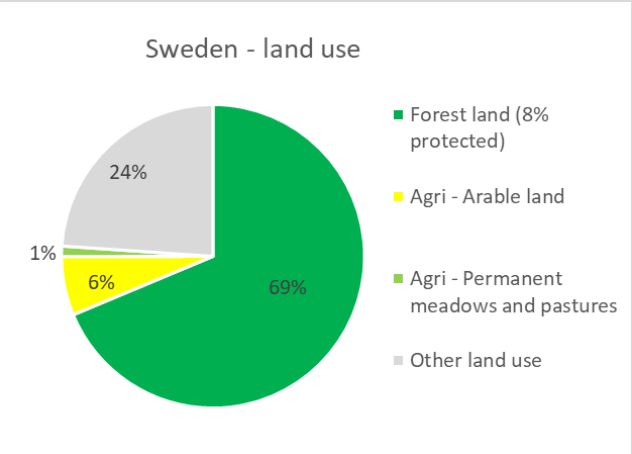

***Figure 1**: Land use in Sweden (2018 figures - Source: FAOstat)*

Final energy consumption

Overall final energy consumption in Sweden (*also including non-energy use of oil, natural gas, and coal in industry*) equates 3.2 tonnes of oil equivalent (toe) per capita, which is higher than the average of IEA Bioenergy member countries. Industry represents a relatively important share of 41% of final consumption of energy carriers in Sweden. Residential energy use is on the high side, which is likely related to the Nordic climate (higher domestic heating requirements).

***Table 1**: Distribution of the final consumption of energy carriers by sector in Sweden (2019 figures - Source: IEA (2021) World Energy Balances and Renewables Information)*

Final consumption energy carriers	Toe/capita (2019)	% of total	*Median* (toe/capita)*
Industry (energy use)	1.10	34%	*0.67*
Industry (non-energy use)	0.23	7%	*0.21*
Transport	0.70	22%	*0.69*
Residential	0.73	23%	*0.57*
Commercial & public services	0.40	12%	*0.34*
other	0.07	2%	
Total	3.23		*2.34*

** Median of the 25 member countries of IEA Bioenergy*[3]

[3] Comparative figures of the different IEA Bioenergy member countries are discussed in the central Countries' Report.

NATIONAL POLICY FRAMEWORK IN SWEDEN

TARGETS AND STRATEGIES

In June 2017, the Riksdag (Swedish Parliament) adopted a climate policy framework for Sweden. The framework includes climate goals (see Table 2), a Climate Act and the Swedish Climate Policy Council. According to the Climate Act the Governments climate policy must be based on climate goals and the act contains provisions on the Government how this work should be performed. The Climate Act entered into force on 1 January 2018. The climate goals were set in June 2017 as the Riksdag adopted the Governments bill "A Swedish Climate Policy Framework". The Climate Policy Council is an independent, interdisciplinary expert body tasked with evaluating how well the Government's overall policy is aligned with the climate goals established by the Parliament and the Government.

In Sweden's Integrated National Energy and Climate Plan submitted in 2020 the government states that "The energy policy must create the conditions for effective and sustainable energy use and a cost-effective energy supply in Sweden, while minimising the damage to health, the environment and climate and facilitating the transition to a sustainable society. Sweden must lead the way on environmental and climate issues and become the world's first fossil fuel-free welfare state".

The Swedish support scheme for renewables has mainly been based on general incentives and technology neutrality, like the carbon tax and quota systems like green electricity certificates and GHG reduction quota in transport. The carbon tax, which is the highest in the world according to the world bank[4], is based on PPP, the polluter pays principle, whereby the fossil fuels pay for their long-term environmental damage and cost and direct subsidies for any renewable alternative have in general been avoided. Bioenergy has thus not had any direct subsidies but has been benefited because its greenhouse gas emissions are estimated to zero.

Fossil Free Sweden was started at the initiative of the Swedish Government in 2015 ahead of the major UN climate conference in Paris and brings together actors in the form of companies, municipalities, regions, and organisations that give their backing to the declaration that Sweden will be one of the first fossil free nations in the world. The initiative is run by an office headed by a national coordinator. Fossil free Sweden works with companies, industries, municipalities and regions to identify obstacles and opportunities in order to accelerate developments. Based on this cooperation Fossil Free Sweden produces roadmaps, strategies and other political proposals that are presented to the Government. Within the fossil free Sweden framework, a biomass strategy is under development where the main objective is propose how biomass can be used effectively and sustainably. The strategy will be presented to the government during 2021.

[4] https://carbonpricingdashboard.worldbank.org/

*Table 2: Renewable energy and climate targets** in Sweden.*

Sector	Share of renewables in gross final consumption per sector	GHG reduction targets
Overall target	50% by 2020	Non-ETS (compared to 1990): -40% by 2020; -63% by 2030; -75% by 2040 Net zero GHG emissions by 2045
Heating and cooling		
Electricity	100% in 2040*	
Transport		70% emissions reduction by 2030 (compared to 2010)

** It is stated in the NECP[5] that this target does not mean a deadline for nuclear energy.*

*** 2030 targets mentioned in the 2020 NECP may be reviewed in the frame of the European Fit for 55 package of 2021.*

A description of renewable energy and climate policies and measures in Sweden is available at the IEA's Policies and Measures Database: https://www.iea.org/policies?country=Sweden

Specific policies related to renewable electricity, renewable heat and transport biofuels will be highlighted in the chapters about the role of bioenergy in different sectors.

[5] https://ec.europa.eu/energy/sites/default/files/documents/se_final_necp_main_en.pdf

THE CONTRIBUTION OF BIOENERGY IN NATIONAL ENERGY SUPPLY

TOTAL ENERGY SUPPLY

The total energy supply (TES) of Sweden in 2019 amounted to 2,022 petajoule (PJ). Fossil energy represents only a quarter of the Swedish TES. Oil products account for 20% (415 PJ), coal products account for 4% (78 PJ) and natural gas for 4% (78 PJ). Non-renewable waste holds a share of 1.7% (34 PJ). The statistics also features 36% or 721 PJ of nuclear energy in nuclear power stations (which represent almost half of national electricity production). Mind that the role of nuclear energy in final energy consumption is lower (~18%) as total energy supply also includes unused waste heat, which distorts the picture somewhat. There is also a substantial amount of electricity (94 PJ) that is exported to neighbour countries. Renewable energy sources have a considerable share of 40.7% in total energy supply or 822 PJ, of which bioenergy represents 62% (513 PJ). Hydropower provides 235 PJ, wind energy 71 PJ and solar power only 3 PJ.

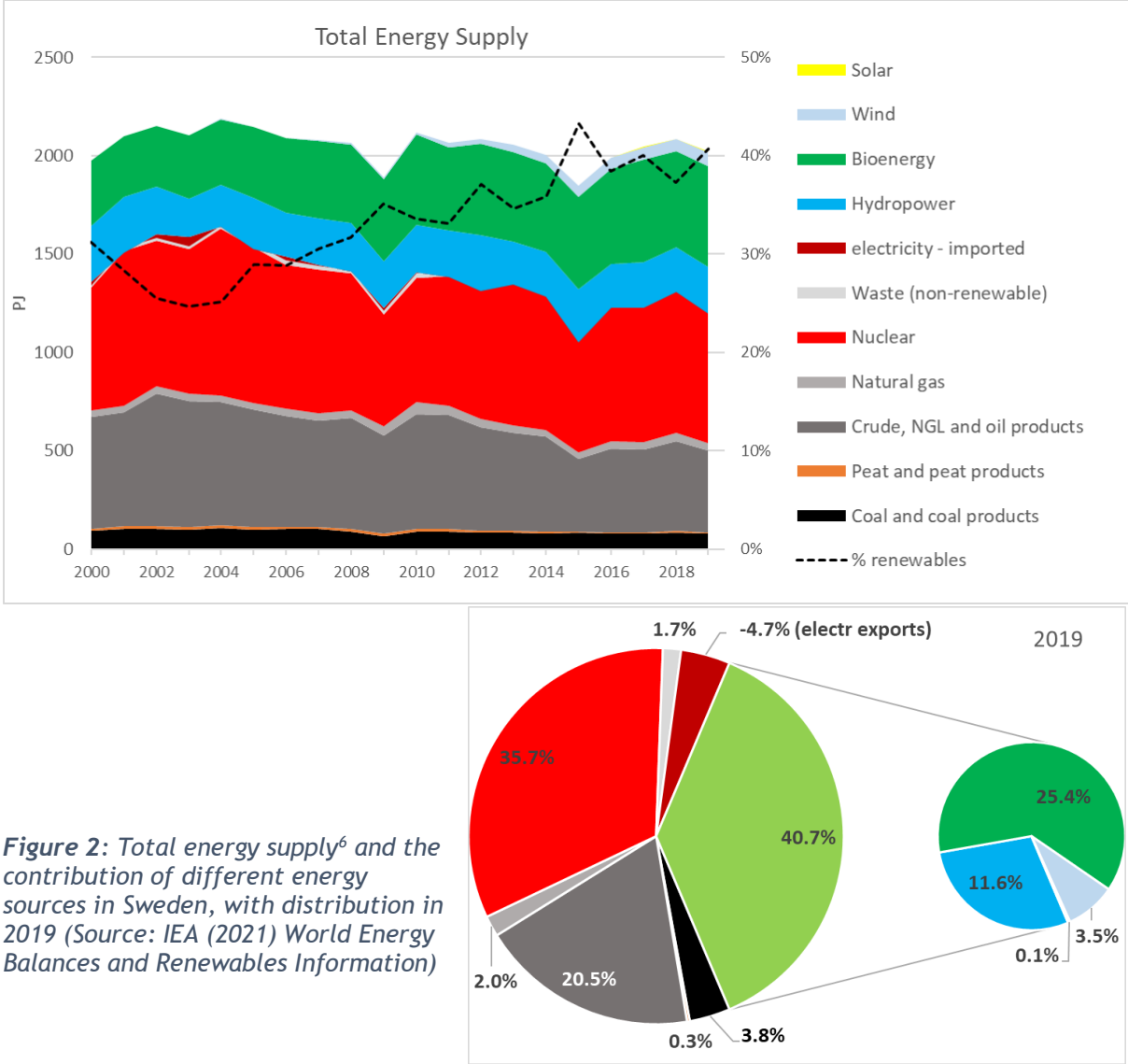

***Figure 2**: Total energy supply[6] and the contribution of different energy sources in Sweden, with distribution in 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)*

[6] Total energy supply refers to the use of resources. In terms of the role in the energy system this distribution overestimates the role of resources producing electricity with a high share of unused waste heat (like nuclear plants).

The total energy supply (TES) in Sweden was quite stable in the past decade. Compared to 2010 the share of fossil fuels has decreased from 35 to 27%. This decrease was mostly in oil products (coming down from 583 to 415 PJ), while gas and coal were relatively stable in the past decade around 80 PJ and 35 PJ respectively. Nuclear energy fluctuated between 570 and 750 PJ in the past 10 years, with somewhat higher levels (>700 PJ) in recent years. The nuclear energy is expected to decrease due to reactors being shut down during 2019-2020.

Since 2010 the share of renewable energy increased from 33% to 40% of TES. The total supply of renewable energy sources in 2019 is still dominated by biomass, which steadily increased in the past 10 years from around 400 to more than 500 PJ. Hydropower fluctuated between 220 and 280 PJ (around 11% of TES) in the past decades; wind power increased from 9 PJ in 2009 to 71 PJ in 2019. Solar energy is slightly growing in recent years, but still at marginal levels of less than 0.2% of TES.

Figure 3 shows that bioenergy in Sweden has steadily increased in the past decades from 300 PJ to around 500 PJ. It is dominated by solid biomass (400 PJ), largely in forest-based industries such as sawmills and pulp and paper mills for the production of process heat and electricity, but also in district heating plants. The next item is liquid biofuels (67 PJ), followed by renewable MSW (36 PJ) and biogas (6 PJ).

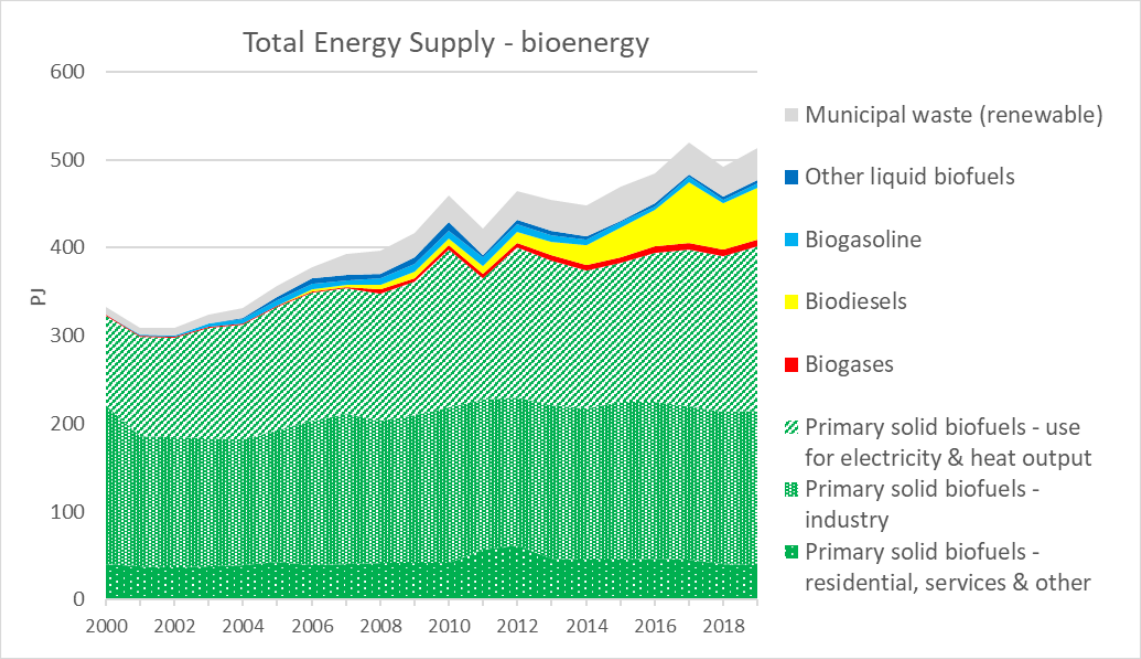

***Figure 3**: Development of total energy supply from bioenergy in Sweden 2000 – 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)*

Evolution of the bioenergy carriers:

- In the past 10 years the use of solid biofuels in industry was fairly stable around 170 PJ. The use in residential applications was also stable around 45 PJ. Solid fuel use for heat output and electricity has grown from 150 to 180 PJ.
- Bioethanol was the first transport biofuel in Sweden. Its consumption (in low blends and E85) peaked in 2011-2012 at 9 PJ and has dropped back to a level of 4-6 PJ since 2014. Biodiesel came later than bioethanol, but its importance increased steadily to a level of 60 PJ in recent years. There is also significant use of liquid biofuels in CHPs (3 PJ in the past years, with a peak in 2010 at 10 PJ).

- Biogas steadily increased from 1 PJ in the early 2000s to 7.5 PJ in recent years. While these volumes are quite modest, they are relevant as a replacement of natural gas (which is only at 40 PJ).
- Renewable municipal waste saw a strong increase from 8 PJ in the early 2000s to 31 PJ in 2010. Levels have currently stabilized around 36 PJ.

Table 3 displays the 2019 total bioenergy supply values on a per capita basis. Compared to the other 24 member countries of IEA Bioenergy (expressed per capita), Sweden ranks in the middle for biogas, but at the top for liquid biofuels, solid biofuels and renewable MSW.

***Table 3**: Total energy supply per capita in 2019 for different bioenergy carriers*

	Supply per capita	*Median IEA Bioenergy members*
Bioenergy	51.1 GJ/cap	*10.6*
Solid biofuels	40.0 GJ/cap	*7.0*
Renewable MSW	3.6 GJ/cap	*0.8*
Biogas	0.8 GJ/cap	*0.7*
Liquid biofuels	6.7 GJ/cap	*1.5*

Source: IEA (2021) World Energy Balances and Renewables Information

Table 4 indicates the amounts of the different bioenergy carriers compared to some relevant reference points, namely the amount of forest in the country (for solid biomass), the amount of generated MSW (for renewable MSW used for energy), the amount of natural gas consumed in the country (for biogas) and the amount of fossil oil products consumed (for liquid biofuels).

***Table 4**: Comparison of the supply of different bioenergy carriers in 2019 to specific reference points*

	Compared to reference points		*Median**
Bioenergy	25.4 %	of total energy supply	*7.2 %*
Solid biofuels	15.5 GJ/ha_forest	compared to the domestic hectares of forest land (excl. protected)	*21.3 GJ/ha_forest*
Renewable MSW	8.3 GJ/ton_MSW	compared to the total generated MSW in the country	*1.4 GJ/ton_MSW*
Biogas	0.193 GJ/GJ_NG	compared to natural gas supply	*0.023 GJ/GJ_NG*
Liquid biofuels	0.163 GJ/GJ_oil	compared to oil products supply	*0.028 GJ/GJ_oil*

Source: energy data from IEA (2021) World Energy Balances and Renewables Information; forest figures from FAOStat; waste figures from World Bank
** Median of the 25 member countries of IEA Bioenergy*[7]

[7] Comparative figures of the different IEA Bioenergy member countries are discussed in the central Countries' Report.

Specific comments in relation to the reference points:

- While the use of solid biofuels per capita is very high, considering the high share of forest in Sweden and the low population density, the use of solid biofuels compared to the domestic forest area is modest (<1 ton_dry mass of wood per hectare[8]). Mind that growth levels in Nordic boreal areas are lower than in more moderate climates.
- The use of renewable MSW for energy production is very high, even when compared to other European countries with well-developed waste management systems. Mind that substantial flows of MSW are imported to Sweden for energy production.
- Biogas is also fairly well developed and represents a significant share of gas supply. Mind that the overall role of natural gas in the Swedish energy system is limited. In recent years, an increasing share of the biogas used in Sweden is imported.
- Transport biofuels are much higher developed compared to other European countries.

ROLE OF BIOENERGY IN DIFFERENT SECTORS

OVERVIEW

***Table 5**: Role of bioenergy and renewable energy in electricity, transport energy and fuel/heat consumption in 2019*

Sector	Share of bioenergy	Share of renewable energy	Overall consumption
Electricity[9]	9.2%	69.6% *(46% hydro)*	142 TWh (511 PJ)
Transport energy (final consumption)	19.7%	21.1%	294 PJ
Overall fuel and heat consumption[10]	Direct biomass: 41.3% Biobased heat: 23.9%	65.3%	556 PJ
TOTAL FINAL ENERGY CONSUMPTION	**35.2%**	**58.4%**	**1330 PJ**

Source: IEA (2021) World Energy Balances and Renewables Information

The overall 2019 share of renewables in **final energy consumption** among electricity, transportation and heat sectors is almost 60%, with bioenergy making up 35% of the energy share (Table 5). Note that these figures are considerably higher than the shares in total energy supply (where unused waste heat, e.g., in nuclear power production, is also included).

[8] Counted with a typical calorific value of wood (dry mass) of 19 GJ/ton$_{\text{dry mass}}$

[9] Renewable electricity production compared to final consumption. Potential renewable shares of imported electricity are not included.

[10] This includes final consumption of fuels and heat in industry, the residential sector, commercial and public services and agriculture/forestry. Transport fuels are excluded. Energy used for transformation and for own use of energy producing industries is also excluded.
Electric heating (direct or through heat pumps) is not included in these figures as this is not separately reported.

The following paragraphs will consider the evolutions in the different sectors.

ELECTRICITY

The Swedish power production is dominated by nuclear power and hydropower, both providing around 66 TWh or 39% of electricity production in 2019. Only 1% is produced by fossil fuels (1.5 TWh) - their role never exceeded 5% in the past decades. 1.7 TWh is also produced from non-renewable waste.

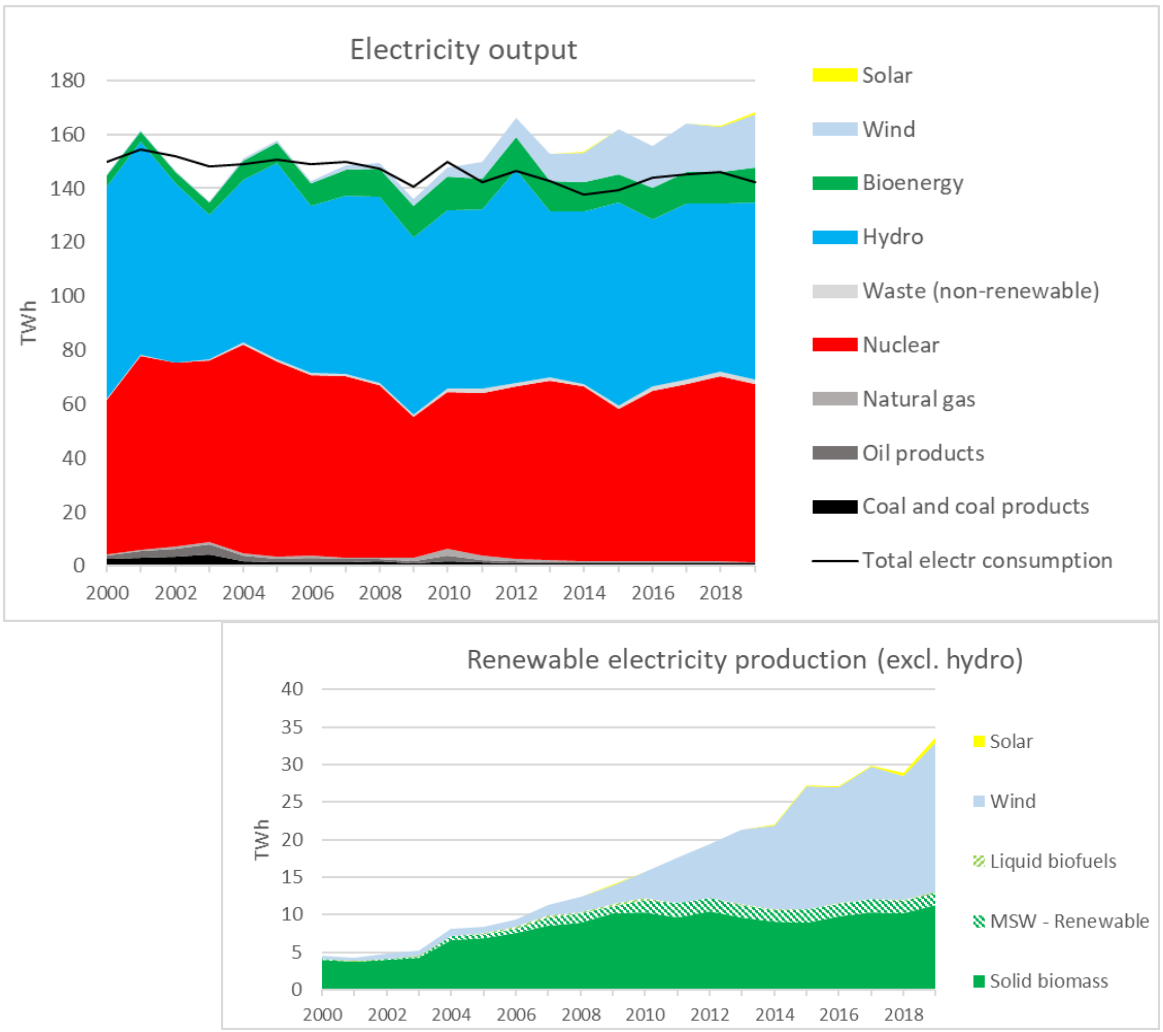

***Figure 4**: Evolution of the electricity mix in Sweden 2000 - 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)*

Apart from hydropower, also wind power at 20 TWh and bioelectricity at 13 TWh (mostly produced in CHPs) play a relevant role in providing renewable electricity. While bioelectricity was fairly stable in the past decade, wind power saw a strong growth. Solar power (0.7 TWh) currently only represents 0.5% of Swedish electricity consumption.

15% of the produced power in Sweden (26 TWh) was exported to neighbour countries in 2019.

Policy framework

The main relevant policy instruments behind these evolutions (with relevance for biobased

electricity) are:

- **Investment grants**: In the periods 1991 – 1995 and 1997 – 2003 there were investment grants available for construction of biomass fuelled CHPs. Many of these plants are still in operation.

- **Carbon tax:** In 1991 a carbon tax was introduced which was high on heat and lower on industry. This tax has since then been raised multiple times, mainly on the heating and service sector, and lately also on industries which are not part of emission trading (ETS).

- **Green certificates:** In 2003 a green certificate scheme was introduced to promote new renewable electricity production. The system is open for many types of renewable electricity production such as bioelectricity, wind, hydropower, solar power etc. Since 2012 Sweden and Norway has a common green certificate scheme with a goal of creating in total 46.4 TWh of new renewable electricity production until 2030. The scheme will end in 2035 and no new plants will be able to enter the scheme after the end of 2021. The certificate price is currently approaching zero and the system is no longer a significant incentive for investments.

HEAT/FUEL

Figure 5 shows the role of different fuels/energy carriers for providing heat in different sectors (industry, residential sector, commercial and public services and other). It also includes heat sold to customers, e.g., through district heating. Fuel use by energy producing industries for transformation and for own use is excluded. Mind that electric heating (direct or through heat pumps) is not included in these figures as this is not separately reported in the IEA database.

The provision of heat in Sweden can be divided in three parts: 21% on fossil fuels (mostly oil, but also some coal and gas), 41% direct biomass (80% of that in industry) and 37% through heat sales (via district heating). Direct biomass uses and heat sales have been fairly stable since 2010, while the amount of fossil fuel use for heat went down slightly. The peak in 2010 was probably related to a cold winter.

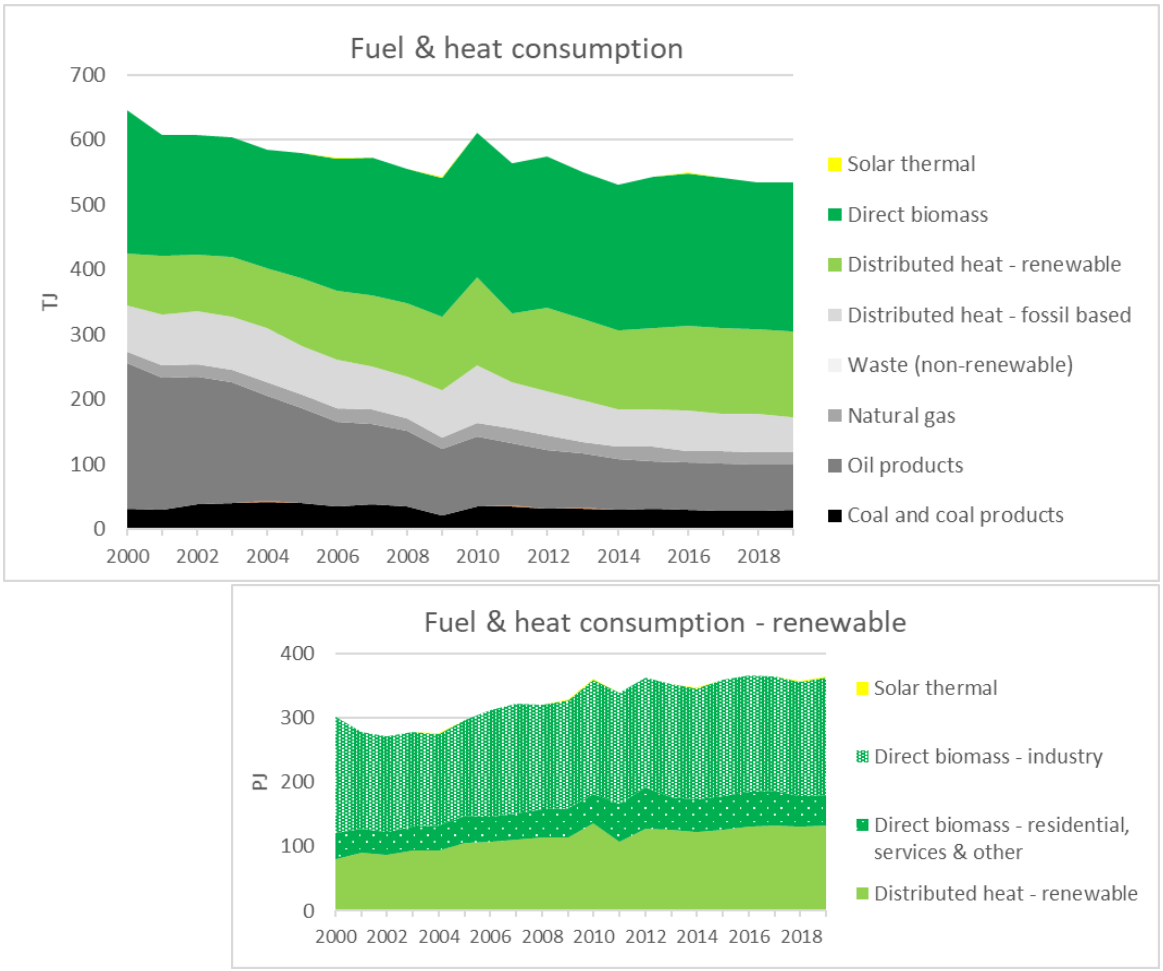

***Figure 5**: Evolution of fuel and heat consumption in Sweden 2000 - 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)*

Heat output generated and sold by CHP plants and heat plants represents more than one third of fuel/heat provided, of which currently more than 70% is produced from biomass, a share which has increased steadily from 53% in 2000 at the expense of fossil fuels which now only represent 6.5% of heat sales. There was also some growth in heat production from waste. The use of residual heat and other sources for heat output is also relevant at 8%.

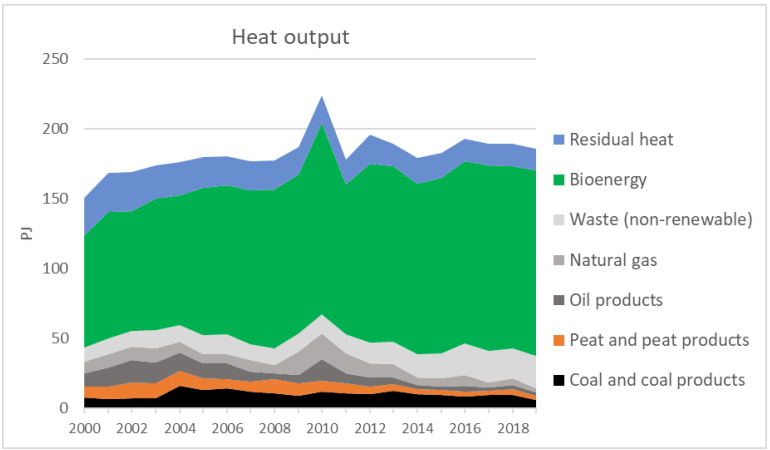

***Figure 6**: Evolution of fuels for heat output in Sweden 2000 - 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)*

Policy framework

The main relevant policy instruments (with relevance for biobased heat) behind these evolutions are:

- **Investment grants**: In the periods 1991 – 1995 and 1997 – 2003 there were investment grants available for construction of biomass fuelled CHPs. Many of these plants are still in operation.
- **Carbon tax:** In 1991 a carbon tax was introduced which was high on heat and lower on industry. This tax has since then been raised multiple times, mainly on the heating and service sector, and lately also on industries which are not part of emission trading (ETS)
- **Green certificates:** In 2003 a green certificate scheme was introduced to promote new renewable electricity production. The system is open for many types of renewable electricity production such as bioelectricity, wind, hydropower, solar power etc. Through the application of CHPs, this also indirectly support the production of renewable heat. Since 2012 Sweden and Norway have a common green certificate scheme with a goal of creating in total 46.4 TWh of new renewable electricity production until 2030. The scheme will end in 2035 and no new plants will be able to enter the scheme after the end of 2021.
- **EU-ETS:** With the current emission allowance prices in the range 50-60€/ton CO2 EU-ETS is a significant driver for bio-heat in industry.
- **Fossil free Sweden:** Within the fossil free Sweden framework the Swedish heating sector has developed a roadmap with a goal to be completely fossil fuel-free (excluding waste) by 2030 and also be climate positive by 2045.

TRANSPORT

Figure 7 shows an overview of the energy used in transport in Sweden, split up by different fuels/energy carriers.

Overall transport fuel consumption in Sweden is relatively stable around 300 PJ. The role of diesel fuels (fossil and biodiesel) increased steadily to a share of 62% in transport fuel consumption, while the share of gasoline went down to 30%. The figure clearly shows the declining trend of fossil fuels since 2005, going down from 300 to 226 PJ, being replaced by biofuels which increased to 60 PJ.

Initially bioethanol was the most important liquid biofuel, both through low blends and E85 (in flex-fuel vehicles) representing a 7% share (by energy) of gasoline in 2012, and currently between 4 and 5%. Biodiesel (FAME and HVO) overtook bioethanol after 2011 and continued to grow fast to a level of 52 PJ in 2018. This represents an impressive share of 28% of diesel fuels sold. A relatively high share of biofuels (or feedstocks) is imported.

Gaseous fuels (natural gas and biogas) represent 2.8% of transport fuels in Sweden, with over 90% of gaseous transport fuels being biogas in 2019.

Electricity represents a share of 3.3% of total transport energy use. This is mostly in rail - the use of electricity in road vehicles is still relatively low in 2019 (0.31% of total transport energy use) but can be expected to grow in the coming years.

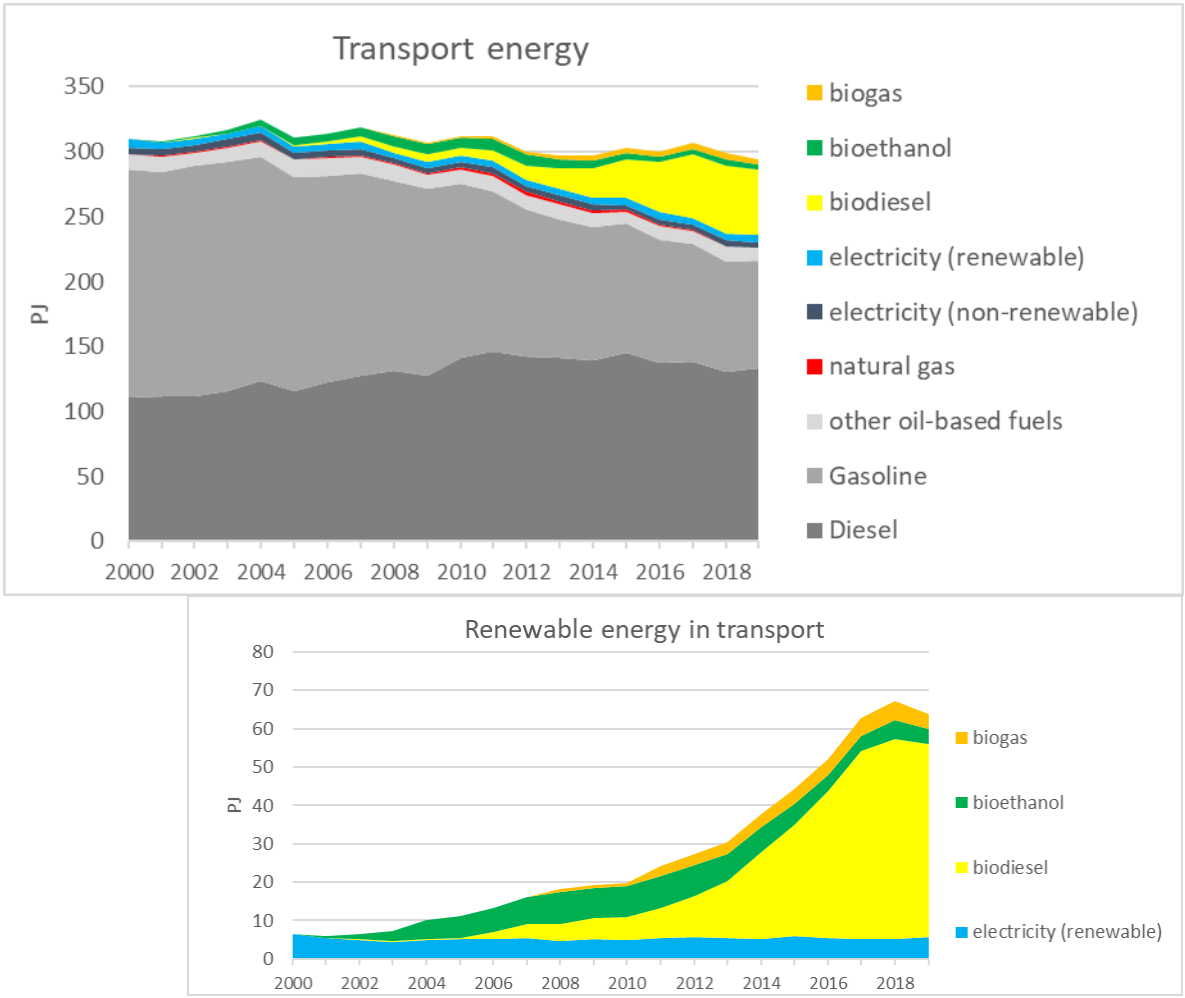

Figure 7: Evolution of transport fuels in Sweden 2000 - 2019 (Source: IEA (2021) World Energy Balances and Renewables Information)

Policy framework

The main relevant policy instruments behind these evolutions are:

- **Tax exemption**: In 2007 a tax exemption (CO2 and energy tax) for biofuels for transport was introduced. It has been prolonged annually and various adjustments have been made to the instrument over the years. When the greenhouse gas reduction quota (see next point) was introduced the tax exemption was changed to only apply to pure biofuels such as HVO100 (100% HVO) and B100 (100% FAME) as well as hight proportion blends such as E85. The tax exemption scheme has been allowed by the European Commission for 2021 and the Swedish government has applied for an extension of one more year.

- **Greenhouse gas reduction quota:** Starting from July 2018, economic operators that are taxable for gasoline and/or diesel are by law bound to reduce the climate impact of their gasoline and/or diesel by a certain percentage every calendar year. This percentage increases every calendar year and is separate for gasoline and diesel. During 2021, the reduction levels are required to be at least 6 percent for gasoline and at least 26 percent for diesel fuel. To reach the required target percentages, fuel suppliers need to increase the biofuel blend in their gasoline

and diesel. During 2021 a change was made in the regulation which made it possible to also use blending of renewable fuels of non-biological origin (electrofuels) to reach the target.

- Direct investment grants are given to climate projects as part of the Climate Leap program, e g for biogas plants and biogas filling stations. Grants have also been given to some production facilities for advanced biofuels.

Developments related to the policy framework:

- The Swedish Energy Agency has received an assignment from the government to suggest further policy instruments to promote domestic biofuels production.

- The government has proposed a greenhouse gas reduction quota for aviation fuel similar to the system for gasoline and diesel.

COMPARISON WITH RENEWABLE ENERGY TARGETS

According to Eurostat[11], the following renewable energy shares in *gross final energy consumption* were reached in Sweden.

***Table 6**: Share of renewables in different sectors in Sweden, according to Eurostat, and compared to the 2020 target*

	2005	2010	2015	2019	*2020 target*
Overall share	40.6%	47.2%	53.8%	56.4%	*49.0%*
In heating & cooling	51.9%	60.9%	68.6%	66.1%	*62.1%*
In electricity	50.9%	56.0%	65.8%	71.2%	*62.9%*
In transport	6.2%	9.2%	24.0%	30.3%	*13.8%*

Sweden already exceeded its overall renewable energy target in 2012 and will clearly exceed the 2020 targets for all sectors.

Mind that some of these figures can differ from the IEA derived data because of different accounting rules. Particularly in transport the Eurostat shares are higher, which is due to the multiple counting of advanced biofuels and renewable electricity towards the transport target. The heating & cooling figure in Eurostat also includes heat pumps.

[11] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_335a&lang=en

RESEARCH FOCUS RELATED TO BIOENERGY

Sweden has a very high proportion of renewable energy production, due to long-standing utilisation of bioenergy and hydroelectric installations and recent advances in the deployment of wind power.

Various funding programmes are dedicated to research on hydropower, wind power, solar cells, sustainable biomass production and conversion into district heating as well as CHP plants. Bioenergy has been given high priority in the R&D portfolio. Over the years, Swedish energy R&D has covered the main economically and environmentally relevant bioenergy topics

Mainly the energy research programs in Sweden are managed by the Swedish Energy Agency (SEA). In 2020 the Energy RD&D programme covered some 60 active sub-programmes and 1600 projects. For a detailed description on current R&D programmes please see the webpage of the energy agency (http://www.energimyndigheten.se/). For the period 2021-2024 the overarching aim of the research is to accelerate the transition to a sustainable society.

A few trends in bioenergy related research in Sweden are:

- BECCS/negative emissions receive increasing interest. There are potential synergies with biorefinery concepts which can give very efficient system solutions with respect to carbon efficiency.
- In transport biofuels research there is an increased focus on air and sea transport for biofuels along with an increased interest for concepts which could be used in drop-in fuel production.

RECENT MAJOR BIOENERGY DEVELOPMENTS

The biobased CHP industry is looking for new business opportunities and ways to be relevant in the energy systems of the future. These include BECCS, integration with heat pumps, new products such as pyrolysis oil, etc., but also possibilities for new business models, e.g., for the grid stabilizing services a large CHP unit can provide in a grid based on intermittent power producers.

A number of Swedish utilities and industries are developing plans for bio-CCS. There are 23 large pulp mills and 15 large CHPs with emissions of more than 300 000 tonnes of biogenic CO2 – a total of close to 30 million tonnes. At many of these, bio-CCS is a feasible option, especially when located at seaside. Stockholm Exergi has already made a commitment to become carbon negative by 2025 using large-scale bio-CCS at its CHP Värtan in Stockholm, capturing 800 000 tonnes CO2. Cities like Växjö, Västerås, Södertälje and others are developing similar projects. CO2 will be stored in the North Sea in cooperation with Norwegian partners. A government inquiry (Vägvalsutredningen) has proposed that bio-CCS should be procured by the state through reverse auctions. Implementation of such proposals can have a major impact on the introduction of bio-CCS and also in the long term on where bio-raw material is used.

Forest biomass by-products such as tall oil and lignin are co-processed, or piloted to be co-processed, respectively, in a fossil refinery. Tall oil is used on a commercial scale by Sunpine in a new factory in Piteå to produce HVO biodiesel. In 2019 the plant was expanded to produce 150 000 tonnes/year.

Preem and RenFuel are assessing, in collaboration pulp and paper industry, the construction of the world's first lignin plant for biofuels.

The use of fossil fuels in the forest industry, which is the biggest energy user in Swedish industry, has decreased by 73% in the last ten years. Oil has been substituted with pellets and bio-oils, mainly in recovery boilers in the pulp industry.

The carbon tax has been increased in recent years in industries and other businesses outside ETS. This increase is promoting conversion from fossil fuels to wood fuels, bio-oils and district heating in breweries, dairies, asphalt preparation, etc. The Swedish greenhouses have in general switched from oil and gas to biomass and industrial waste heat.

Pyrocell project in Gävle will produce 25 000 tonnes of pyrolysis oil from sawdust at Setra Kastet sawmill.

Södra in 2021 started a plant recovering residual biogenic methanol from one of its large pulp mills, producing 5 000 tonnes per year.

The company Cortus has constructed a 6 MW WoodRoll® gasifier at the Höganäs steel plant - substituting fossil fuels in steel making processes by producing renewable energy fuel gas on a commercial scale.

LINKS TO SOURCES OF INFORMATION

The following websites provide useful information and data on national Swedish bioenergy policy, production and consumption.

- National Renewable Energy Action Plan (NREAP): http://ec.europa.eu/energy/renewables/action_plan_en.htm
- Swedish Energy Agency statistics: https://www.energimyndigheten.se
- Energy in Sweden 2021 – an overview: https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022
- Sweden. The framework: energy policy and climate change: http://www.iea.org/textbase/nppdf/free/2013/sweden2013_excerpt.pdf
- Fossil free sweden: https://fossilfrittsverige.se/en/start-english/
- Energy Efficiency Policies and Measures in Sweden: http://www.odysseemure.eu/publications/national-reports/energy-efficiency-sweden.pdf
- The Swedish Climate Strategy: http://www.government.se/contentassets/32e5a14843804c07a22c874b7418f79f/the-swedish-climate-strategy-a-summary
- Swedish board of forestry: www.skogsstyrelsen.se
- Sweden large forest research programme: www.futureforests.se

- The forest research institute: www.Skogforsk.se

Relevant ministries in Sweden are:

- Ministry of Enterprise and Innovation: http://www.government.se/government-of-sweden/ministry-of-enterprise-and-innovation/
- Ministry of Infrastructure: https://www.government.se/government-of-sweden/ministry-of-infrastructure/
- Ministry of Education and Research: http://www.government.se/government-of-sweden/ministry-of-education-and-research/
- Ministry of Environment: http://www.government.se/government-of-sweden/ministry-of-the-environment/
- Ministry of Finance: http://www.government.se/government-of-sweden/ministry-of-finance/

Relevant stakeholders in academia and industry:

- Swedish Environmental Protection Agency: http://www.swedishepa.se
- IVL Swedish Environmental Research Institute: http://www.ivl.se
- RISE, Research Institutes of Sweden: http://www.rise.se

Funding organizations at national level:

- Swedish Energy Agency (SEA): https://www.energimyndigheten.se/en
- Swedish Government Agency for Innovation Systems (Vinnova): http://www.vinnova.se/en
- Swedish Research Council (Vetenskapsrådet): http://www.vr.se
    - Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS): http://www.formas.se/en

Programmes and initiatives: Competence Centres

- Biogas Research Centre (BRC): http://www.liu.se
- Swedish Gasification Centre (SFC): http://www.sfc-sweden.se
- Competence Centre Combustion Processes (KCFP): http://www.lth.se/kcfp/english/
- Swedish Centre of Excellence in Electrical Power Engineering (EKC^2): http://researchprojects.kth.se

- Competence Centre for Catalysis (KCK): http://www.kck.chalmers.se
- High Temperature Corrosion Centre (HTC): http://www.htc.chalmers.se
- Combustion Engine Research Centre (CERC): http://www.chalmers.se
- Competence Centre for Gas Exchange (CCGEx): http://www.kth.se/en/itm/inst/mmk/forskning/centra/ccgex-competence-center-for-gas-exchange-1.279297
- The Swedish Knowledge Centre for renewable transportation fuels: http://www.f3center.se/