Importance of Swedish Cogeneration Plants
for the Domestic Energy System and the North European Power Exchange

Master of Science Thesis within the Sustainable Energy Systems Programme

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Gothenburg, Sweden 2011

MASTER’S THESIS

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Cover: *Rya Natural Gas Combined Cycle Heat and Power Plant*
Rosén, Peter G.A. *Göteborg Energi*.Gothenburg: Kristisk massa; 23 August 2009. [retrieved: 8 August 2011]. Accessible at: http://www.flickr.com/photos/26527162@N04/3847283215/

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Abstract

This report examines Swedish cogeneration importance for the domestic energy system and for the North European power exchange. Carbon dioxide emissions and generation cost of Swedish cogeneration is compared to imported or that by export replaced average electricity to and from Sweden. The comparison is for a historic period (2005-2010) where known annual electricity exchange data and cogeneration generation by fuel is used to compare actual emissions and cost. And a future period (2011-2020) based on the NREAP report, where projected electricity and cogeneration investments are used to estimate future CO_2-emissions and generation cost. Also the new Rya NGCC CHP plant is compared to the North European marginal electricity generation for the historic period (2005-2010). The comparison is based on emissions of CO_2, NO_x and SO_x.

The method uses fixed values for emissions factors, generation prices and fuel to energy efficiencies based on qualified sources for average values. The comparison is visualised in both diagram and tables.

The result implies that the imported electricity has lower CO_2-emissions compared to Swedish cogeneration. However when removing Norway from the comparison the result is different, now the imported electricity has higher CO_2-emissions. The comparison for Swedish cogeneration and the by export replaced abroad average electricity is different annually depending on how much electricity Sweden exports to Norway. Removing Norway from the comparison makes Swedish cogeneration better from an emission point of view.

The estimated generation cost of both imported and exported electricity is lower than Swedish cogeneration, even when the heat income from sold heat is accounted for. If Norway is once again removed from the comparison , the results shows that the generation cost of both the imported and by export replaced average electricity is similar to Swedish cogeneration. As cogeneration also generates useful heat it can be assumed to be a better alternative compared to the average electricity generation in these countries. Swedish cogeneration can however not compete with the cheap and emission free Norwegian hydro power.

Future CO_2-emissions will decrease faster for the North European average electricity compared to Swedish cogeneration, but will still be higher. The cost of generating this electricity will still be higher than Swedish cogeneration but the gap will decrease. Sweden will based on the results join Norway and generate enough CO_2-free electricity by 2015 to meet its annual domestic needs.

The efficient Rya NGCC CHP has lower emissions compared to marginal electricity in Northern Europe. The use of natural gas which is the cleanest fossil fuel alternative and the lower average efficiency in the abroad power generation makes Rya a relatively clean facility. Especially when keeping in mind the high heat demand that exists in Gothenburg's urban area during winter season when Rya is operated.

Keywords: average electricity, emissions, generation cost, marginal electricity, Rya NGCC CHP, Swedish cogeneration.

Den svenska kraftvärmens betydelse för det inhemska energisystemet och för det nordeuropeiska elubytet
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Sammanfattning

Denna rapport undersöker svensk kraftvärmes betydelse för det inhemska energisystemet och för nordeuropeiska elmarknaden. Koldioxidutsläpp och elgeneringskostnad från svensk kraftvärme jämförs med både importerad och genom export ersatt medelel till och från Sverige. Jämförelsen består av dels på en historisk period (2005-2010) där årlig data av elutbytet och genererad kraftvärme med olika bränslen används för att jämföra faktiska utsläpp och kostnader. Och en framtida period (2011-2020) som är baserad på NREAP-rapporten, där planerade el- och kraftvärmeinvesteringar används för att uppskatta framtida CO_2-utsläpp och produktionskostnader. Det nyligen konstruerade Rya kraftvärmeverk jämförs även med den nordeuropeiska marginella elproduktionen för den historiska perioden (2005-2010). Jämförelsen är baserad på CO_2, NO_x och SO_x utsläpp.

Metoden använder fasta värden för emissionsfaktorer, elgeneringspriser och bränsle till energi effektivitet baserat på kvalificerade källor för årliga medelvärden. Jämförelsen visualiseras med hjälp av både diagram och tabeller.

Resultatet visar att importerad el har lägre CO_2-utsläpp jämfört med svensk kraftvärme. Men när den norska importerade elen utesluts från jämförelsen blir resultatet annorlunda, då har den importerad elen högre CO_2-utsläpp. Resultatet för jämförelsen mellan svensk kraftvärme och den med export ersatta utländska medelelen är olika varje år beroende på hur mycket el som Sverige exporterat till Norge. Tas Norge bort från jämförelsen är den svenska kraftvärmen bättre ur utsläppsvinkel.

Den uppskattade genereringskostnaden för både importerad och exporterade el är lägre än svenska kraftvärme, även när värmeintäkter från såld värm tas med i beräkningarna. Om Norge återigen avlägsnas från jämförelsen visar resultatet att kostnaderna för både den importerade och av export ersatta medelelen har ungefär samma kostnad som svensk kraftvärme. Eftersom kraftvärme också genererar nyttiggjord värme kan den antas vara ett bättre alternativ jämfört med den genomsnittliga elgenerationen i dessa länder. Svensk kraftvärme kan dock inte konkurrera med den billig och utsläppsfria norska vattenkraften.

De framtida CO_2-utsläppen minskar snabbare för den nordeuropeiska medelelen jämfört med svenska kraftvärme, men är ändå högre. Kostnaden för att generera denna el kommer fortfarande att vara högre än svenska kraftvärme men skillnaden minskar. Sverige kommer att

enligt resultaten ansluta sig till Norge och generera tillräckligt med CO_2-fri el till år 2015 för att uppfylla sina årliga inhemska behov.

Rya kraftvärmeverk har lägre utsläpp jämfört med nordeuropeisk marginalel. Användningen av naturgas som är det renaste av de fossila bränslen och de lägre genomsnittliga effektiviteten i den utländska kraftgenereringen gör Rya är renare antlernativ. Detta särskilt om man har i åtanke den stora värmeefterfrågan som existerar i Göteborgs stad under vintersäson då anläggningen tas i bruk..

Nyckelord: elgenereringskostnad, marginalel, medelel, Rya kraftvärmeverk, svensk kraftvärme, utsläpp.

Preface

This report is the result of a desire to investigate the importance of Swedish cogeneration both from a domestic and a North European perspective. Göteborg Energi AB has constructed their new cogeneration plant Rya in 2006; and the facility has now generated electricity and district heating to the people of Gothenburg for a couple of years. Cogeneration and the new Rya NGCC CHP plant are important part of the company's business strategy. Göteborg Energi therefore wants to investigate their and other Swedish cogeneration plants role and influence on the North European electricity market that they are a part of.

The report is the concluding part of my education on the master's degree program Sustainable Energy Systems at Chalmers University of Technology. The project will correspond to 30 ECTS and will be presented early autumn 2011.

I would like to take this opportunity to express my sincere gratitude to Göteborg Energi AB who provided me the opportunity to write my master's thesis with them. I would especially like to thank my supervisor Peter Maksinen and his whole team at the Energy Trading Department for all assistance and support during the project. The experience to work alongside you have been fun, inspiring and increased my knowledge of the energy business a great deal. Thank you!

I would also like to thank Agata Persson (Svenska Kraftnät), Karin Björkman, Lena Ljungman, Olof Ingelsten, Paul Leinberg and Ulf Hagman (all at Göteborg Energi) for providing me with necessary data for the report. I want to thank my classmate Helena Nakos for excellent opposition of my report and at the seminar. Finally, I would like to thank my examiner Lina Bertling (Chalmers) for all her assistance and guidance that has helped me complete this report.

Yours Sincerely

Mubashir Virk
Gothenburg, August 2011

Table of Contents

I. List of Abbreviations

AC	Alternate Current
DC	Direct Current
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DLS	Driftledningssystem (Göteborg Energi AB)
ECN	Energy Research Centre of the Netherlands
ECTS	European Credit Transfer System
EEX	European Energy Exchange
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EUR	Euro (€)
ETS	Emissions Trading Scheme
EUF	Energy Utilization Factor
GW	Gigawatt
GWh	Gigawatt Hour
GWh_{el}	Gigawatt Hour Electricity
GWh_{heat}	Gigawatt Hour Heat
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kV	Kilovolt
LHV	Lower Heating Value
MW	Megawatt
MWh	Megawatt Hour

MWh_{el}	Megawatt Electricity
MWh_{fuel}	Megawatt Hour Fuel
MW_{heat}	Megawatt Hour Heat
NGCC	Natural Gas Combined Cycle
nm^3	Normal Cubic Meter
NO	Nitric Oxide
NO_x	See NO and NO_2
NO_2	Nitrogen Oxide
NREAP	National Renewable Energy Action Plan
PHR	Power to Heat Ratio
RES-E	Renewable Energy Sources-Electricity
RES-H&C	Renewable Energy Sources-Heating and Cooling
RES-T	Renewable Energy Sources-Transport
SEK	Swedish Krona
SO_x	Sulfur Oxide
TWh	Terawatt Hour
TWh_{el}	Terawatt Hour Electricity
TWh_{fuel}	Terawatt Hour Fuel
TWh_{heat}	Terawatt Hour Heat
VAT	Value Added Tax

II. Nomenclature

C_{fuel}	Electricity Generation Cost by Fuel [SEK/MWh]
$C_{fuel,CHP}$	CHP Generation Cost by Fuel [SEK/MWh]
E_{fuel}	Electricity generation Emissions by Fuel [kg/MWh]
$\dot{m}_{gas}$	Natural Gas Flow [kg nm^3/h]
G_{total}	Total Generation [MWh]
$G_{total,m}$	Total Marginal Generation [MWh]
P_{aux}	Electricity Consumption by Auxiliary Equipment [MWh]
P_{loss}	Electricity Consumption by Internal Losses [MWh]
P_{net}	Net Electricity [MWh]
P_{fuel}	Electricity Generation by Fuel [MWh]
P_{other}	Electricity Generation by non-fuel source [MWh]
η_{th}	Thermal Efficiency [-]
η_{fuel}	Fuel Thermal Efficiency [-]
Q_{input}	Heat Input [MWh]
Q_{heat}	Useful Heat Output [MWh]

III. Figures

IV. Tables

1. Introduction

Large scale electricity generation in Sweden has always been dependent on the country's ability to use its large hydro resources. The use of oil to generate electricity was drastically reduced after the energy crisis during the seventies, and was replaced mainly by nuclear power. During this period a small extent of electricity generation with renewable fuels started replacing fossil fuelled cogeneration. Nuclear power continued to increase its share of the total electricity generation, and today it generates roughly the same amount as hydropower (see Figure 1).

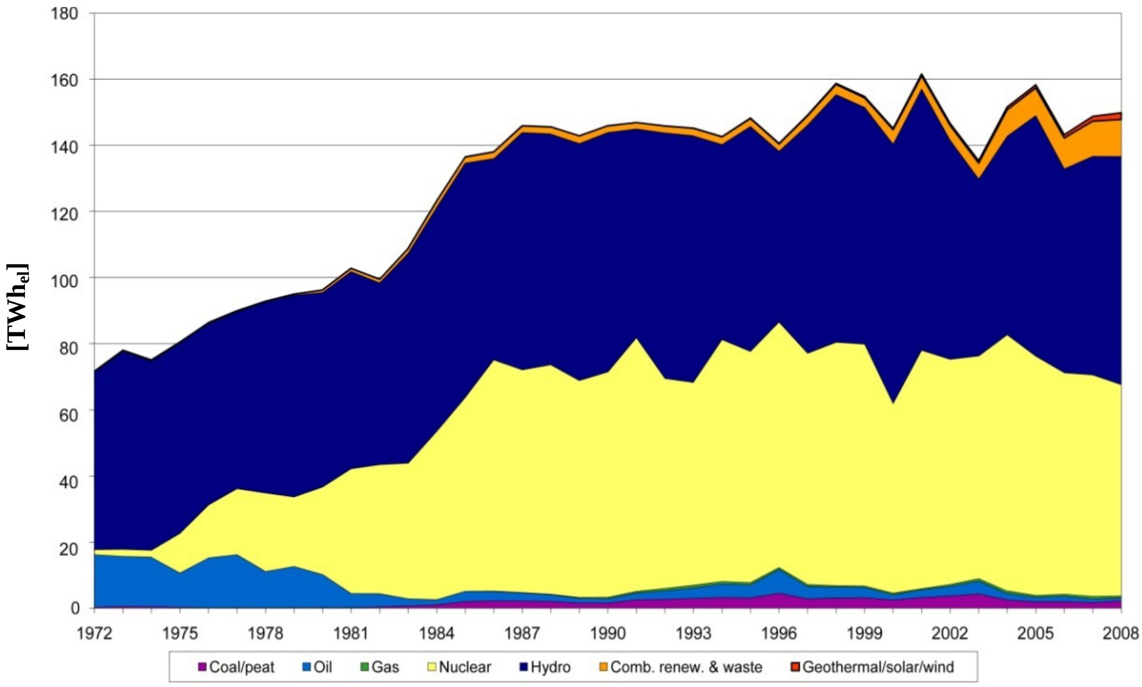

Figure 1. Historic Swedish electricity generation by fuel[1] (1972-2008).

The widespread use of district heating in Sweden has continued to increase the share of electricity production from combined heat and power (CHP) plants. Today the country generates almost one tenth of its electricity by using cogeneration [1].

1.1 Cogeneration

A cogeneration plant generates electricity and useful heat. The heat can be used to supply hot water or steam for industrial processes or to supply district heating. District heating has been the larger end use of heat generated from cogeneration during the last five years in Sweden [2]. In this report only district heating generating CHP will be

[1] Picture from the International Energy Agency (IEA)

considered when analyzing the importance of cogeneration for the domestic energy system and to the North European power exchange.

1.1.1 District Heating in Sweden

District heating use was initially started in some Swedish municipalities in the 1950s. In this initial phase, oil was the primary energy source. Oil continued to be the main fuel choice until a transition to other alternatives took place in the seventies [3]. The fuel mix has since then transitioned from primarily fossil to now being mainly bio-based today (see Figure 2).

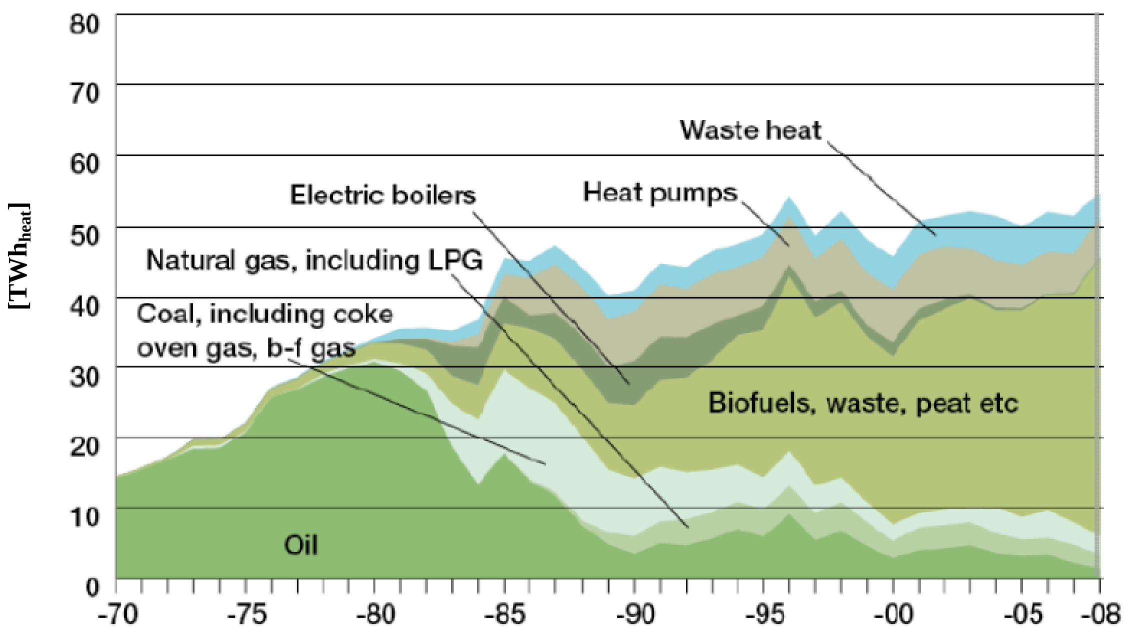

Figure 2. Historic Swedish district heating generation by fuel (1970-2008)[2].

Today local district heating networks are available in more than 270 out of Sweden's 290 municipalities, supplying over 50 TWh [4]. The capacity of district heating has been constantly increasing (see Figure 3) and is expected to continue to do so in the foreseeable future as investments in new capacity are expected by many studies (see [5] and [6]).

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[2] Figure based on data from Statistics Sweden (SCB); further processed by the Swedish Energy Agency (Energimyndigheten).

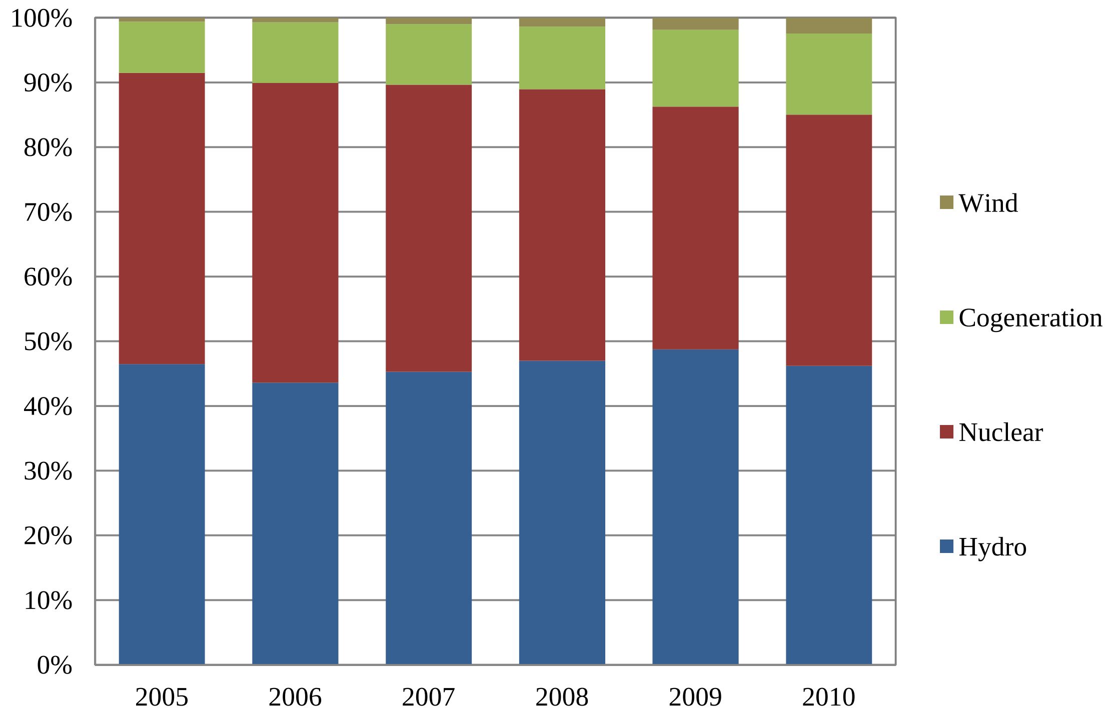


Figure 3. Technology share of total Swedish electricity generation[3].

One of the main benefits of using district heating for heating purposes, is the flexibility it offers to use different fuel alternatives and to make use of industrial waste heat that would otherwise been difficult to utilize. District heating also replaces heat generation in individual buildings to some few large plant chimneys, making it more economically feasible to install advanced exhaust cleaning equipment. Also district heating networks increase the ability to use cogeneration and thus increase the achievable energy utilization of thermodynamic processes.

Due to natural reasons district heating is primarily used during winter season; when the outdoor temperature is lower and the demand of heat is increased. This means that cogeneration plants are also primarily operated during the cold months of the year. As this report will examine the importance of cogeneration for the domestic energy system and the North European electricity exchange, all analysis will be done during winter season. The winter season will be assumed to start in October and end in April, i.e. 8 months annually. The period represents the time when district heating generating cogeneration plants are normally operated in Sweden [7].

1.1.2 District Heating in Gothenburg

District heating in Gothenburg started in 1953 with the opening of the Sävenäs combined heat and power plant, followed by one in Rosenlund the following year. Both

[3] Source: Swedish Statistics (SCB) and Svensk Energi

facilities continue to be essential to Gothenburg's district heating system until today. The city's waste incineration plant in Sävenäs began delivering waste heat to the district heating network in 1972 [8].

The use of oil decreased in the 1980s, and waste heat mainly from the existing large oil refineries in the city was utilized. Natural gas as an alternative fuel for oil was introduced 1988. The ability to produce heat and electricity was greatly increased when Göteborg Energi constructed their most recent facility, the Rya natural gas fired combined cycle combined heat and power (NGCC CHP) plant in 2006. Natural gas is today and is likely to continue to be the most important fuel to Gothenburg's district heating system in the foreseeable future [7].

1.1.3 Göteborg Energi AB

Göteborg Energi AB is the leading energy supplying company in western Sweden. It's the country's largest public energy utility and is owned by the city of Gothenburg. The company has three natural gas fired cogeneration plants that supply the city with both electricity and district heating (see Table 1). Also the company has recently installed a turbine in the bio fueled Sävenäs HP3 plant monthly generating 42.0 GWh_{heat} and 6.3 GWh_{el} [9] in January 2011.

Table 1. Natural gas fired cogeneration plants owned by Göteborg Energi.

Plant Name	**Average Annual Generation (2007-2010)**[4]	
	[GWh_{el}]	[GWh_{heat}]
Högsbo CHP	43	36
Rosenlundsverket	126	50
Rya NGCC CHP	849	990

Göteborg Energi's ability to generate electricity by cogeneration has increased significantly after introducing the Rya NGCC CHP plant. In 2005 when Rya was still under construction, Göteborg Energi produced 134 GWh of Electricity [10]. In 2010 a record year for the company the total electricity production was 1160 GWh, almost a tenfold increase, and Rya CHP producing about 88 % of that amount [11].

In addition to the above mentioned facilities Göteborg Energi operates additional facilities to meet the heat demand from the city's district heating network; the facilities and type of fuel it uses are summarized in Appendix A. A large portion of the supplied heat to Gothenburg district heating network is industrial waste heat that is bought by Göteborg Energi mainly from refineries operating in the city (see Figure 4).

[4] Source: Göteborg Energi AB. *Produktionsrapporter (2005-2010)*. Gothenburg; 2005-2011.

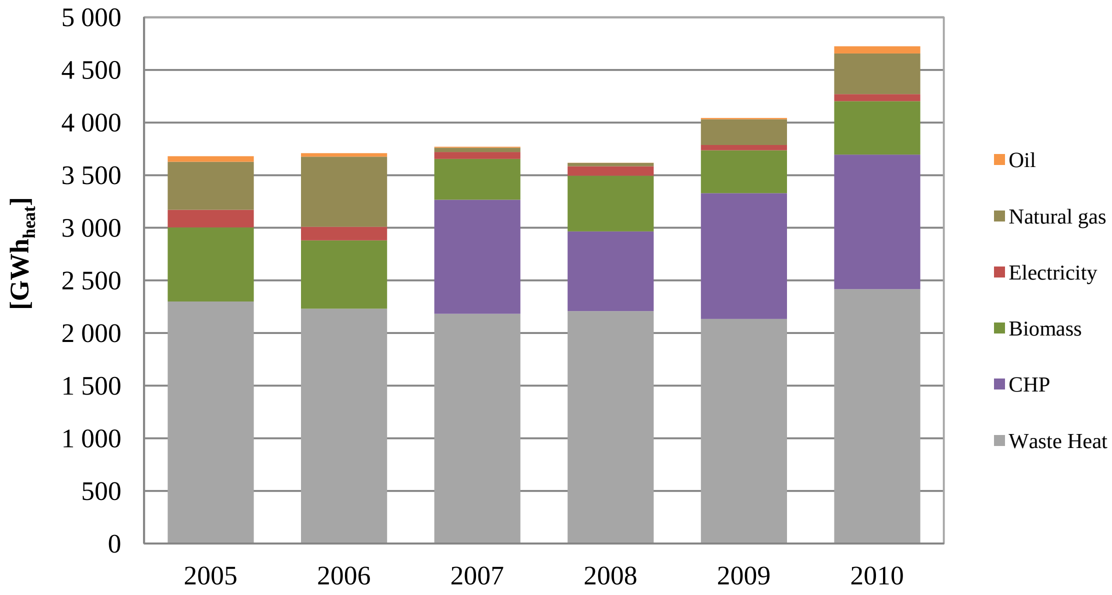


Figure 4. Göteborg Energi's district heating generation by fuel (2005-2010).

The total electricity and heat produced by Göteborg Energi's own facilities and the percentage share of Rya CHP are presented in Table 2. CHP technologies are an important part of the company's business strategy and are likely to continue to be in the future [12].

Table 2. Heat and electricity generated by Göteborg Energi's own facilities (2005-2010).

Year	**Heat** [GWh_{heat}]	**Electricity** [GWh_{el}]	**% produced by Rya** Heat	Electricity
2005	1737	134	0 %	0 %
2006	1760	330	12 %	67 %
2007	1737	892	55 %	93 %
2008	1608	626	41 %	91 %
2009	2034	1068	57 %	92 %
2010	2452	1160	49 %	88 %

1.1.4 Rya NGCC CHP

The Rya NGCC CHP plant is the largest and most important cogeneration facility for Göteborg Energi. Construction started in the fall of 2004. The plant was operated for testing mode in late 2006, and was fully operational in the beginning of 2007 [7].

The gas is transported directly from the Swedish gas grid that imports gas from Danish fields in the North Sea (see Figure 5). The plant has a capacity of 600 MW_{fuel} and is designed to be able to generate 261 MW_{el} and 294 MW_{heat} (2). The plant was expected to generate enough energy to meet 30 % of Gothenburg's power requirements and 35 % of the heat demand when constructed [13].

The 3x44 MW gas turbines are fed with pressurized natural gas between 26 and 28 bars [13]. The hot exhaust from the gas turbines is cooled in a Heat Recovery Steam Generator (HRSG), generating steam for the second steam cycle; the exhaust is then further cooled by preheating the inlet air to the gas turbine. The produced steam from the HRSG is expanded in a 137 MW steam turbine generating additional electricity [13]. The exhaust steam is further condensed with heat exchanger providing heated water that is supplied to Gothenburg's district heating network.

1.2 The Swedish Electricity Grid

The Swedish electricity grid, apart from being connected to its Nordic neighbors also has the ability to import electricity from Germany and Poland. These countries are connected with two separate high voltage direct current (HVDC) cables placed at the bottom of the Baltic Sea (see Table 3 and Figure 5).

Table 3. Transfer capacity between Sweden and neighboring countries[5].

Country	Name	Physical Thermal Transfer Capacity [MW]	Alternative-/ Direct Current (AC/DC)
Norway	Ritsem-Ofoten	1360	AC
Norway	Ajaure-Rössåga	330	AC
Norway	Järpströmmen-Nea	340	AC
Norway	Haslesnittet	2200	AC
Finland	Finland norr	2700	AC
Finland	Fennoskan	550	DC
Finland	Fennoskan 2	800	DC
Denmark	Kontiskan	750	DC
Denmark	Öresundsförbindelsen	1960	AC
Germany	Baltic Cable	690	DC
Poland	SwePol Link	720	DC

The existing physical transfer capacity to and from Sweden is currently 12.4 GW, and can be compared to the capacity of ten large nuclear plants. The installment of a new cable, NordBalt, of 700 MW between Sweden and the three Baltic states has been decided and planned to be completed in 2016 [14].

[5] Source: Svenska Kraftnät

1.3 The Swedish Gas Grid

Sweden has no known large natural gas resources and has not built any nation-wide gas grid. A high pressure gas grid still exists in western Sweden and is connected with Denmark. The gas is transported from the large existing resources in the North Sea. The gas pipes transport the gas from Malmo to Gothenburg and further North up to Stenungsund. The Swedish High voltage electric (440, 220 kV) and gas grid (80 bar) and its connections to other countries can be seen in Figure 5.

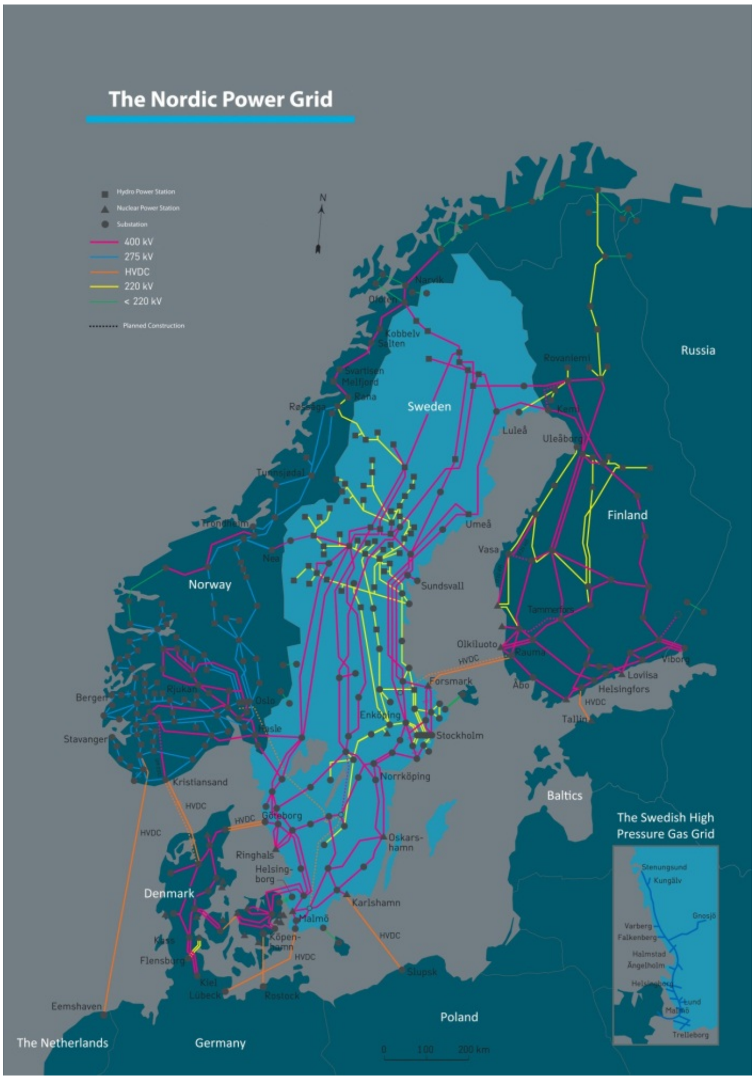


Figure 5. Swedish electricity and gas grid and connections to neighboring countries[6].

[6] Picture from the Svenska Kraftnät (SVK)

1.4 The Nordic Power Market

The electricity generated in Sweden is sold either based on direct bilateral agreements between energy producers and distributors or more commonly on Nord Pool which is the name of the joint Nordic electricity market. The bilateral agreements are ordinarily based on the Nord Pool prices when settling contracts, as the spot price of electricity on the Nordic power market is normative for the region [15].

In a pool-operated electricity market, such as Nord Pool, the market is cleared where the bids from electricity producers and system demand intersect for the bidding period. The most expensive generated unit of electricity that the market accepts to buy determines the price for all electricity sold during the bidding period. The bidding period for Nord Pool is normally an hour [15].

A single spot price on electricity is settled this way for all of Sweden, but after the 1st of November 2011, the country will be divided into four different price areas (see Figure 2). This will on occasions lead to an increase of the electricity prices in the southern parts of Sweden. This due to that low cost electricity generated from hydropower are concentrated in the Northern part of the country and currently existing transmission bottle-necks to the south of Sweden is likely to split the market price when the load is high. The majority of the cogenerations plants in Sweden are located in the southern part of Sweden, where the population density is higher [16].

If the electricity is generated from fossil fuelled fired technologies emitting carbon dioxide, an additional cost for the EU ETS credits is added on the electricity price. The prices for emission allowance are determined as other market commodities, based on supply and demand. The supply is decided by a cap on carbon emissions that is determined individually in every country [17]. Also emission taxes for other air pollutants increases the generation price of electricity in fuel based electricity generation in Sweden [18].

Sweden has introduced a support scheme, electric certificates, to promote renewable electricity. These electric certificates provide financial investment and operating support to the most competitive of the renewable technology alternatives. This also aids renewable electricity to compete with conventional generation technologies [19].

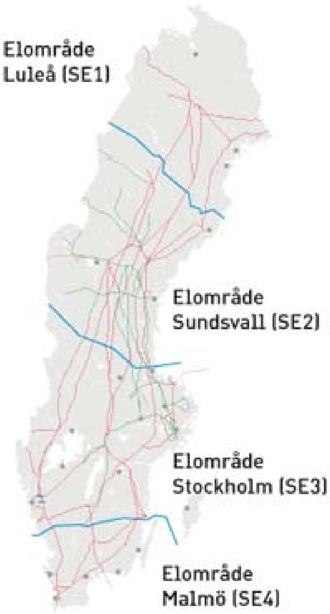


Figure 6. Future Swedish price areas[7].

1.5 Marginal Electricity Cost

The most expensive technology determines the marginal price of electricity. In Sweden the most inexpensive way to generate large scale electricity is by utilizing the existing hydro power resources. The most expensive is fossil fuel fired condensing that Sweden only utilizes when all other alternatives have been exhausted and as backup power (see Figure 6).

Cogeneration is under normal circumstances the marginal generation in Sweden and coal condensing on the Nordic and the North European power market [20]. As Sweden is a part of this larger electricity market, and exchange electricity with the neighboring countries. The generation cost for coal condensing determine the marginal price of electricity also in Sweden during most time of the year [20].

[7] Figure from Svenska Kraftnät

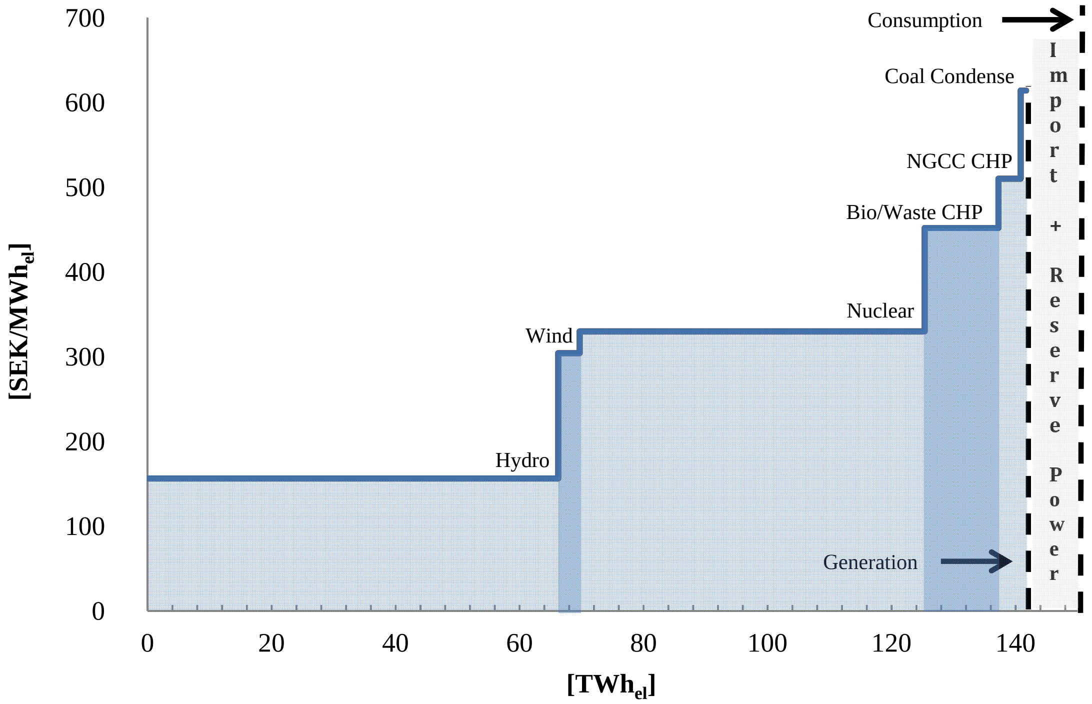


Figure 7. Electricity generation cost[8] for different technologies distributed on the Swedish Electric Year 2010.

The marginal price of electricity in Germany (EEX) has historically been more expensive compared to Nord Pool (see Figure 7). The Nordic power market has larger access to cheaper generation technologies. Also when fossil fuels are used for power generation cogeneration is more often utilized [21]. The income for the sold heat then contributes to lower the cost for generating electricity.

In the four interconnected Nordic countries hydro power is the dominant electricity generation source. As hydro power is the cheapest source of energy generation the amount of water in the reservoirs during a year determines the need of other more expensive electricity sources.

[8] Based on ELFORSK 2007*"el från nya anläggningar"* model. Fixed and running cost (including taxes and subsidies; VAT excluded).

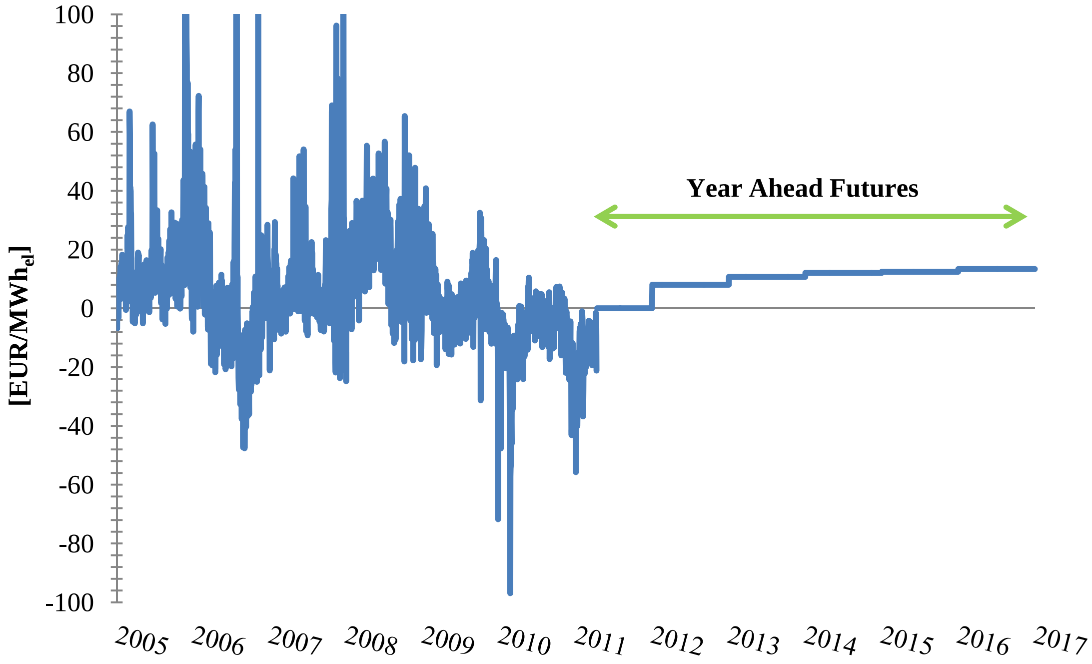


Figure 8. Price difference between EEX and Nord Pool Spot, positive value means EEX price more expensive and vice versa[9].

1.6 Electricity generation in Northern Europe

As mentioned earlier (see section 1.2) Sweden is able to import and export electricity from its Nordic neighboring countries (Denmark, Finland and Norway) and from Germany and Poland. These countries will from now on be mentioned as *"Northern Europe"* and the Scandinavian countries and Finland as *"Nordic"* when mentioning them as a group in the report.

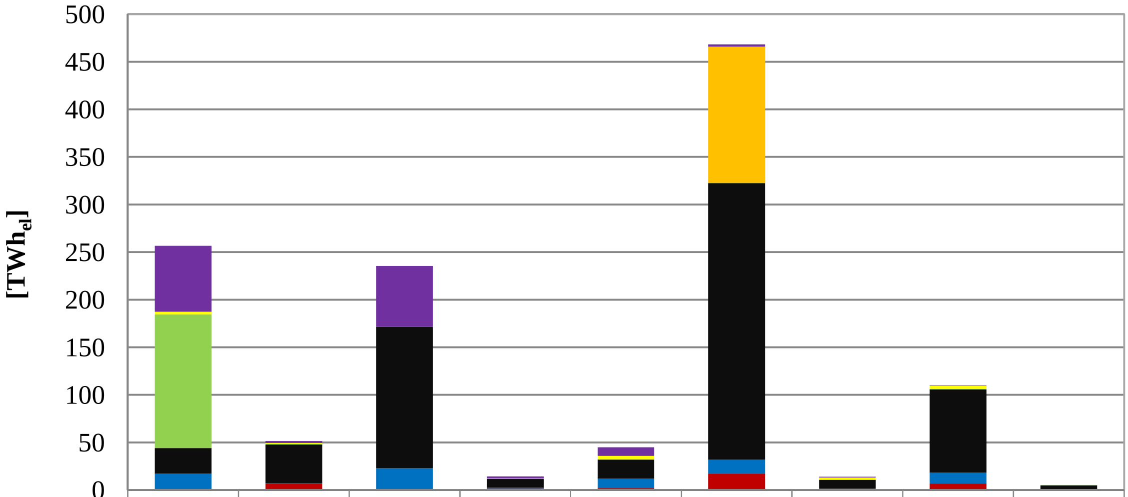
The electricity generation in the Nordic countries is primarily dependent on hydro power which generated about 58 % of the total electricity in 2008. Electricity generation in the four individual countries is very different, with Norway having practically all of its electricity generated by hydro power while Denmark has almost none. Finland generates the largest amount of its electricity, 30%, from nuclear power. Denmark generated 20 % of its electricity from wind power, but coal accounted for the largest share and generates about half of the electricity in the country. Fossil fuels (coal, oil and gas) generated 11 % of the total Nordic electricity in 2008 [22].

Germany and Poland are two countries that are highly dependent on coal fired power generation. In Poland 89 % of all electricity was coal power in 2008. The same percentage for Germany was 46 %. Both countries also use large amount lignite (brown

[9] Data collected from EEX and Nord Pool

coal) when generating electricity from coal fired power plant. Detailed monthly and annual data for all North European countries for the historic time period between 2005-2010 are presented in Appendix B.

Nuclear power today exists in Finland, Germany and Sweden. The total generation by source in each individual country and the North European share of each technology are presented in Figure 9 and 10.



	Hydro	Wind	Nuclear	Waste	Biomass	Coal	Oil	Gas	Other
Sweden	69,2	2,0	63,9	2,2	9,1	2,2	0,9	0,6	0,0
Poland	2,7	0,8	0,0	0,3	3,5	143,4	2,3	3,2	0,0
Norway	140,5	0,9	0,0	0,1	0,3	0,2	0,0	0,4	0,2
Germany	27,0	40,6	148,5	9,4	19,9	290,6	9,2	87,7	4,4
Finland	17,1	0,3	23,0	0,5	10,1	14,3	0,4	11,2	0,5
Denmark	0,0	6,9	0,0	1,9	2,1	17,5	1,1	6,9	0,0

Figure 9. Generation in TWh$_{el}$ by technology for North European countries (2008)[10].

[10] Source: International Energy Agency (IEA)

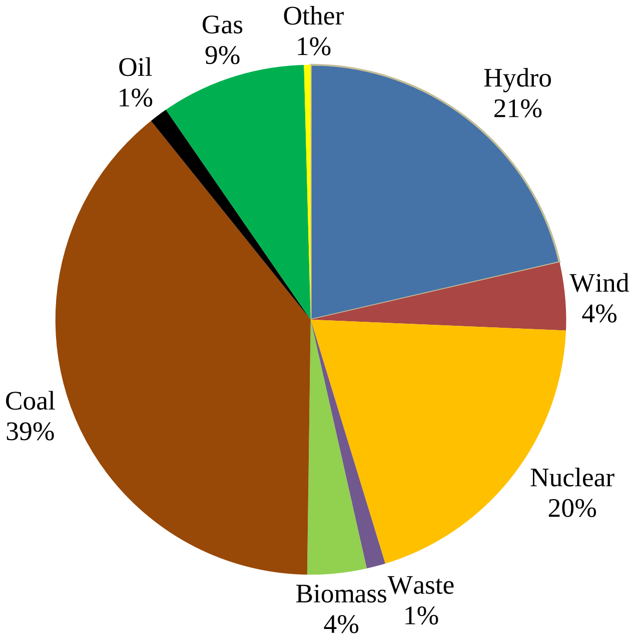


Figure 10. Total share of electricity generation in Northern Europe (2008).

1.7 Emissions

Emissions are inevitable when burning fuels for energy generating purposes. The most significant air polluting emission from fuel burning for energy generation is carbon dioxide (CO_2), nitrogen oxides (NO_x) and Sulfur dioxides (SO_x). This is the air pollutants that will be treated in this report when comparing cogeneration to other heat and electricity generating methods.

1.7.1 Carbon Dioxide

Carbon dioxide is produced when the carbon in organic fuels is burnt in the presence of oxygen. Carbon dioxide is an essential component for the vital photosynthesis on the planet, and is by itself harmless for humans and animals. A higher concentration in the atmosphere of CO_2 contributes to the greenhouse effect [23]. To avoid global warming due to burning of carbon a balance must be kept between the anthropogenic emissions and the earth's natural capacity to convert CO_2 back to carbon and oxygen, through photosynthesis so a balance can be kept [23].

Burning fossil fuels, i.e. lignite, coal, oil and natural gas increases the amount of carbon dioxide in the atmosphere as the anthropogenic use is much faster larger than reproduction of these fuels. Biomass burning also emits carbon dioxide when burned but if the same amount is replanted after harvesting, the net emission can be considered to be zero. In this report carbon dioxide emissions from biomass and waste incineration used for heat and electricity generation will be assumed to be zero.

Peat is a fuel that can be categorized somewhere between biomass and fossil fuels, and how it should be classified is not fully consensus in the academic world [24]. In this report peat will be categorized as a slow renewable fuel as is common practice in Sweden and assumed to have no carbon dioxide emissions [25]. Emission factors from fossil fuels used for electricity generation are presented in Table 4.

Table 4. Emission factors for fossil fuels[11].

Fossil Fuels	**Emission Factor** [kg CO_2/MWh_{fuel}]
Lignite	364.0
Coal	334.8
Oil	204.5
Natural Gas	274.3

1.7.2 Nitrogen Oxide

Nitrogen Oxides (NO_x) refers to the two compounds Nitric oxide (NO) and nitrogen dioxide (NO_2) which is produced when fuels are combusted at high temperatures. NO_x is air pollutant that causes acidification and is hazardous to human and animal health [26]. Emission factors of nitrogen oxide caused by electricity generation are presented in Table 5.

Table 5. Emission factors for nitrogen oxides.

Fossil Fuels	**Emission Factor** [kg NO_x/MWh_{fuel}]
Biomass	0.22
Coal/Lignite	0.29
Oil	0.54
Natural Gas	0.18
Waste	0.32
Peat	0.25

1.7.3 Sulfur Oxide

Sulfur oxides (SO_x) are produced when fuels containing sulfur are combusted. SO_x is an air pollutant that causes acidification and is hazardous to human and animal health [27]. Emission factors of sulfur dioxide caused by electricity generation of different fuels are presented in Table 6.

[11] Table 4-6, source: Swedish Environmental Protection Agency (Naturvårdsverket) Emission Factors for Electricty Generation. Lignite value based on IPCC emission factor used for calculations electricity generation.

Table 6. Emission factors for sulfur dioxide.

Fossil Fuels	Emission Factor [kg SO_x/MWh_{fuel}]
Biomass	0.07
Coal/Lignite	0.61
Oil	0.36
Natural Gas	0.00
Waste	0.09
Peat	0.47

1.8 Swedish Electricity Exchange

The gross electricity exchange during the winter season (October-April) is presented in two different sections: Import and Export. The data presented cover the historic five year period 2005-2010. Figures illustrating the same data in a staple diagram can be seen in Appendix C. A similar diagram for the annual gross electricity import and export during the whole year to and from Sweden is also presented in Appendix D.

1.8.1 Import

The largest amount of electricity imported to Sweden between the years 2005-2010 was from Norway. During winter season a total of 27.8 TWh was imported to Sweden from its Nordic neighbors. The import from Norway has decreased steadily during the five year period from 7 063 GWh in 2005 to only 2 934 GWh electricity in 2010.

All other countries except Poland, exported their largest amount to Sweden in 2010 during the investigated five year period. There are three main reasons behind the record Swedish import from other countries that have large fossil fueled power generation in 2010. A large amount of the Swedish nuclear capacity was unavailable and undergoing maintenance work; the availability of water in the domestic and Norwegian reservoirs was low; and that Northern Europe experienced a historic cold winter [28].

The imported electricity from Poland shows no clear pattern during the investigated time period. The total annual imported electricity to Sweden from neighboring countries for the period 2005-2010 can be seen in Table 7.

Table 7. Gross electricity import to Sweden (October-April).[12]

Country [TWh_{el}]	2005	2006	2007	2008	2009	2010	Total
Denmark	0.69	3.14	1.94	1.58	2.09	4.24	13.68
Finland	0.66	1.80	2.74	2.55	3.20	4.62	15.57
Germany	0.27	0.84	0.60	0.29	0.58	1.70	4.28
Norway	7.06	4.43	3.87	5.13	4.40	2.93	27.82
Poland	0.79	1.20	0.21	0.09	0.22	0.44	2.95

1.8.2 Export

Sweden exports most of its electricity to its Nordic neighbors primarily because the available transfer capacity to these countries is larger than that to Poland and Germany (see Table 3). The amount of electricity transferred to Norway is dependent on the water availability and electricity demand there. The export to other Nordic countries, which have more expensive coal condense as marginal electricity generation is dependent on domestic Swedish electricity demand, availability in the domestic hydro and nuclear power plants and transfer capacity to these countries.

The amount electricity exported to Germany and Poland is larger than the amount imported in the time period 2005-2010. The Nordic neighbors were net exporters to Sweden during the same period. The total annual export electricity to Sweden from neighboring countries for the period 2005-2010 can be seen in Table 8.

Table 8. Gross electricity export from Sweden (October-April).

Country [TWh_{el}]	2005	2006	2007	2008	2009	2010	Total
Denmark	3.47	1.05	1.90	3.34	1.90	0.42	12.08
Finland	3.75	2.44	1.27	2.45	1.09	1.07	12.07
Germany	1.92	1.10	0.97	1.59	0.52	0.21	6.31
Norway	1.41	4.49	3.12	1.71	1.76	3.88	16.37
Poland	0.57	0.01	1.00	1.36	0.64	0.22	3.80

1.9 NREAP

The National Renewable Energy Action Plans (NREAP) is an individual energy plan that all EU member states presented to the European commission in 2010 [29]. In the plan each country is obliged to provide a detailed roadmap of their national legally binding 2020 target for the percentage share of renewable energy in their final energy generation. The legally binding targets are presented in the Directive (2009/28/EC) presented in Table 9.

[12] Table 7 and 8 are based on data from Svenska Kraftnät.

Table 9. Legally binding targets to 2020 for EU member states.

Country	Renewable share of total energy consumption	
	In 2005	Target 2020
Denmark	17 %	30 %
Finland	29 %	30 %
Germany	6 %	18 %
Poland	7 %	15 %
Sweden	40 %	49 %

Each country has accordingly provided a detailed energy supply plan to achieve this overall target of renewable energy sources; by building new renewable energy capacity in the three energy sectors: transport (RES-T), heating and cooling (RES-H&C) and electricity sector (RES-E).

The RES-E description provides detailed plans on how each country annually will increase their share of renewable electricity generation. The directive also obliges the member state to conduct measures in order to improve their energy efficiency. The reference year for renewable energy increase and energy efficiency is 2005 in the NREAP.

2. Objective

2.1 Aim

The aim of the master's thesis is to determine the importance of Swedish cogeneration for the domestic energy system and the North European power exchange. In order to perform this, the technology mix of electricity generation in every country in Northern Europe will be analysed. Also the electricity exchange between Sweden and its neighboring countries during the period when the country's cogeneration plants are utilized will be determined and used to estimate cogenerations influence.

The comparison will be based on an estimate of the costs and CO_2-emissions associated with *average electricity* in every country and *Swedish cogeneration*. The results will be used to compare imported and exported electricity with the economic and environmental performance of the domestic electricity generation by district heating producing cogeneration.

Also the emissions from *Rya NGCC CHP plant* will be compared with the *marginal electricity* generation of in Northern Europe. Definitions for average and marginal electricity are presented in the *"Method"* chapter.

Swedish cogeneration and average electricity will be analysed for the time period 2005-2020, i.e. both for a historic and a future period. Rya NGCC CHP and marginal electricity will only be analysed during a five year period 2005-2010. This historic analysis will beside CO_2-emissions and electricity cost also compare the NO_x and SO_x pollutants of fossil fuel burning (see Table 10).

Table 10. Analysis subject and periods for compared electricity generation.

Comparison	Compared Items	Period
Average Electricity and Swedish Cogeneration	CO_2, generation cost	2005-2020
Marginal Electricity and Rya NGCC CHP	CO_2, SO_x, NO_x	2005-2010

2.2 Scope

The study is solemnly based on Swedish cogeneration plants and their contribution to the domestic energy generation; and the influence they have on Sweden's electricity exchange with other countries. Beside data of the electricity production of cogeneration plants, the heat contribution will also be accounted for. In order to more accurately analyse the societal benefits of cogeneration and their importance for the Swedish energy system.

Emissions will be calculated based on the fuel mix for district heating producing cogeneration plants. As district heating generating cogeneration is primarily used when a heat demand exists, the electricity exchange will be analysed during the winter months (October-April) when there normally is a demand for district heating in Sweden.

The import and export will only be analysed for the countries currently connected with Sweden (countries and connections listed in Table 3). The analysis period will be divided in a historic period between 2005-2010 where existing generation and exchange data will be collected, compiled and analysed (see *"Materials"*). And a future period that extends the current decade 2010-2020; where future generation will be projected by using official presented energy plans in each country. The plans presents planned new renewable electricity generation capacity and an estimate of the future domestic total electricity generation.

Special attention will be given to Göteborg Energi new Rya NGCC Cogeneration plant, which will be used as a reference plant for the thesis. The emission from Rya and marginal electricity in Northern Europe will be compared.

3. Method

The work will start by an orientation of the existing knowledge and data that correctly describe the electricity generation within Sweden, and the exchange with other countries. Information about the Swedish cogeneration plants and their contribution to the country's electricity and production will be used to determine their importance to the power exchange.

The collected data is compiled, modeled and analysed to determine the emission avoidance and economic benefits of the Swedish cogeneration plants and there importance for the energy system. Based on these results and made calculations, conclusions and future recommendations of the use of cogeneration in Sweden will be formulated.

Calculations will be done to determine and compare aspects of Swedish cogeneration and North European average and marginal electricity. The average electricity is defined as all electricity generated in the country, while the marginal electricity will only be based on the fossil fuel electricity generation.

The comparison between average and marginal generation in Northern Europe and Swedish cogeneration is made by assuming that the imported or by export replaced electricity is exchanged according to the historic import and export presented in Table 7 and 8. This means that both average and marginal electricity will be assumed percentage wise follow the import and export to and from each neighboring country.

The method to determine the total generation, emissions and economic cost for the time period 2005-2020 is presented in two separate sections below. The method to determine the performance of Rya NGCC CHP is also presented in the end of this chapter.

3.1 Emissions

Emissions from fuel burning to generate electricity are assumed to be similar in all countries, and are based on The Swedish Environmental Protection Agency emission factors for electricity generation (see Table 4-6). The thermal efficiency (η_{th}), i.e. fuel to electricity generation efficiency is also assumed to be equal in all countries. The values used in the calculations for different fuels to estimate emissions are summarized in Table 11.

Table 11. Estimated average thermal efficiency of different fuels.

Fuel	Thermal Efficiency, η_{th}
Lignite, η_l	35 %
Coal, η_c	38 %
Oil, η_o	40 %
Natural Gas, η_g	40 %
Biomass, η_b	30 %
Peat, η_p	30 %
Waste, η_w	20 %

Emissions will be calculated for both average (E_a) and marginal electricity (E_m). Only CO_2-emissions will be considered for average electricity while also NO_x and SO_x emissions will be calculated for marginal electricity. North European fuel powered (P_{Fuel}) generation of average and marginal electricity will be divided with total generation (G_{total}) and total marginal generation ($G_{Total,M}$) respectively. The calculations will be based on the monthly data for each North European country presented in Appendix B.

The general equations used to calculate the average and marginal electricity emissions pollutants examined is:

$$E_{a,CO_2} = \frac{\left(\frac{P_{coal}\times E_{coal,CO_2}}{\eta_c} + \frac{P_{oil}\times E_{oil,CO_2}}{\eta_o} + \frac{P_{gas}\times E_{gas,CO_2}}{\eta_g}\right)}{G_{total}} \quad [\text{kg CO}_2/\text{MWh}_{\text{el}}] \tag{1}$$

$$E_{m,CO_2} = \frac{\left(\frac{P_{coal}\times E_{coal,CO_2}}{\eta_c} + \frac{P_{oil}\times E_{oil,CO_2}}{\eta_o} + \frac{P_{gas}\times E_{gas,CO_2}}{\eta_s}\right)}{G_{total,m}} \quad [\text{kg CO}_2/\text{MWh}_{\text{el}}] \tag{2}$$

$$E_{m,NO_x} = \frac{\left(\frac{P_{coal}\times E_{coal,NO_x}}{\eta_c} + \frac{P_{oil}\times E_{oil,NO_x}}{\eta_o} + \frac{P_{gas}\times E_{gas,NO_x}}{\eta_g}\right)}{G_{total,m}} \quad [\text{kg NO}_x/\text{MWh}_{\text{el}}] \tag{3}$$

$$E_{m,SO_x} = \frac{\left(\frac{P_{coal}\times E_{coal,SO_x}}{\eta_c} + \frac{P_{oil}\times E_{oil,SO_x}}{\eta_o} + \frac{P_{gas}\times E_{gas,SO_x}}{\eta_g}\right)}{G_{total,m}} \quad [\text{kg SO}_x/\text{MWh}_{\text{el}}] \tag{4}$$

3.2 Economics

The generation price of electricity from different technologies is assumed to be equal in the different countries, and is based on estimated Swedish cost of producing electricity. The price includes emissions tax, subsidies and an assumed heat income of 180 SEK/MWh if cogeneration (CHP) is utilized. The price is an estimate of the retail price of electricity and is based on Elforsk report *"el från nya anläggningar 2007"* (see Table 12).

The generation price from oil condensing is estimated to cost between the price of coal and gas condensate. Coal cogeneration is estimated to cost between coal condensing and CHP. Cost of new RES-E in every country is assumed to equal average price between of wind power and biomass CHP in Sweden.

Table 12. Electricity generation price for different technologies.

Fuel	**Price [SEK/MWh$_{el}$]**
FUELS ($\boldsymbol{C_{fuels}}$)	
Coal/Lignite	639
Coal/Lignite CHP	$(\boldsymbol{C_{Coal}} + \boldsymbol{C_{G,CHP}})/2$ = 568
Oil	$(\boldsymbol{C_{Coal}} + \boldsymbol{C_{Gas}})/2$ = 649
Natural Gas	658
Natural Gas (CHP)	497
Biomass/ Peat (CHP)	492
Waste (CHP)	412
OTHER ($\boldsymbol{C_{other}}$)	
Nuclear	330
Wind	304
Hydro	156
RES-E	$(\boldsymbol{C}_{Bio,CHP} + \boldsymbol{C_{Wind}})/2$ = 398

The cost of producing average (C_a) and marginal electricity (C_m) in all North European countries will be estimated by using these fixed prices. The prices represent the cost of producing the same electricity in Sweden (see Table 12). The estimated cost for producing Swedish cogeneration (with heat income) will be compared with marginal electricity generated from condensing of coal, oil and gas which are assumed to be imported to Sweden from its neighboring countries. The cost of producing average and marginal electricity will be calculated based on these equations:

$$C_a = \frac{(\sum P_{fuels} \times \sum C_{fuels}) + (\sum P_{other} \times \sum C_{other})}{G_{total}} \qquad [\text{SEK/MWh}_{el}] \qquad (5)$$

The fuels using electricity and all the other generation technologies (see Table 12) is summarized toshorten the equation.

$$C_m = \frac{P_{coal} \times C_{coal} + P_{oil} \times C_{oil} + P_{gas} \times C_{gas}}{G_{total,m}} \qquad [\text{SEK/MWh}_{\text{el}}] \qquad (6)$$

Not all waste heat from fossil fuel generated electricity is condensed in Northern Europe. To more correctly estimate the generation cost the amount average percentage share of CHP per gross electricity production in every country is multiplied with the total electricity generation and is assumed to be produced by an equal amount gas and coal. The average CHP share of the total electricity production is presented in Table 13.

Table 13. Cogeneration share of total electricity generation in Northern Europe.[13]

Country	Average 2005-2010
Denmark	45.4 %
Finland	35.9 %
Germany	12.6 %
Norway	0.1 %
Poland	40 %
Sweden	8.6 %

3.3 Cogeneration

The efficiency of cogeneration plant is generally described by the Energy Utilization Factor (EUF) thermal efficiency (η_{th}) and the power to heat ratio (PHR). The EUF accounts for both products from a cogeneration plant, the useful heat and the net electricity (see Equation 7).

$$EUF = \frac{Q_{heat} + P_{net}}{Q_{input}} \qquad (7)$$

Useful heat from a cogeneration is supplied either as steam for industrial processes or as hot water to a district heating network. Heat that is condensed for cooling purposes is thus not considered as useful heat.

The net electricity is the power supplied by the plant to the grid. After internal losses and the electric use from auxiliary equipment has been supplied (see Equation 7).

$$P_{net} = P_{electricity} - P_{aux} - P_{loss} \qquad (8)$$

The heat input is the energy supplied by the fuel into the cogeneration plant. For the Rya CHP the fuel is natural gas (see Equation 1-2). The abbreviations stand for the higher (HHV) and lower (LHV) heating value of the natural gas. The LHV subtracts the head needed for vaporization while the HHV accounts for it.

[13] Eurostat data 2009

$$Q_{Input} = \dot{m}_{gas} \times HHV \quad (9)$$

$$Q_{Input} = \dot{m}_{gas} \times LHV \quad (10)$$

The LHV therefore yields a higher efficiency than the HHV, as it assumes that less energy are supplied to the cogeneration plant. The temperature when determining the heating values is 25 Celsius. Heating values used to calculate the efficiencies for Rya CHP can be seen in Table 13.

Table 14. Average heating value natural gas[14].

Heating Value	**[kWh/nm^3]**
HHV	12,1
LHV	11,0

The two different form of energy generated by cogeneration, electricity and heat represents different forms of energy with electricity representing the higher form. Electricity is also under normal circumstances the more expensive of the two.

The EUF treats the two commodities as similarly important when calculating the overall efficiency, and to compliment the thermal efficiency (η_{th}) is to determine the ratio of net electricity generated as a result of the input of fuel. The thermal efficiency is defined as:

$$\eta_{th} = \frac{P_{net}}{Q_{input}} \quad (11)$$

Also to further characterize a cogeneration plant the power-to-heat ratio (PHR) is used. The PHR is a simple ratio between the net electricity and the useful heat generated. The PHR is defined as:

$$PHR = \frac{P_{net}}{Q_{heat}} \quad (12)$$

[14] Estimated from data from Swedgas

4. Materials

4.1 Indata

The results used to perform the analysis in this project work are based on data collected from number sources and have been carefully chosen to correctly represent the North European energy system. All data is derived from established organizations, agencies and companies with recognized expertise in the area which the data is collected.

The annual and monthly imported and exported electricity to and from Sweden is based on retrieved data from Svenska Kraftnät. This data is used as official Swedish statistics at Swedish statistics (SCB).

The Nordic annual and estimated monthly electricity production and consumption is based on statistics from NordEl (2005-2008) and from ENTSO-E (2010). The data for 2009 have not yet been published and are instead averaged from previous years (2005-2008) for corresponding month. All Nordic monthly fossil fuelled power generation is reported together under the same heading. To estimate the monthly consumption by fuel for electricity generation, the annual consumption in every country of coal, oil and gas is multiplied with the total amount fossil thermal power for the corresponding month.

The annual and monthly generation and consumption of electricity in Germany and Poland for the reference period is based on data from ENTSO-E (2005-2010). The fossil production data for Germany, as the Nordic countries, is not specified on monthly basis but presented jointly as fossil fuels. Annual percentage use in each country of coal, oil and gas is therefore multiplied with the amount thermal fossil power for the corresponding month. The annual electricity generation for different technologies in Germany is based data on data from IEA. The detailed monthly production from different electricity generation technology in each North European country for the time period 2005-2010 can be found in Appendix B.

The annual generation (2005-2010) of electricity, heat and emissions from Göteborg Energi’s different cogeneration and district heating producing facilities is based on the company’s official internal production reports. The detailed daily data used to analyse the performance of Rya NGCC CHP is collected from Göteborg Energi proprietary data acquisition software DLS.

A projected likely future development of electricity generation, until 2020 for the EU member countries (Denmark, Finland, Germany, Poland and Sweden) is made. The future generation is based on the NREAP that was presented by each member to the commission in 2010. The report presents a detailed plan for the planned new additional renewable electricity, RES-E for each member state for the time period 2005-2020. The data for the renewable and non-renewable electricity and the estimated electricity demand in each country for 2005-2020 are presented by The Energy research Centre of the Netherlands (ECN).

4.2 Assumptions

In order to be able to estimate the present and future emissions and electricity production costs associated with North European electricity generation a number of assumptions and simplifications have been made. For cogeneration the historic emission are only presented for district heating generating cogeneration plants and facilities producing industrial heat is thus not considered. Also the future increase of electricity generation from cogeneration will be assumed to be entirely bio-based and half of the additional Swedish RES-E will be assumed to be cogeneration according to the expectations in the NREAP [30]. The cost of generating electricity in all North European countries will be assumed to have the same cost as in Sweden.

The marginal electricity is assumed to be generated by the fuel mix ratio of lignite, coal, oil and gas condensing in the neighboring countries. The ratio, but not the amount, of the marginal fossil fuels mentioned will be assumed to be similar in 2020 as in 2010 for all North European countries. Norway will in the calculations be assumed to have zero emissions in their average and marginal electricity emissions during the current decade.

Nuclear power today exists in Finland, Germany and Sweden, and no other country is assumed in the calculations to introduce the technology before 2020. Finland is the only country currently building new capacity. The 1600 MW Olkiluoto 3 unit is expected to be operating 2013 [31] and will be accounted for in the calculations. Additional units are planned in Finland but none is assumed to be completed before 2020 [31]. The new power plant is assumed to be available during 90 % of the time annually.

An estimated one fifth of all electricity in Germany is generated by nuclear power. The German government decided to temporarily close seven of its oldest reactors to conduct checks and maintenance in March 2011. After the meltdown incidents at the Fukushima power plant Germany decided to dismantle all of its nuclear capacity until 2022. It was also decided that the seven stopped reactors undergoing checks would be permanently closed [32]. The remaining German nuclear capacity is assumed to stay in operation until 2020 in the calculations.

Swedish electricity producers have not published any public plans to invest in new nuclear power until 2020. The three nuclear reactors Forsmark, Ringhals and Oskarshamn are all planning for upgrades to increase their respective power output. An additional generation of 8 TWh of nuclear power is expected until 2020 [33]. The capacity is assumed to increase linearly in the calculations during the decade.

The annual amount of imported and exported electricity and produced electricity in Swedish cogeneration plants for the time period 2011-2020 is assumed to be constant and equal to the average value for all neighboring countries during the historic period 2005-2010. Also the marginal production in Swedish cogeneration plants will be assumed to be similar in 2020 as in 2010.

The assumptions and simplifications are made in order to use the collected data to perform analysis of the present and future emissions and cost from generation of North European average and marginal electricity. The results will be compared with the corresponding economic and emission performance for Swedish cogeneration.

5. Results

The results will be presented in two sections: Cogeneration and Northern Europe. The cogeneration chapter is divided in two parts; the first will present the results for Swedish cogeneration. Analysis of the domestic cogeneration will be presented for a historic and future period.

The historic period is between 2005-2010 where collected data from various sources will be used to determine the generation. The analysis will also estimate the emissions of CO_2, NO_x and SO_x and the generation cost of Swedish cogeneration. An analysis of the period for the years 2011-2020 will also be made to estimate future CO_2-emissions and generation cost associated with Swedish cogeneration. The second part will analyse the Rya NGCC CHP performance during its first production years 2007-2010. This analysis will present the historic emissions of CO_2, NO_x and SO_x of Rya.

Also the Northern Europe section will be divided in two chapters. The first will analyse the average electricity and examine each countries CO_2-emissions and generation cost. Here future projected cost and emissions based on the NREAP, will also be presented for the period 2011-2020. The second subject will deal with European marginal electricity (for definition see *"Methods"*). The estimated emissions and generation cost of North European marginal electricity will be presented for the period 2005-2010.

5.1 Swedish Cogeneration

The historic electricity generation by district heating generating cogeneration plants can be seen in Figure 11. The associated electricity production is also displayed by a line in the same Figure. The 2010 fuel use is an estimate based on Svensk Energi's net generation for cogeneration and calculated by gross use of fuel efficiencies (listed in Table 11) are used.

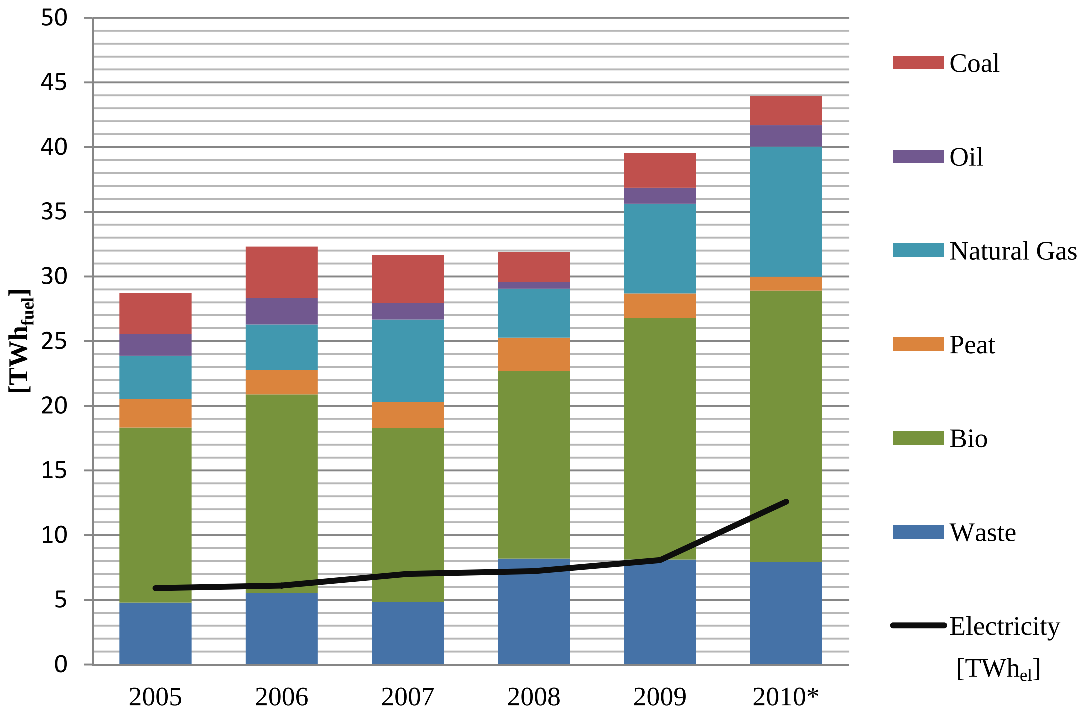


Figure 11. Historic Swedish cogeneration generation by fuel.[15]

In the estimated generation cost of Swedish cogeneration all electricity generated by oil and coal is assumed to have the same prime as condense. And all natural gas generated electricity is assumed to be generated by cogeneration. The cost of average CHP is presented in Table 13, the corresponding emissions of NO_x and SO_x are found in Appendix A.

Table 15. Historic average CO_2-emissions and generation cost for Swedish Cogeneration.

Year	2005	2006	2007	2008	2009	2010
CO_2-emissions [kg CO_2/MWh_{el}]	393	378	426	250	346	279
CHP Cost [SEK/MWh_{el}]	505	507	504	485	491	492

The future expansion of cogeneration, including industrial heat, is assumed to be entirely CO_2-free according to the NREAP. According to the ECN data an increase of 7.3 TWh is expected until 2020 (base year 2005). In the estimations (see Table 11) CO_2-free cogeneration is assumed to increase annually according to the NREAP projections.

[15] Sources: SCB, Svensk fjärrvärme and Svensk Energi

All other cogeneration fuels are assumed to be constant and similar to the generation in 2010.

Table 16. Future expansion of Swedish cogeneration.

[TWh$_{fuel}$]	2010*	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 - Free	30	33	34	34	35	35	36	36	37	37	38
Total CHP	44	47	48	48	49	49	50	50	51	51	52

Based on these results the future average cost of cogeneration is estimated. The future CO_2-free expansion of cogeneration and the corresponding production cost estimate in presented in Figure 12.

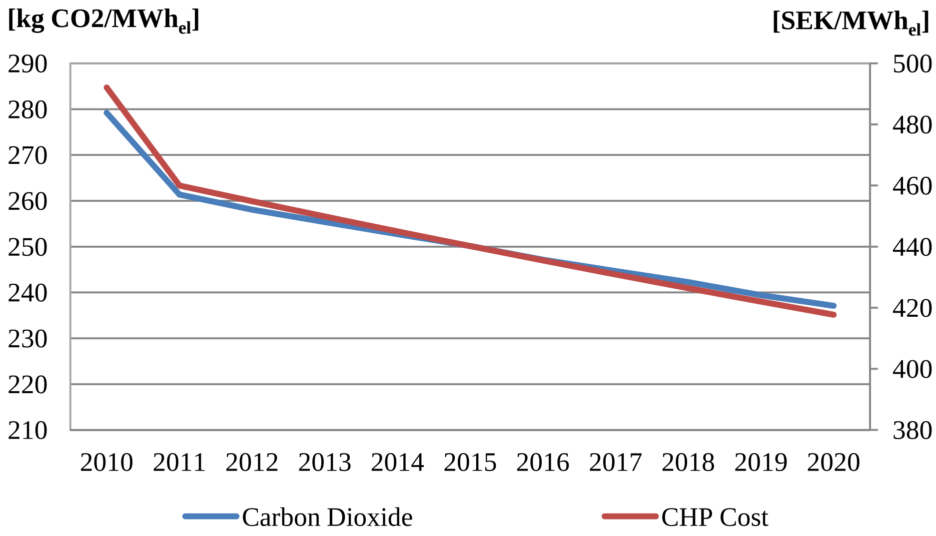


Figure 12. Future CO_2-emissions and generation cost of Swedish cogeneration.

5.1 Rya NGCC CHP

The total annual district heating, net electricity and emissions for the Rya NGCC CHP plant is summarized in Figure 13. The average annual production of heat and electricity during the time period 2007-2010, was 851 GWh$_{el}$ and 988 GWh$_{heat}$, which correspond to an average PHR of 0.86.

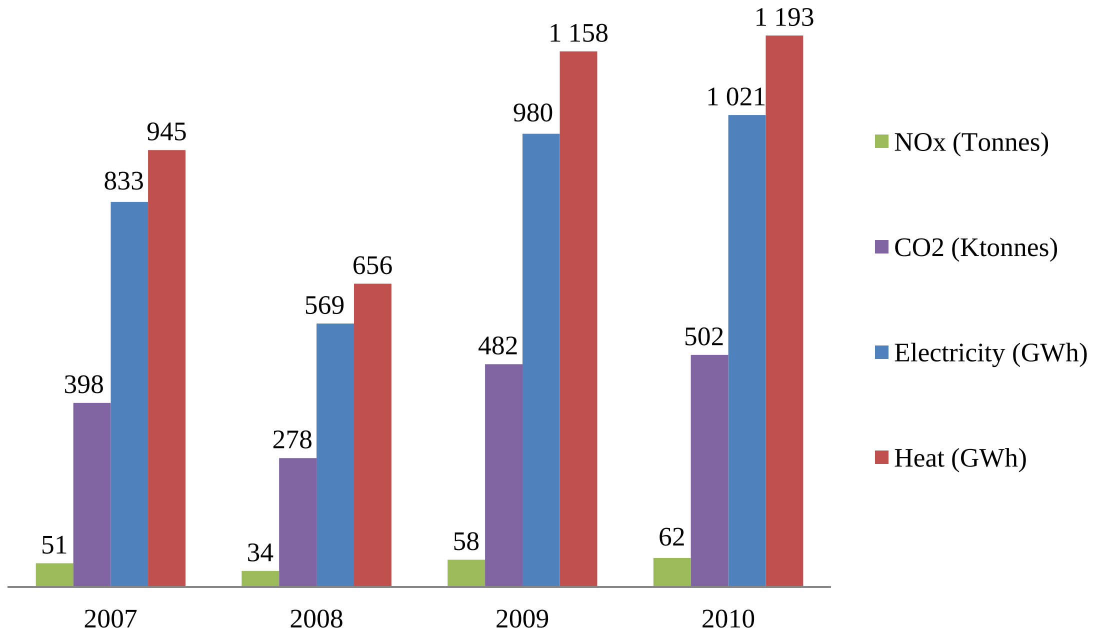


Figure 13. Rya NGCC CHP cogeneration and corresponding emissions.

The plant is constructed to operate in order maximize the EUF (see Equation 7); by applying a lower PHR (see Equation 12). If electricity generation was the primary product to the plant a PHR of around 1.2 would be more suitable [13].

This operation makes it possible to achieve EUF higher than 90 % under favorable conditions in the NGCC CHP plant (calculating with LHV). Maximizing the EUF still affects the thermal efficiency negatively (see Equation 11). The average transformation to useful heat and net electricity in Rya CHP is annually 88 % (LHV). The corresponding annual average thermal efficiency was 42 % (see Figure 14).

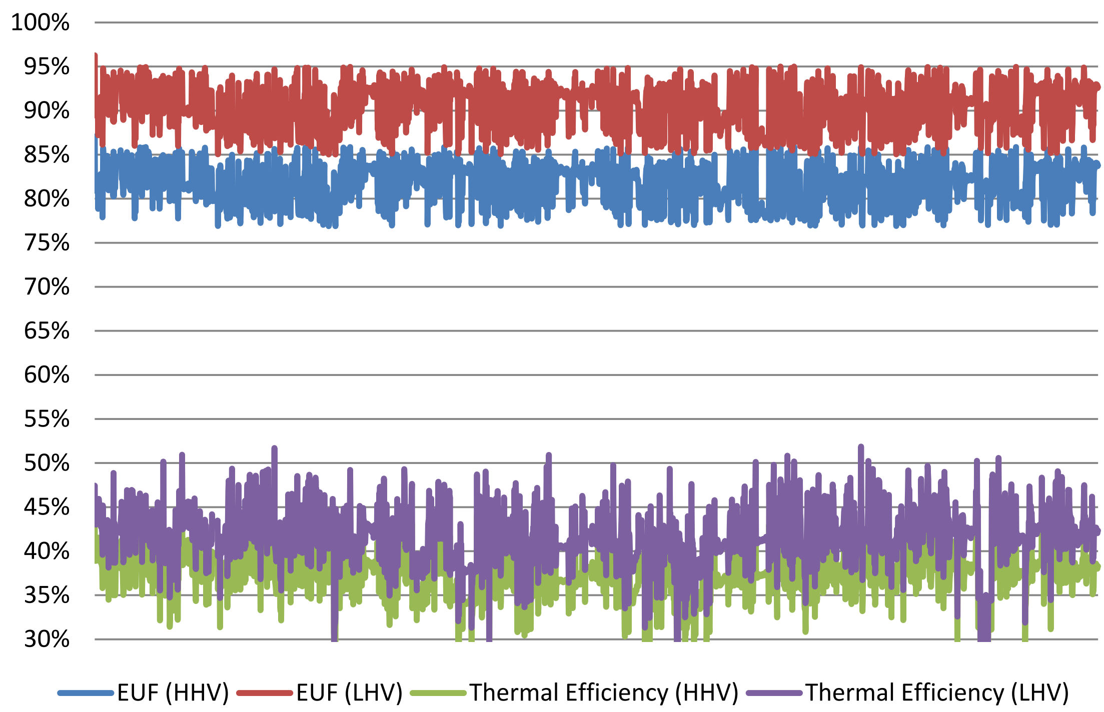


Figure 14. Annual EUF and thermal efficiency (η_{th}) of Rya NGCC CHP (2008)

The average emissions for Rya NGCC CHP during the production year 2007-2010 are summarized in Table 17. The sulfur dioxide emissions are practically zero and are neglected in when compared with marginal electricity

Table 17. Emissions Rya NGCC CHP (2007-2010).

RYA NGCC CHP [kg/MWh$_{el}$]	2007	2008	2009	2010
CO_2	**478**	**489**	**492**	**492**
SO_X	**0**	**0**	**0**	**0**
NO_X	**0.06**	**0.06**	**0.06**	**0.06**

5.3 Average Electricity

The annual historic CO_2-emissions from North European average electricity from each individual country are presented below (see Table 18). The monthly average CO_2-emissions for the same period are presented in Appendix F in a diagram for each country.

The CO_2-emissions are highest in Poland where coal generation is dominant. Germany and Denmark are quite similar where the German lignite fired coal plants increase the average emissions though Germany unlike Denmark have nuclear power. Norway and Sweden have very low average emissions in their electricity generation. Sweden's CO_2-

emissions are primarily from marginal generation and cogeneration, while Norway only uses fossil fuels as reserve power during the year.

Table 18. CO_2-emissions from Average Electricity in Northern Europe.

Country [kg CO_2/MWh_{el}]	2005	2006	2007	2008	2009	2010
Denmark	564	576	578	574	575	580
Finland	264	355	315	259	210	267
Germany	596	578	606	565	514	568
Norway	4	4	6	4	17	19
Poland	904	903	898	899	894	885
Sweden	45	61	55	49	54	35

The future carbon dioxide emissions for average electricity for each country are based on the increase of renewable RES-E in each country. All fossil fueled capacity is estimated to remain similar percentage wise during the decade (2010-2020). Nuclear power is increased or decreased based on the public plans for each country (see *"Assumptions"*). The projections based on the NREAP (2011-2020) are presented together with the historic production (2005-2010) for each country in diagrams in Appendix G.

Future carbon dioxide emissions (2011-2020) are estimated to decrease due to the increase of renewable power in all countries. Norway is assumed to have no net emissions of carbon dioxide and is therefore omitted from the diagram (see Figure 15). The diagram can be compared with figure 12 to compare the future emissions of Swedish cogeneration and North European average electricity.

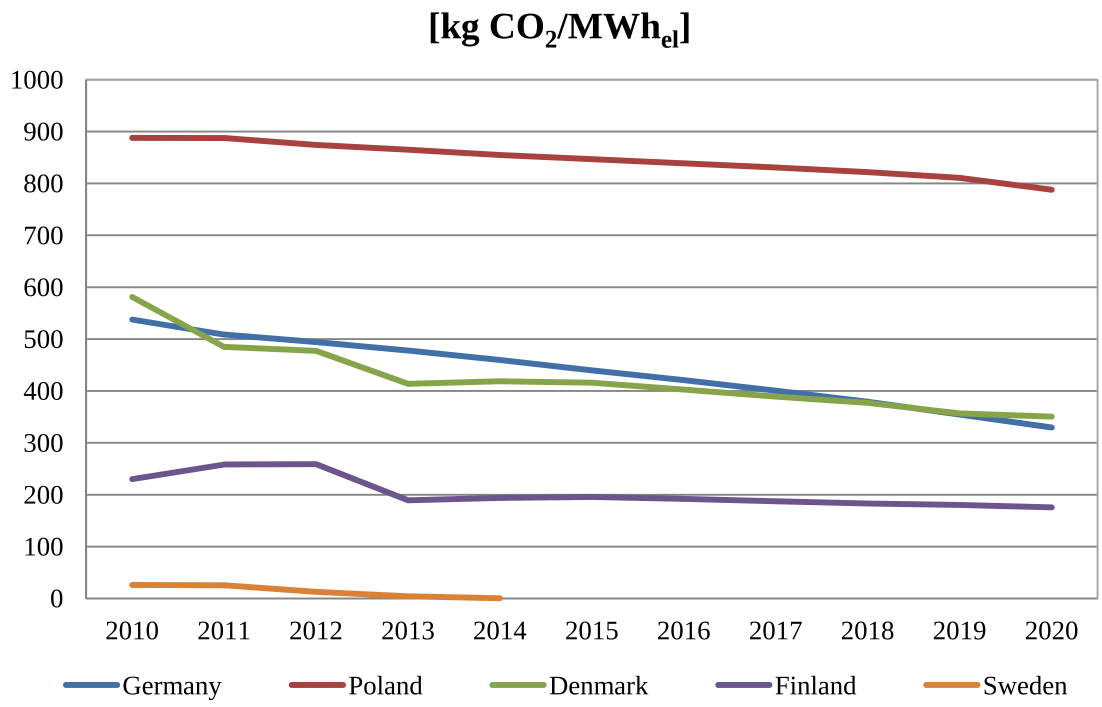


Figure 15. CO_2-emissions from future average electricity in Northern Europe.

As can be observed in the figure Sweden is based on the calculations estimated to have zero net emissions after 2014. The increase of RES-E and the increased power output in the nuclear power plants will together with the existing hydro capacity manage to supply the whole projected Swedish electricity consumption by 2014 on an annual basis.

The electricity cost for average electricity in Northern Europe for the historic period is presented in table 19. Future estimated cost for North European electricity is presented in figure 16. Norway is omitted from figure 15 as the country in this report is assumed to generate enough hydro power annually to during the current decade to meet its annual domestic needs. This means that the average cost of electricity in Norway is assumed to be equal to the generation cost of hydro (see Table 12) during the current decade.

Table 19. Historic annual cost of average electricity.

Country [SEK/MWh]	2005	2006	2007	2008	2009	2010
Denmark	531	557	534	529	539	532
Finland	388	434	411	386	404	398
Germany	474	485	490	485	475	478
Norway	160	161	162	161	164	178
Poland	597	600	599	596	592	588
Sweden	254	262	259	258	260	268

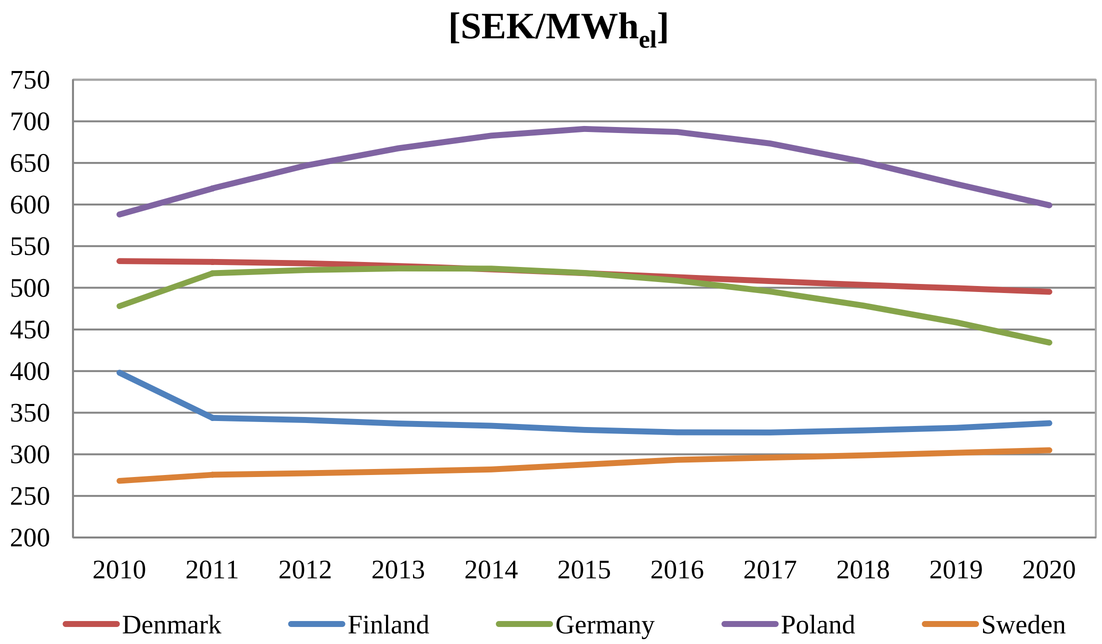


Figure 16. Estimated future average price for North European electricity.

The future prices are estimated and based on the NREAP projections and the assumptions made in the report. The diagrams for the annual increase in all Northern European countries is presented in Appendix H. The future estimated cost of North European average electricity can be compared to the one for Swedish cogeneration (see Figure 12).

5.4 Marginal Electricity

The annual historic emissions of CO_2, NO_x, and SO_x from North European marginal electricity from each individual country are presented below in the three tables (see Table 20-22). These results are visualized in a staple diagram together with the corresponding for Rya NGCC CHP in Appendix G.

Poland also has the highest CO_2-emissions when looking at the marginal electricity. Germanys marginal emissions is although almost as high due to that it has a higher ratio of lignite fired coal power plants compared to Poland. Denmark, Sweden and Finland use percentage wise more gas and oil in their marginal electricity generation and have lower CO_2-emissions. Norway only uses gas as marginal (reserve) electricity and therefore has the same emissions during all years during the investigated period.

The countries with large coal based power generation: Poland, Germany and Denmark have large sulfur emissions. Norway has none due to only natural gas is utilized. Natural gas in the fossil fuel with highest NO_x emissions and therefore Norway is estimated to have the highest nitric oxide emissions in their marginal electricity.

Table 20. Historic CO_2-emissions of North European marginal electricity.

Country [kg CO_2/MWh_{el}]	2005	2006	2007	2008	2009	2010
Denmark	738	785	781	769	575	729
Finland	548	606	561	521	674	761
Germany	881	861	863	855	866	865
Norway	511	511	511	511	511	511
Poland	925	925	924	927	926	915
Sweden	620	601	521	653	550	721

Table 21. Historic SO_x emissions of North European marginal electricity.

Country [kg SO_x/MWh_{el}]	2005	2006	2007	2008	2009	2010
Denmark	1.01	1.51	1.16	1.11	1.13	1.13
Finland	0.73	1.00	1.04	0.70	0.87	0.92
Germany	1.45	1.51	1.51	1.49	1.50	1.50
Norway	0	0	0	0	0	0
Poland	1.60	1.60	1.60	1.60	1.60	1.59
Sweden	0.79	0.83	0.92	0.91	0.85	0.72

Table 22. Historic NO_x emissions of North European marginal electricity.

Country [kg NO_x/MWh_{el}]	2005	2006	2007	2008	2009	2010
Denmark	0.98	0.85	0.93	0.94	0.94	0.94
Finland	1.09	0.99	0.97	1.09	1.03	1.01
Germany	0.86	0.85	0.85	0.86	0.86	0.86
Norway	1.35	1.35	1.35	1.35	1.35	1.35
Poland	0.80	0.80	0.80	0.81	0.80	0.80
Sweden	1.00	1.04	1.08	1.11	1.07	1.15

6. Conclusions

The conclusions chapter will contain two sections. The first with compare the CO_2-emissions and estimated generation cost of North European imported and that of exported replaced average electricity with that of Swedish cogeneration. The comparison will be both for the historic (2005-2010) and a future period (2011-2020) where projected emissions and generation cost will be estimated with the help of the NREAP data.

The other section will compare the emissions of (CO_2, NO_x, and SO_x) of North European marginal electricity with the data from Rya NGCC CHP. The comparison will be for the historic period 2005-2010 (Rya NGCC CHP started generation 2007). Swedish cogeneration and Rya NGCC CHP will be compared with the average and marginal electricity based on the imported (see Table 7) and exported (see Table 8) electricity from and to Sweden for the period 2005-2010.

The average imported and exported average and marginal electricity will be calculated by multiplying each North European countries average and marginal electricity with import and export to Sweden respectively. This will estimate what emissions and cost of the imported electricity to Sweden and the electricity that is replaced in other countries by Swedish cogeneration on a yearly basis.

6.1 Swedish Cogeneration and Average Electricity

The imported average electricity had lower CO_2-emissions compared with the average emissions from Swedish cogeneration plants during the period 2005-2010. The largest amount of electricity to Sweden was imported from Norway (see Table 7) during this period. Norway has almost no CO_2-emissions in their average electricity (see Table 18). A dashed line is visualizing the CO_2-emissions North European imported electricity without Norwegian electricity. This results in a much higher average emissions and now the imported average electricity s higher than that of Swedish cogeneration (see Figure 17).

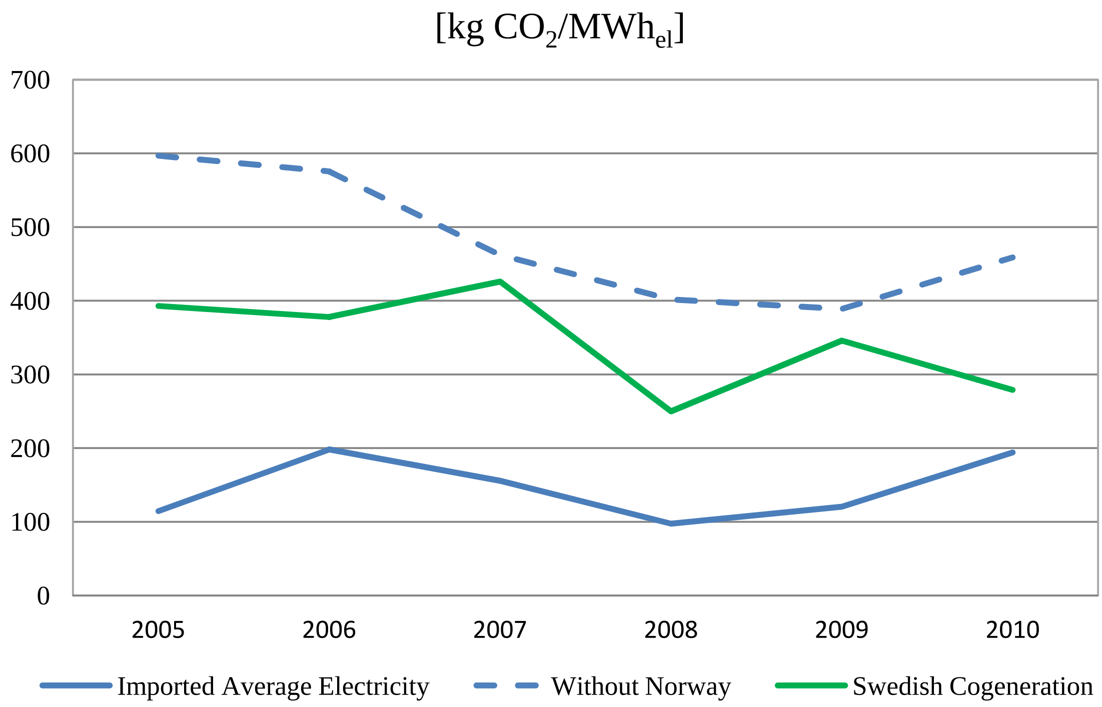


Figure 17. CO_2-emissions imported average electricity compared to Swedish cogeneration.

Below the exported electricity from Sweden is assumed to replace North European average electricity and compared with Swedish cogeneration (see Figure 18). During years when Sweden exports a lot of electricity to Norway the replaced electricity emissions is lower compared to cogeneration. Some year's cogeneration has lower emissions compared to average exported electricity. In 2008 a lot of renewable fuels was used to generate cogeneration (see Figure 11) and in both 2008 and 2009 relative little electricity was exported to Norway resulting in higher average emissions compared to cogeneration. If the export to Norway is omitted in the calculating the average electricity replaced by Swedish export has higher emissions compared to Swedish cogeneration (see Figure 18).

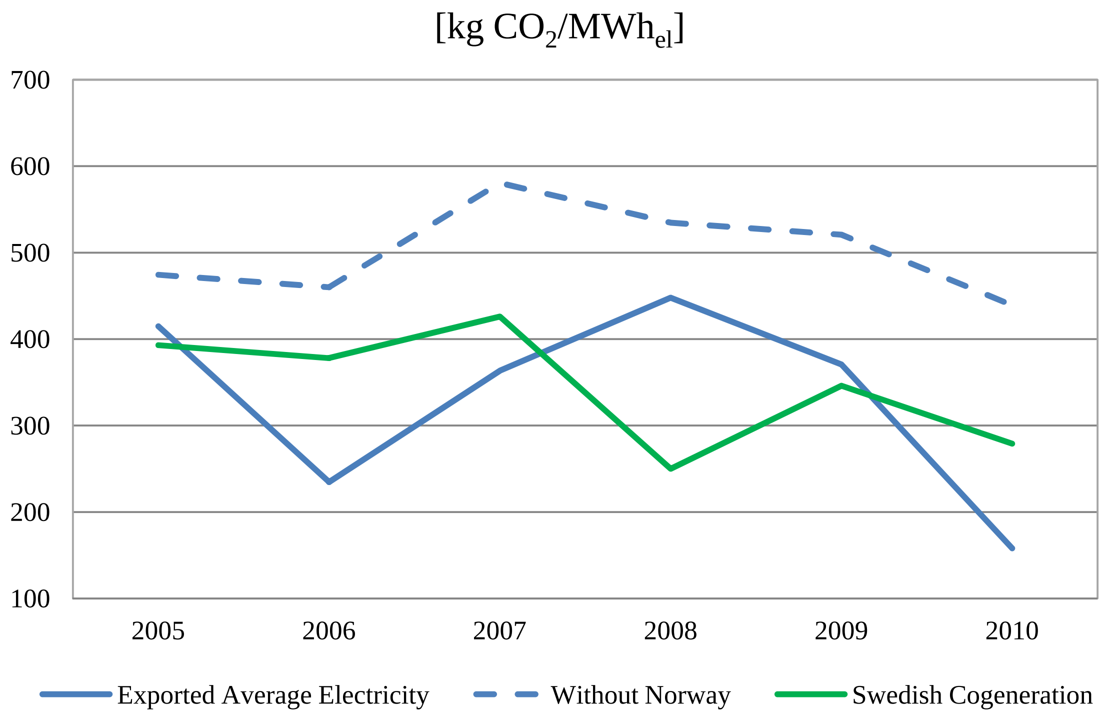


Figure 18. CO_2-emissions from replaced electricity by export compared to Swedish Cogeneration.

When comparing the estimated cost of the imported electricity and the assumed replaced electricity by export the cost is for electricity lower compared to that of Swedish cogeneration. If Norway the country with far the lowest cost for electricity generation in Northern Europe is omitted from the calculations the results are different. The cost of both imported and assumed replaced average electricity then have a very similar price to that of Swedish cogeneration (see Figure 19 and 20).

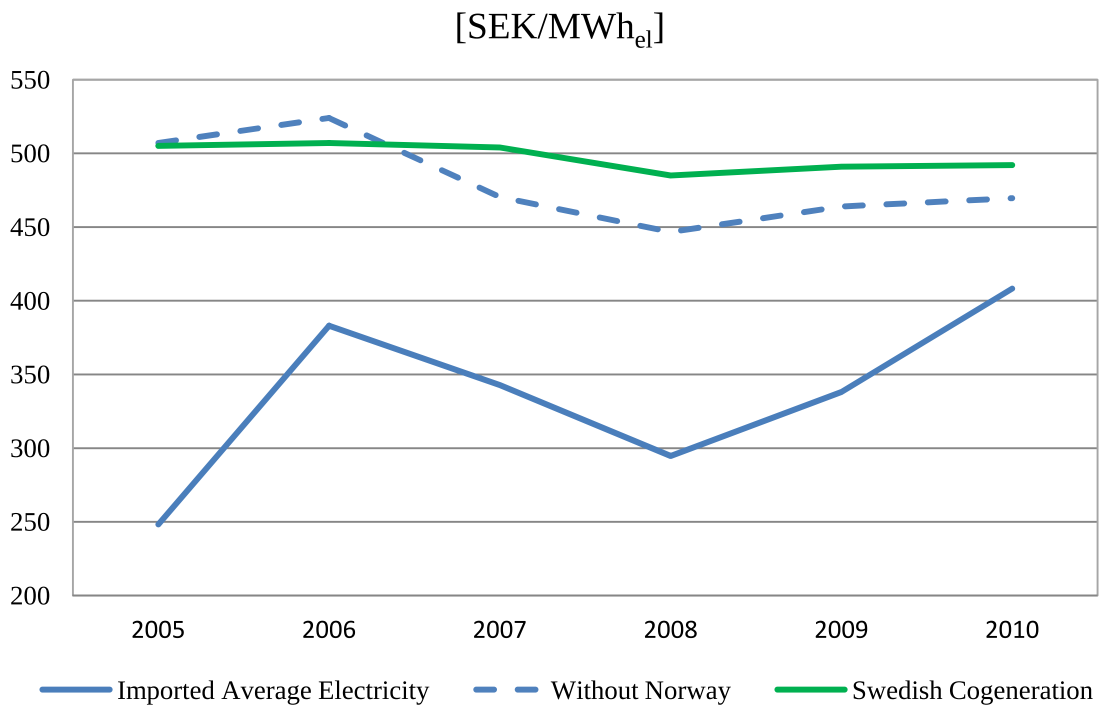


Figure 19. Cost of imported average electricity compared to Swedish cogeneration.

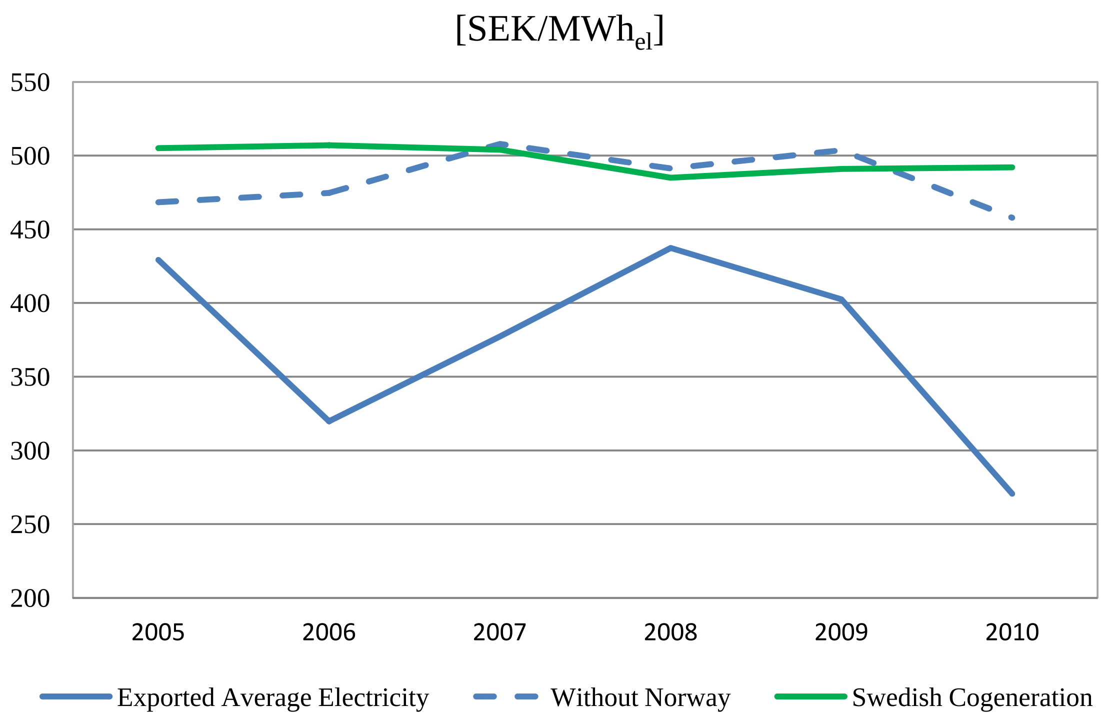


Figure 20. Cost of assumed replaced average electricity by export compared to Swedish cogeneration.

6.2 Rya NGCC CHP and Marginal electricity

If assuming marginal electricity was imported to Sweden during 2005-2010 the CO_2-emission vary a lot depending on which country the electricity was imported from (see Table 20). Rya NGCC CHP always have lower emissions then the marginal emission in other countries due to that natural gas is the fossil fuels with lowest CO_2-emissions.

Norway that only has natural gas as marginal generation still have higher emissions than Rya due to a lower thermal efficiency is estimated in their generation (see Table 21). Sweden's own marginal electricity CO_2-emissions during this period was also significantly higher compared to that of Rya NGCC CHP (see Table 20).

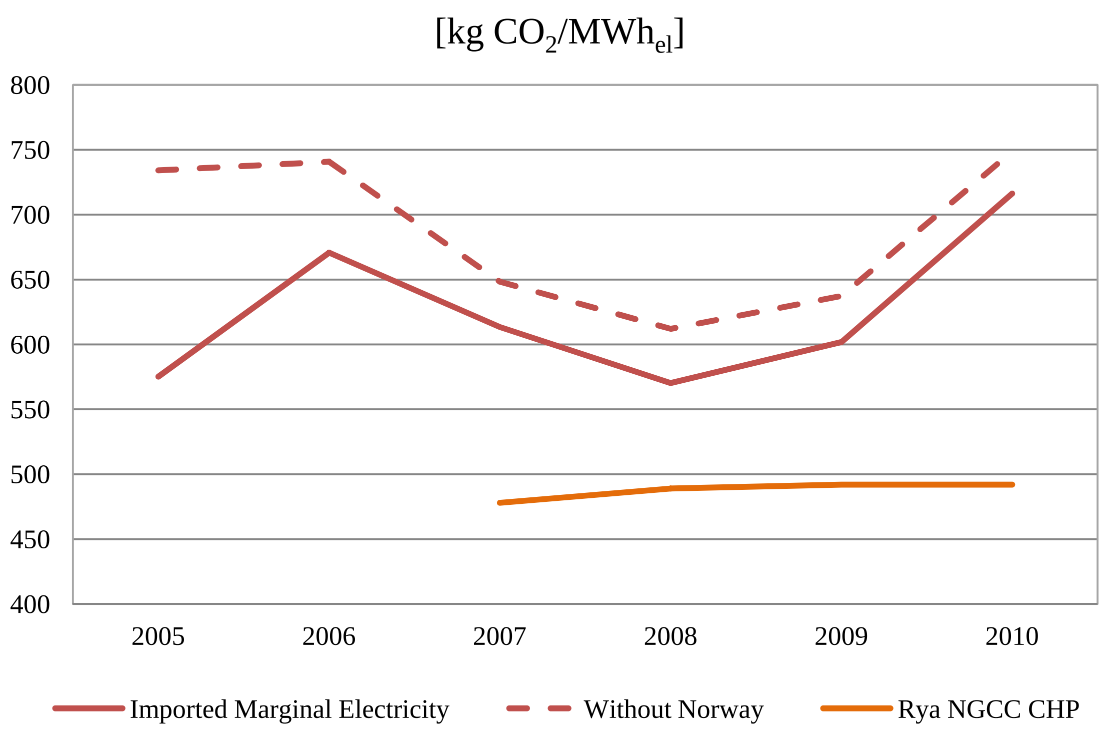


Figure 21. CO_2-emissions from imported marginal electricity compared to Rya NGCC CHP

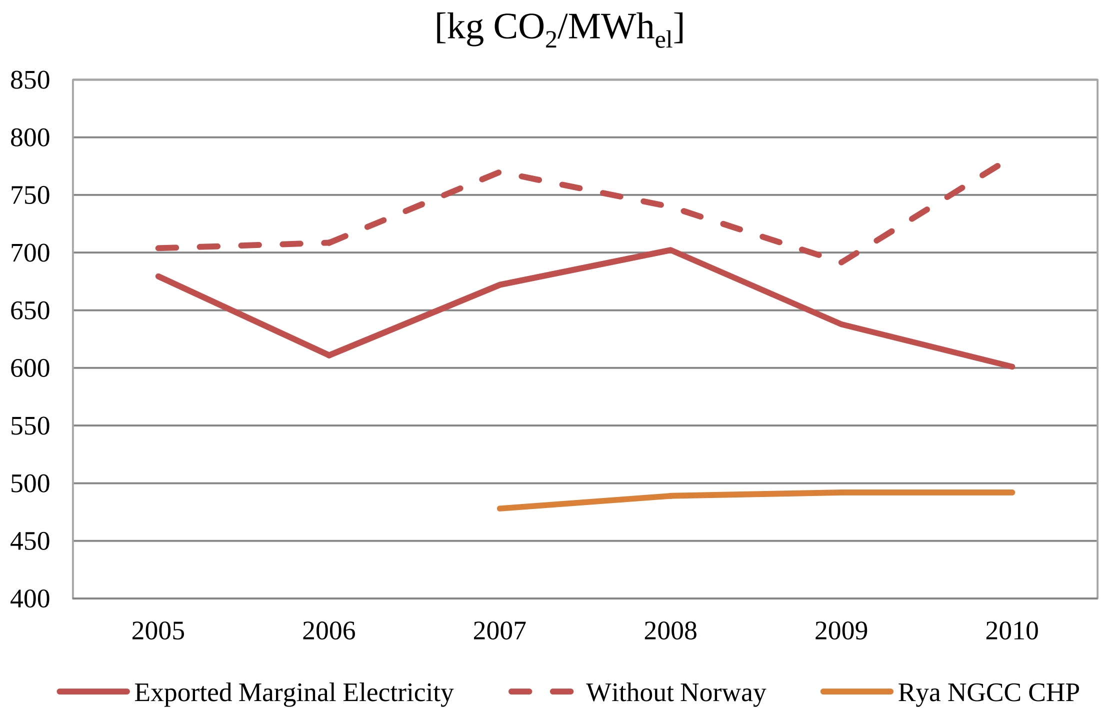


Figure 22. Cost of assumed replaced average electricity by export compared to Rya NGCC CHP.

7. Discussion

A discussion based on the results and conclusions in the report is presented below. The discussion chapter is divided in two sections: Swedish Cogeneration and a discussion of future work than can conduct to achieve better and more accurate results.

It is important when comparing cogeneration with average and marginal electricity to remember that cogeneration also generates heat which is beneficial for the society. This product can also be generated by electricity, but this would most probably lead to higher cost and emissions both for average and marginal electricity.

7.1 Swedish Cogeneration

CO_2-emissions from Swedish cogeneration are higher compared to the North European imported average electricity. This is also true for most of the years when assuming the exported electricity from Sweden replace the average electricity in other countries. But if we present the results without Norway that has almost no CO_2-emissions in their electricity generation the results are very different. Cogeneration now has lower CO_2-emissions when calculating with both imported and by exported replaced electricity. Swedish cogeneration can therefore be assumed to be a better alternative than important electricity from these other countries from an emissions point of view.

The cost of Swedish cogeneration electricity is also higher then importing electricity and replacing exported electricity. Removing Norway displays quite similar cost for Swedish cogeneration and North European imported and replaced electricity from other countries. As cogeneration also generates useful heat it can be assumed that it's a better alternative than the average electricity for all countries except Norwegian electricity. Swedish cogeneration cannot still compete with the cheap and emissions free hydro generated electricity from Norway.

The future (2011-2020) results implies that the average emissions of North European average electricity will decrease more rapidly compared to that of Swedish cogeneration. The estimated average cost of generating this future average electricity will still be higher for these countries. Finland large nuclear investments will decrease the emissions significantly, while Poland increased renewable generation will not lower the average emissions and cost significantly as also the total electricity generation will increase (see Figure 15 and 16).

The efficient Rya NGCC CHP has lower emissions compared to marginal electricity in Northern Europe. The use of natural gas which is the cleanest fossil fuel alternative and the lower average efficiency in the abroad power generation makes Rya a relatively clean facility, especially when considering the high heat demand that exists in Gothenburg's urban area.

7.2 Future Work

When making predictions on future investments in electricity generation one thing is certain, the predictions will always be wrong. Hopefully they will still aid to roughly visualise where the electricity market is headed. The predictions until 2020 assumed in this report is based on country specific energy plan, many on them based on already planned investments. The projected NREAP plan is though needed to closely be followed to make certain every country really follows the plan presented to the Commission.

Electricity generation cost is dependent on a many often country specific parameters. In this report values representing the Swedish electricity generation cost is used; to better estimate the real cost of foreign electricity the electricity market in each North European needs to be analysed more in depth.

The future prices for different fuels, especially fossil fuel needs also to be investigated further as they will affect electricity prices. Also this will help to make predictions on what fossil fuel will enjoy the largest investments during the current decade. Also emissions taxes and future prices on EU ETS and electric certificates need to analysed to better estimate future electricity generation cost.

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Appendix A: Göteborg Energi District Heating Plants and Swedish Cogeneration Annual Emissions.

Table 23. Göteborg Energi's District Heating Generating plants.

Plant Name	Primary Fuel	Monthly Heat Generation (GWh)	Monthly Electricity Generation (GWh)
Angered	Oil	2.78	
Björndammen	Oil	1.60	
Högsbo CHP	Natural Gas	36.0	41.7
Marconi	Oil	0.195	
Rosenlund	Natural Gas	64.0	20.6
Rya CHP	Natural Gas	655.5	569.4
Rya Heat Pump	Electricity	145	
Rya HVC	Natural Gas	41.2	
Sisjön	Natural Gas	1.0	
Sävenäs	Biomass	471.8	

Table 24. Swedish Cogeneration Annual Emissions.

Emissions [kg/MWh]	2005	2006	2007	2008	2009	2010
CO_2	393	378	426	250	346	279
NO_x	0.84	0.92	0.72	0.63	0.62	0.37
SO_x	1.27	1.39	1.13	1.12	1.22	0.86

Appendix B: Northern Europe's Monthly Generation by Source 2005-2010.

Table 25. Monthly electricity generation in Denmark by source in GWh_{el}[16].

MONTH	YEAR	HYDRO	COAL	GAS	OIL	WIND	Tot.	CONSUMPTION
1	**2005**	**4**	**1666**	**988**	**34**	**1076**	**3768**	**14664**
2	2005	3	1692	1004	35	639	3373	14051
3	2005	3	1945	1154	40	586	3728	14789
4	2005	2	1319	782	27	502	2633	11855
5	2005	2	1117	662	23	438	2243	11115
6	2005	1	1233	731	26	462	2452	10035
7	2005	1	983	583	20	305	1892	9176
8	2005	1	1131	671	23	433	2259	10114
9	2005	1	1232	731	25	384	2373	10668
10	2005	1	1352	802	28	450	2632	12259
11	2005	2	1521	902	31	602	3059	13326
12	2005	2	1838	1090	38	738	3706	15283
1	**2006**	**2**	**2812**	**926**	**11**	**512**	**4263**	**16019**
2	2006	3	2676	882	10	385	3956	14303
3	2006	2	3034	1000	12	517	4564	15528
4	2006	2	2184	720	8	499	3413	12282
5	2006	2	1737	572	7	602	2920	11009
6	2006	1	1967	648	8	324	2948	9796
7	2006	1	1887	622	7	193	2709	9213
8	2006	1	2074	683	8	258	3024	9866
9	2006	1	2109	695	8	505	3318	10071
10	2006	2	2343	772	9	501	3627	11687
11	2006	3	2482	818	10	868	4181	12976
12	2006	3	2433	802	9	943	4190	13616
1	**2007**	**5**	**1981**	**739**	**96**	**1225**	**4046**	**12949**
2	2007	3	2302	859	112	679	3955	11863
3	2007	4	1891	705	92	754	3447	12374
4	2007	2	1357	506	66	585	2516	11016
5	2007	2	1321	493	64	427	2307	11108
6	2007	2	1382	515	67	265	2231	10782
7	2007	2	1193	445	58	507	2205	10939
8	2007	2	1310	489	64	434	2299	11192
9	2007	2	1505	561	73	686	2828	11288
10	2007	2	2058	768	100	307	3235	12656
11	2007	2	2404	896	117	711	4130	12772

[16] Table 24-29 : Data provided by ENTSO-E. Grey marked data are estimated values based on total yearly or monthly fossile generation values. 2009 data is missing for Nordic coutries and averaged for previous years

MONTH	YEAR	HYDRO	COAL	GAS	OIL	WIND	Tot.	CONSUMPTION
12	2007	3	2299	857	112	592	3863	13267
1	**2008**	**4**	**1883**	**822**	**103**	**1088**	**3899**	**13452**
2	2008	3	1665	726	91	876	3362	12239
3	2008	4	1528	667	84	808	3089	12546
4	2008	3	1456	635	80	286	2461	11778
5	2008	2	1323	577	73	234	2209	11001
6	2008	1	1225	535	67	553	2381	10953
7	2008	1	1010	440	55	385	1891	11231
8	2008	1	981	428	54	482	1946	11149
9	2008	2	1386	605	76	377	2445	11546
10	2008	2	1809	789	99	687	3386	12379
11	2008	2	2121	925	117	762	3927	12071
12	2008	2	2246	980	123	446	3797	12507
1	**2009**	**3**	**2085**	**869**	**61**	**975**	**3994**	**12118**
2	2009	3	2084	868	62	645	3661	11114
3	2009	3	2100	881	57	666	3707	11687
4	2009	2	1579	661	45	468	2755	9931
5	2009	2	1374	576	42	425	2420	9395
6	2009	1	1452	607	42	401	2503	8844
7	2009	1	1268	522	35	347	2174	8626
8	2009	1	1374	568	37	402	2382	9001
9	2009	2	1558	648	46	488	2741	9267
10	2009	2	1890	783	59	486	3220	10388
11	2009	2	2132	885	69	736	3824	10865
12	2009	2	2204	932	71	680	3889	11644
1	**2010**	**2**	**2085**	**869**	**61**	**762**	**4041**	**3507**
2	2010	2	2084	868	62	517	3769	3112
3	2010	3	2100	881	57	677	3809	3197
4	2010	2	1579	661	45	632	3036	2723
5	2010	2	1374	576	42	607	2570	2742
6	2010	1	1452	607	42	401	1899	2655
7	2010	1	1268	522	35	421	1895	2573
8	2010	1	1374	568	37	539	2006	2683
9	2010	2	1558	648	46	764	2692	2762
10	2010	2	1890	783	59	873	3328	2960
11	2010	3	2132	885	69	896	3560	3180
12	2010	2	2204	932	71	724	4157	3546

Table 26. Monthly electricity generation in Finland by source in GWh_{el}.

MONTH	YEAR	HYDRO	NUCLEAR	COAL	GAS	OIL	BIO	WIND	Tot.	CONSUMPTION
1	**2005**	**1389**	**2002**	**1106**	**1407**	**237**	**680**	**19**	**6840**	**8454**
2	2005	1277	1808	1112	1414	238	683	16	6549	7944
3	2005	1187	2000	1345	1710	288	826	11	7367	8584
4	2005	1050	1923	920	1170	197	565	11	5836	6889
5	2005	1371	1529	616	784	132	379	12	4823	5621
6	2005	1135	1755	251	319	54	154	9	3677	4102
7	2005	772	1915	435	553	93	267	5	4041	5903
8	2005	938	1599	642	817	138	395	12	4540	6552
9	2005	983	1844	648	824	139	398	20	4855	6626
10	2005	1011	1997	882	1121	189	542	21	5763	7391
11	2005	1111	1946	977	1242	209	600	20	6105	7801
12	2005	1235	2015	1239	1575	265	761	11	7101	8644
1	**2006**	**1316**	**2015**	**1954**	**1189**	**218**	**752**	**18**	**7463**	**8975**
2	2006	1162	1809	1925	1172	215	741	7	7031	8366
3	2006	999	2007	2173	1323	243	837	9	7590	8920
4	2006	856	1950	1628	991	182	627	10	6243	7437
5	2006	1305	1519	1323	805	148	510	8	5618	6686
6	2006	1109	1725	1272	774	142	490	12	5525	6292
7	2006	571	1908	1381	841	154	532	11	5398	6320
8	2006	494	1529	1742	1060	195	671	5	5695	6582
9	2006	644	1569	1974	1201	221	760	13	6382	6642
10	2006	713	1973	2116	1288	237	815	12	7153	7639
11	2006	886	1957	2168	1319	242	835	18	7425	8191
12	2006	1287	2021	1774	918	198	845	24	7067	8061
1	**2007**	**1297**	**2030**	**1834**	**1362**	**54**	**944**	**17**	**7539**	**8916**
2	2007	1237	1833	1921	1427	57	989	7	7472	8715
3	2007	1186	2025	1704	1266	50	877	12	7120	8385
4	2007	997	1952	1350	1003	40	695	20	6057	7316
5	2007	1462	1555	1125	835	33	579	13	5602	6992
6	2007	1114	1776	1025	761	30	528	8	5242	6203
7	2007	1111	1975	797	592	23	410	8	4917	6437
8	2007	1088	1770	1094	812	32	563	10	5370	6733
9	2007	968	1623	1432	1063	42	737	20	5885	6863
10	2007	1080	2009	1748	1298	51	900	23	7110	7578
11	2007	1173	1959	1990	1478	59	1024	22	7705	8256
12	2007	1277	1992	1968	1462	58	1013	29	7799	8287
1	**2008**	**1402**	**2001**	**1246**	**1613**	**44**	**850**	**32**	**7189**	**8856**
2	2008	1335	1897	1086	1406	38	741	27	6529	8020
3	2008	1478	2029	1052	1362	37	718	24	6701	8298
4	2008	1392	1957	898	1162	32	613	14	6067	7226
5	2008	1753	1457	715	925	25	488	13	5377	6801
6	2008	1395	1802	670	866	24	457	15	5229	6102

MONTH	YEAR	HYDRO	NUCLEAR	COAL	GAS	OIL	BIO	WIND	Tot.	CONSUMPTION
7	2008	1250	1960	652	844	23	445	12	5187	6239
8	2008	1270	1679	842	1090	30	575	17	5503	6542
9	2008	1261	1433	1051	1360	37	717	16	5875	6646
10	2008	1373	1848	1081	1398	38	737	35	6511	7263
11	2008	1533	1955	1184	1532	42	808	29	7081	7551
12	2008	1446	2019	1128	1459	40	769	29	6889	7502
1	**2009**	**1302**	**2014**	**1618**	**1374**	**124**	**871**	**22**	**7324**	**8897**
2	2009	1192	1835	1564	1331	122	831	15	6889	8253
3	2009	1149	2017	1579	1380	135	860	17	7136	8414
4	2009	1071	1947	1208	1045	99	679	15	6065	7152
5	2009	1475	1481	924	804	74	555	12	5326	6524
6	2009	1196	1746	765	635	55	453	13	4862	5699
7	2009	940	1938	728	651	64	469	12	4803	6168
8	2009	948	1648	959	852	85	590	12	5093	6522
9	2009	958	1612	1216	1029	96	664	18	5593	6635
10	2009	1031	1937	1396	1221	113	776	28	6501	7431
11	2009	1149	1958	1536	1350	121	843	23	6980	7970
12	2009	1279	2016	1593	1350	126	908	24	7296	8298
1	**2010**	**1104**	**2022**	**1949**	**1298**	**65**	**1127**	**24**	**8264**	**9283**
2	2010	947	1826	1776	1237	62	998	20	7483	8220
3	2010	895	2022	1620	1239	58	1041	27	7560	7885
4	2010	1061	1954	1244	900	46	897	20	6640	6892
5	2010	1483	1346	841	671	32	820	16	5553	6518
6	2010	1228	1670	607	452	25	635	20	4825	5795
7	2010	996	1934	374	427	27	690	23	4689	5941
8	2010	949	1661	473	481	31	746	17	4676	6203
9	2010	932	1589	978	696	43	709	23	5393	6400
10	2010	980	1857	1153	997	49	886	47	6469	7284
11	2010	1040	1971	1362	1179	55	947	29	7082	8052
12	2010	1150	2032	1858	1338	70	1150	27	8333	8994

Table 27. Monthly electricity generation in Germany by source in GWh_{el}.

MONTH	YEAR	HYDRO	NUCLEAR	FOSSILE	LIGNITE	COAL	GAS	OIL	RES-E	WIND	Tot.	CONSUMPTION
1	**2005**	**1835**	**15072**	**31026**	**7090**	**11817**	**1376**	**350**	**6574**	**5907**	**54507**	**50927**
2	2005	1744	13483	32703	5135	12455	1956	4744	3995	3328	51925	48766
3	2005	2030	14728	32636	5609	12430	2136	4734	3425	2758	52819	49467
4	2005	2203	13244	29486	5044	11230	1921	4277	2443	1732	47376	45074
5	2005	2470	11350	26930	4323	10257	1646	3906	2326	1615	43076	43240
6	2005	2105	10822	27703	4122	10551	1570	4019	2093	1398	42723	43598
7	2005	2189	11423	28033	4351	10677	1657	4066	2404	1525	44049	43805
8	2005	2111	11848	25710	4512	9792	1719	3729	2398	1519	42067	43010

MONTH	YEAR	HYDRO	NUCLEAR	FOSSILE	LIGNITE	COAL	GAS	OIL	RES-E	WIND	Tot.	CONSUMPTION
9	2005	1868	12357	25755	4706	9809	1792	3736	2479	1601	42459	43081
10	2005	1778	13422	29174	5112	11111	1947	4232	3253	2337	47627	46034
11	2005	1546	12749	33481	5998	12752	1164	377	3218	2302	50994	49063
12	2005	1707	14033	34936	6602	13306	1281	394	3774	2859	54450	50306
1	**2006**	**1644**	**15228**	**35742**	**12960**	**13687**	**2757**	**366**	**4481**	**3677**	**57095**	**52891**
2	2006	1596	13773	34905	11523	13366	2452	357	3007	2203	53281	49124
3	2006	1955	14559	35223	12788	13488	2721	360	3596	2701	55333	51141
4	2006	2311	13467	27785	10823	10640	2303	284	3151	2152	46714	44741
5	2006	2476	11702	25963	11082	9942	2358	266	4007	3008	44148	43565
6	2006	2255	12639	27193	10513	10413	2237	278	2133	1130	44220	43178
7	2006	1981	12731	28632	10165	10964	2163	293	1990	929	45334	45224
8	2006	2236	12444	26089	10333	9990	2198	267	3164	1943	43933	43645
9	2006	1959	13273	25565	10525	9790	2239	261	3348	2173	44145	42926
10	2006	1934	13593	28275	11477	10827	2442	289	4870	3172	48672	45998
11	2006	1801	12129	31737	12078	12153	2570	325	5983	4477	51650	48617
12	2006	1849	13187	32017	12649	12260	2691	327	6234	4730	53287	48028
1	**2007**	**1940**	**13193**	**32990**	**11789**	**13182**	**2548**	**317**	**8975**	**7512**	**57098**	**52511**
2	2007	1804	12199	32081	11268	12819	2435	308	4759	3328	50843	47759
3	2007	1968	12925	33225	12413	13276	2682	319	5805	4254	53923	50293
4	2007	1644	11189	29614	10749	11833	2323	285	4203	2491	46650	44479
5	2007	1980	11120	26731	11093	10681	2397	257	4172	2455	44003	43023
6	2007	2232	10535	28006	11049	11191	2388	269	3792	1964	44565	44017
7	2007	2503	9318	28653	11915	11449	2575	275	4915	2991	45389	45204
8	2007	2255	9393	28833	12174	11521	2631	277	3828	1825	44309	44619
9	2007	2181	9628	26861	10875	10733	2350	258	5012	3043	43682	42259
10	2007	1897	10565	32748	11552	13085	2496	315	3423	1596	48633	46728
11	2007	1906	10941	33398	12405	13345	2681	321	5776	3996	52021	47942
12	2007	2051	12197	32831	12294	13119	2657	316	5794	4080	52873	47065
1	**2008**	**2017**	**12303**	**34159**	**12157**	**12925**	**2980**	**334**	**8453**	**6563**	**56932**	**52096**
2	2008	1772	12433	33498	10906	12675	2673	328	6202	4304	53905	49868
3	2008	2144	13178	30841	12413	11670	3043	302	7718	5532	53881	48947
4	2008	2134	11637	31656	11531	11978	2827	310	4160	2026	49587	46639
5	2008	2261	11320	26658	11527	10087	2826	261	4004	1648	44243	43024
6	2008	2217	10172	27021	10495	10224	2573	264	4323	2032	43733	44131
7	2008	2251	10341	28749	11234	10878	2754	281	4493	2256	45834	46350
8	2008	2081	12100	25496	11374	9647	2788	249	5184	2881	44861	44225
9	2008	1635	11432	27544	10873	10422	2665	269	4341	2131	44952	43347
10	2008	1669	11394	31415	12301	11887	3015	307	5766	3544	50244	46525
11	2008	1560	11971	30001	11346	11352	2781	293	6411	4385	49943	46428
12	2008	1732	12793	29328	11970	11097	2934	287	5315	3127	49168	45582
1	**2009**	**1456**	**12605**	**34472**	**12319**	**11378**	**2653**	**398**	**5510**	**3352**	**54043**	**50809**
2	2009	1316	11152	30777	11133	10158	2397	355	5245	3203	48490	46262
3	2009	1789	11096	29427	11719	9713	2524	340	6248	3762	48560	47275

MONTH	YEAR	HYDRO	NUCLEAR	FOSSILE	LIGNITE	COAL	GAS	OIL	RES-E	WIND	Tot.	CONSUMPTION
4	2009	2092	10494	23882	9758	7883	2101	276	4818	2180	41286	40235
5	2009	2229	10092	21995	10203	7260	2197	254	5756	2962	40072	40590
6	2009	2074	9496	25663	9053	8470	1949	296	5567	2800	42800	41487
7	2009	2243	8941	26653	8421	8797	1813	308	5386	2576	43223	42671
8	2009	1848	10406	23589	9531	7786	2052	272	4852	1986	40695	40172
9	2009	1577	9830	25378	8140	8376	1753	293	5383	2675	42168	40653
10	2009	1469	10089	29816	9614	9841	2070	344	6253	3588	47627	45411
11	2009	1528	11410	28565	11211	9428	2414	330	7915	5418	49418	45454
12	2009	1832	12342	30001	9612	9902	2070	346	5814	3310	49989	45846
1	**2010**	**1574**	**12546**	**35871**	**12585**	**11837**	**2769**	**355**	**5507**	**3114**	**55498**	**51096**
2	2010	1472	11141	33672	11470	11112	2523	333	5960	3507	52245	48572
3	2010	1715	11679	30940	11023	10210	2425	306	7328	4345	51662	48685
4	2010	1648	10133	27053	10528	8927	2316	268	6260	2974	45094	42082
5	2010	1787	10667	25581	10813	8442	2379	253	6028	2564	44063	42788
6	2010	2058	9125	27520	10775	9082	2371	272	5220	1794	43923	44736
7	2010	1916	10831	26802	11032	8845	2427	265	5453	1650	45002	44225
8	2010	2034	11507	23037	9567	7602	2105	228	6027	2458	42605	42872
9	2010	1911	11392	23224	9597	7664	2111	230	6141	2884	42668	41299
10	2010	1857	9784	30482	11084	10059	2438	302	7010	3734	49133	46749
11	2010	1777	11566	29655	9752	9786	2145	294	6504	3835	49502	46869
12	2010	1949	13002	30441	11793	10046	2594	301	6363	3806	51755	48246

Table 28. Monthly electricity generation in Norway by source in GWh_{el}.

MONTH	YEAR	HYDRO	GAS	WIND	PRODUCTION	CONSUMPTION
1	**2005**	**13257**	**99**	**46**	**13402**	**12736**
2	2005	13278	69	35	13382	11823
3	2005	13540	80	24	13644	12460
4	2005	10784	61	29	10874	10278
5	2005	9828	82	31	9941	9591
6	2005	9489	79	39	9607	8753
7	2005	9090	76	23	9189	8116
8	2005	9301	70	42	9413	8396
9	2005	9463	74	66	9603	8977
10	2005	11153	92	50	11295	10240
11	2005	12942	96	59	13097	11363
12	2005	14340	98	63	14501	13175
1	**2006**	**14639**	**99**	**77**	**14815**	**13521**
2	2006	13065	94	48	13207	12085
3	2006	13497	87	40	13624	13178
4	2006	9449	92	43	9584	10445
5	2006	7840	76	41	7957	9235
6	2006	8402	95	44	8541	8186

MONTH	YEAR	HYDRO	GAS	WIND	PRODUCTION	CONSUMPTION
7	2006	7865	102	38	8005	7560
8	2006	8281	99	24	8404	7890
9	2006	7796	83	47	7926	8032
10	2006	8447	78	64	8589	9644
11	2006	10021	109	89	10219	11040
12	2006	10617	109	118	10844	11756
1	**2007**	**12306**	**100**	**87**	**12493**	**12831**
2	2007	12717	96	61	12874	12278
3	2007	11236	103	88	11427	11662
4	2007	10009	95	96	10200	10187
5	2007	10274	68	60	10402	9646
6	2007	9777	82	45	9904	8563
7	2007	10224	106	45	10375	8416
8	2007	11094	94	47	11235	8641
9	2007	11346	166	90	11602	9327
10	2007	11414	144	91	11649	10649
11	2007	12056	171	96	12323	12059
12	2007	12590	218	95	12903	13092
1	**2008**	**13422**	**126**	**94**	**13642**	**13162**
2	2008	12751	92	106	12949	11985
3	2008	13449	101	76	13626	12486
4	2008	11144	102	53	11299	10789
5	2008	10454	93	44	10591	9703
6	2008	10599	103	48	10750	9002
7	2008	10273	100	50	10423	8473
8	2008	10023	97	40	10160	8519
9	2008	10146	96	61	10303	9101
10	2008	11660	88	122	11870	10698
11	2008	12658	82	116	12856	11906
12	2008	14084	67	107	14258	13027
1	**2009**	**13576**	**180**	**80**	**13836**	**13435**
2	2009	12776	161	63	13001	12247
3	2009	12455	184	46	12684	12442
4	2009	9892	175	57	10123	10367
5	2009	9063	156	44	9262	9446
6	2009	8923	168	47	9138	8531
7	2009	8951	177	44	9172	8020
8	2009	9214	140	42	9396	8271
9	2009	9458	128	63	9650	8808
10	2009	10714	126	89	10929	10355
11	2009	11853	180	90	12123	11800
12	2009	13000	218	97	13314	13173
1	**2010**	**14256**	**477**	**94**	**14827**	**14925**

MONTH	YEAR	HYDRO	GAS	WIND	PRODUCTION	CONSUMPTION
2	2010	12071	455	65	12591	13063
3	2010	10554	547	0	11185	12425
4	2010	8072	519	66	8657	10136
5	2010	6918	459	43	7420	9056
6	2010	6348	481	59	6888	8152
7	2010	7303	499	64	7866	7536
8	2010	7373	339	56	7768	7911
9	2010	8540	223	51	8814	8601
10	2010	10895	228	119	11242	10542
11	2010	11589	441	91	12121	12631
12	2010	13367	599	100	14066	14814

Table 29. Monthly electricity generation in Poland by source in GWh_{el}.

MONTH	YEAR	HYDRO	FOSSILE	LIGNITE	COAL	GAS	RES-E	WIND	Tot.	CONSUMPTION
1	**2005**	**312**	**12513**	**4005**	**8152**	**355**	**22**	**15**	**12847**	**12115**
2	2005	258	11797	3741	7692	365	16	10	12071	11187
3	2005	362	12670	4189	8123	358	25	17	13057	11775
4	2005	423	11163	3697	7086	381	18	11	11604	10337
5	2005	355	10719	3900	6427	392	16	9	11090	9980
6	2005	301	10204	3823	6004	376	16	8	10521	9599
7	2005	260	10511	3736	6640	135	21	13	10792	9831
8	2005	320	10414	3829	6391	195	14	6	10748	9994
9	2005	234	11077	3892	7009	177	14	6	11325	10211
10	2005	236	12407	3990	8046	371	18	10	12661	11252
11	2005	224	12937	4013	8495	430	23	14	13184	11735
12	2005	265	13770	4501	8824	445	21	13	14056	12596
1	**2006**	**266**	**14558**	**4660**	**9484**	**413**	**18**	**12**	**14842**	**13314**
2	2006	244	12672	4019	8262	392	21	15	12937	11569
3	2006	286	13455	4449	8626	380	25	18	13766	12408
4	2006	396	11614	3846	7372	396	25	18	12035	10644
5	2006	237	10862	3952	6513	397	31	23	11130	10339
6	2006	236	10761	4032	6332	397	15	9	11012	10180
7	2006	157	10910	3878	6892	140	17	9	11084	10560
8	2006	206	10975	4035	6735	205	23	15	11204	10530
9	2006	213	11547	4057	7306	184	32	23	11792	10724
10	2006	151	12421	3995	8055	371	19	11	12591	11626
11	2006	205	12741	3952	8366	423	46	38	12992	12024
12	2006	197	13220	4321	8472	427	54	43	13471	12580
1	**2007**	**249**	**13175**	**4434**	**8314**	**427**	**73**	**65**	**13497**	**12949**
2	2007	286	12253	3872	7993	387	46	37	12585	11863
3	2007	315	12277	3880	7989	408	48	39	12640	12374
4	2007	198	10985	3506	7095	383	44	36	11227	11016

MONTH	YEAR	HYDRO	FOSSILE	LIGNITE	COAL	GAS	RES-E	WIND	Tot.	CONSUMPTION
5	2007	156	11117	3669	7278	170	29	21	11302	11108
6	2007	168	10839	3731	6906	202	31	22	11038	10782
7	2007	146	11033	3945	6985	103	41	32	11220	10939
8	2007	148	11261	3961	7112	188	42	31	11451	11192
9	2007	230	11722	3891	7572	258	52	41	12004	11288
10	2007	232	13311	4047	8863	400	44	31	13587	12656
11	2007	262	13319	4064	8839	416	102	92	13683	12772
12	2007	294	13836	4510	8886	440	70	59	14200	13267
1	**2008**	**241**	**13390**	**4224**	**8728**	**439**	**112**	**102**	**13743**	**13452**
2	2008	236	12099	3842	7839	418	100	89	12435	12239
3	2008	294	12161	3758	7966	437	94	81	12549	12546
4	2008	269	11501	4018	7077	406	47	35	11817	11778
5	2008	247	10720	4026	6455	239	39	27	11006	11001
6	2008	166	10927	3976	6777	174	55	43	11148	10953
7	2008	202	11051	4175	6803	73	46	34	11299	11231
8	2008	195	11023	4130	6795	97	62	48	11280	11149
9	2008	175	11373	4380	6700	293	48	34	11596	11546
10	2008	228	12129	4518	7192	420	113	99	12470	12379
11	2008	188	11899	4240	7242	417	138	124	12225	12071
12	2008	227	12539	4362	7729	448	94	80	12860	12507
1	**2009**	**188**	**13082**	**4442**	**8192**	**447**	**100**	**88**	**13370**	**13009**
2	2009	224	11540	3857	7278	405	90	74	11854	11526
3	2009	320	12302	3985	7889	429	100	83	12722	12199
4	2009	317	10389	3631	6358	400	75	60	10781	10484
5	2009	203	9657	3696	5693	268	92	77	9952	9923
6	2009	245	10015	3729	6076	209	97	79	10357	10243
7	2009	262	10456	4066	6329	60	82	65	10800	10727
8	2009	198	10491	3908	6442	141	97	79	10786	10689
9	2009	165	10847	3959	6630	257	108	89	11120	10893
10	2009	228	12237	3746	8058	434	128	109	12593	12260
11	2009	290	11908	3873	7620	415	174	154	12372	12033
12	2009	257	12835	4061	8315	458	116	94	13208	12830
1	**2010**	**259**	**13276**	**3984**	**8785**	**508**	**134**	**116**	**13669**	**13402**
2	2010	193	11985	3787	7749	449	120	102	12298	11898
3	2010	313	12340	4174	7763	403	178	157	12831	12617
4	2010	307	10626	3623	6644	358	147	126	11080	11082
5	2010	334	10730	3547	7004	179	144	121	11208	11297
6	2010	313	10573	3656	6704	213	125	101	11011	10851
7	2010	266	11007	4005	6799	203	121	100	11394	11369
8	2010	293	10770	3812	6776	182	148	126	11211	11210
9	2010	307	11105	3670	7143	292	227	203	11639	11402
10	2010	262	12319	3816	8056	447	255	231	12836	12477
11	2010	255	12094	3743	7928	423	242	221	12591	12280

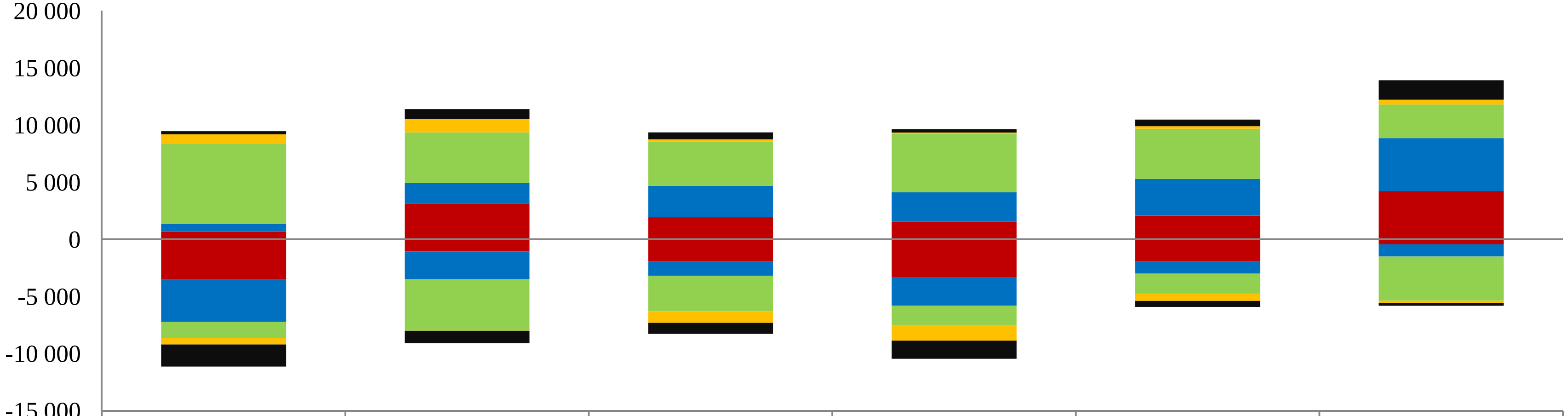
12	2010	303	13445	3734	9334	377	240	217	13988	13679

Table 30. Monthly electricity generation in Sweden by source in GWh_{el}.

MONTH	YEAR	HYDRO	NUCLEAR	COAL	GAS	OIL	BIO	WIND	PRODUCTION	CONSUMPTION
1	**2005**	**7036**	**6900**	**433**	**236**	**512**	**276**	**143**	**15537**	**14664**
2	2005	6568	6062	435	237	514	277	93	14185	14051
3	2005	6296	6239	440	240	520	280	65	14079	14789
4	2005	5293	5978	327	178	386	208	68	12439	11855
5	2005	5675	5145	270	147	319	172	53	11780	11115
6	2005	5320	4752	194	106	230	124	57	10783	10035
7	2005	4660	5506	166	91	196	106	42	10767	9176
8	2005	5990	4677	167	91	197	106	59	11287	10114
9	2005	5956	5617	174	95	206	111	72	12231	10668
10	2005	6011	5963	249	136	294	158	83	12893	12259
11	2005	6290	6244	329	180	389	210	103	13745	13326
12	2005	7048	6377	441	241	522	281	93	15003	15283
1	**2006**	**7115**	**6592**	**432**	**389**	**518**	**302**	**90**	**15438**	**16019**
2	2006	6199	5994	385	347	462	270	66	13723	14303
3	2006	6189	6615	431	387	517	301	70	14510	15528
4	2006	4637	6382	309	278	371	216	72	12266	12282
5	2006	5239	6038	208	187	249	146	79	12146	11009
6	2006	3863	4571	158	142	189	111	54	9088	9796
7	2006	3023	5173	157	141	188	110	40	8832	9213
8	2006	3697	3504	166	149	199	116	41	7871	9866
9	2006	4055	3420	190	171	228	133	82	8279	10071
10	2006	4733	5418	277	249	332	194	91	11294	11687
11	2006	5681	5546	385	347	462	270	129	12820	12976
12	2006	6745	5730	368	344	442	245	173	14047	13616
1	**2007**	**7286**	**6308**	**365**	**487**	**325**	**406**	**184**	**15362**	**12949**
2	2007	7096	4495	371	495	330	412	109	13308	11863
3	2007	6742	6176	315	420	280	350	125	14407	12374
4	2007	5830	6244	270	360	240	300	113	13356	11016
5	2007	5817	5758	222	296	197	246	85	12620	11108
6	2007	5193	4177	167	223	149	186	64	10158	10782
7	2007	4290	4705	157	210	140	175	100	9778	10939
8	2007	4684	4203	141	189	126	157	91	9592	11192
9	2007	3946	4264	158	210	140	175	136	9028	11288
10	2007	4265	5705	262	350	233	291	94	11200	12656
11	2007	4962	5873	370	493	329	411	155	12592	12772
12	2007	5418	6371	397	530	353	442	174	13686	13267
1	**2008**	**7149**	**6593**	**292**	**535**	**292**	**535**	**277**	**15675**	**13452**
2	2008	6832	5839	265	486	265	486	231	14405	12239

MONTH	YEAR	HYDRO	NUCLEAR	COAL	GAS	OIL	BIO	WIND	PRODUCTION	CONSUMPTION
3	2008	6763	6547	267	490	267	490	197	15021	12546
4	2008	5849	6445	212	389	212	389	93	13590	11778
5	2008	6472	5066	167	307	167	307	63	12550	11001
6	2008	5364	3650	135	248	135	248	129	9909	10953
7	2008	4129	4741	127	233	127	233	85	9675	11231
8	2008	4104	4417	122	224	122	224	145	9358	11149
9	2008	4495	4978	166	305	166	305	122	10537	11546
10	2008	5245	4709	214	392	214	392	259	11424	12379
11	2008	5705	4076	271	497	271	497	247	11564	12071
12	2008	6321	4205	289	530	289	530	148	12311	12507
1	**2009**	**7172**	**6213**	**331**	**441**	**386**	**574**	**190**	**15305**	**14661**
2	2009	6595	5256	316	417	370	529	140	13624	13333
3	2009	6179	6133	316	409	337	545	147	14065	13829
4	2009	5081	6114	242	317	246	435	117	12552	11620
5	2009	5760	5541	182	228	190	347	99	12348	10973
6	2009	5020	4446	132	186	143	275	98	10302	10243
7	2009	4212	4910	121	181	133	245	101	9904	9924
8	2009	4750	4284	119	132	129	241	113	9768	10397
9	2009	4638	4327	138	161	189	292	148	9893	10770
10	2009	5208	4932	210	231	289	401	197	11467	12214
11	2009	5754	5278	294	403	311	511	220	12773	12981
12	2009	6330	5688	337	411	386	567	194	13912	14225
1	**2010**	**7273**	**4670**	**132**	**555**	**282**	**1349**	**253**	**14687**	**16221**
2	2010	6277	3891	125	522	281	1201	200	12651	14209
3	2010	4904	5088	126	506	100	1306	280	12480	13909
4	2010	3795	5522	92	380	19	1059	240	11241	11169
5	2010	5597	5699	44	204	16	867	216	12785	10631
6	2010	5362	5082	4	213	14	707	188	11707	9647
7	2010	4957	4427	0	230	13	600	240	10557	9062
8	2010	5274	4619	1	9	2	601	227	10792	9662
9	2010	4739	3356	0	25	204	738	328	9508	10278
10	2010	5786	2864	48	27	370	972	458	10666	12090
11	2010	6133	4653	116	500	101	1170	469	13285	13762
12	2010	6118	5755	189	410	326	1337	380	14671	16450

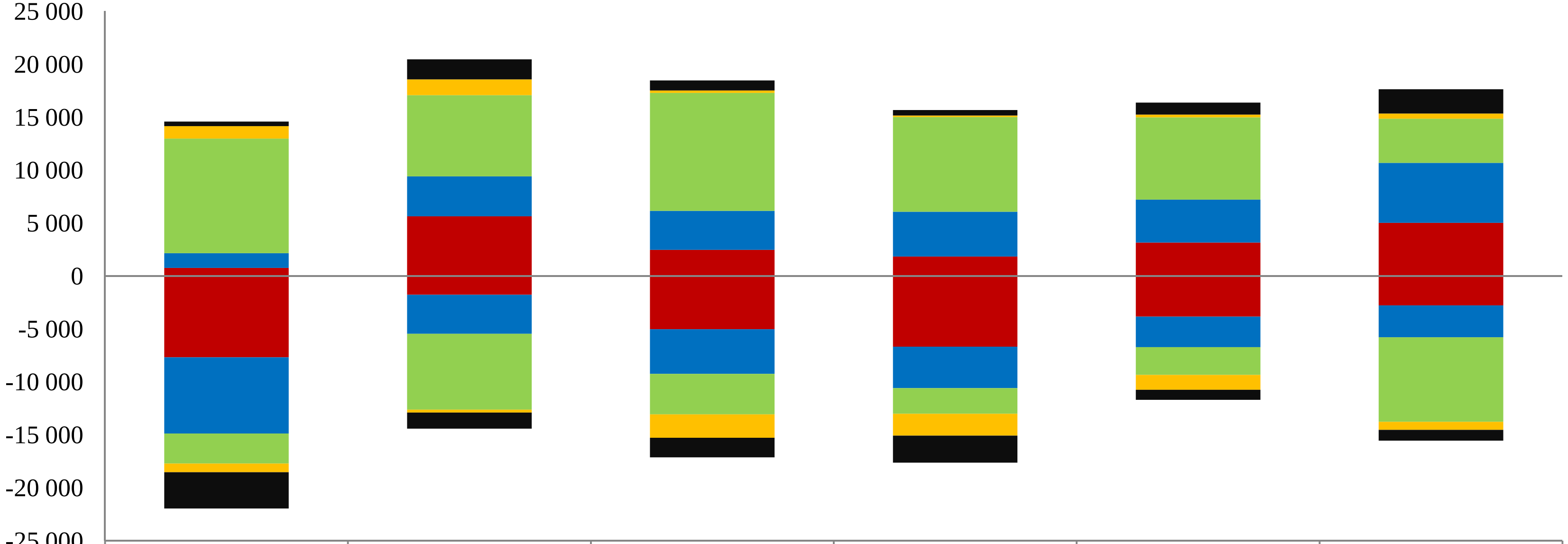
Appendix C: Annual Winter (October-April) Import and Export to and from Sweden (2005-2010).



	2005	2006	2007	2008	2009	2010
> Germany	270	842	602	288	578	1 700
< Germany	-1 931	-1 101	-968	-1 587	-521	-211
> Poland	787	1 196	207	92	223	436
< Poland	-566	-13	-1 001	-1 358	-636	-219
> Norway	7 063	4 427	3 871	5 133	4 395	2 934
< Norway	-1 406	-4 486	-3 123	-1 707	-1 756	-3 875
> Finland	664	1 800	2 744	2 550	3 200	4 623
< Finland	-3 754	-2 436	-1 274	-2 449	-1 089	-1 070
> Denmark	688	3 139	1 943	1 577	2 093	4 243
< Denmark	-3 469	-1 052	-1 897	-3 336	-1 896	-421

Figure 23. Winter import/export of GWh_{el} to (+) and from (-) Sweden (October-April).

Appendix D: Annual Import and Export from and to Sweden (2005-2010).



	2005	2006	2007	2008	2009	2010
> Germany	423	1 896	936	518	1 132	2 290
< Germany	-3 433	-1 518	-1 858	-2 546	-949	-1 014
> Poland	1 182	1 498	230	145	254	494
< Poland	-817	-264	-2 211	-2 065	-1 394	-760
> Norway	10 816	7 667	11 144	8 945	7 764	4 174
< Norway	-2 835	-7 177	-3 826	-2 426	-2 633	-7 996
< Finland	1 393	3 769	3 690	4 220	4 068	5 664
> Finland	-7 194	-3 676	-4 213	-3 907	-2 882	-3 012
> Denmark	761	5 637	2 462	1 841	3 150	5 014
< Denmark	-7 690	-1 782	-5 029	-6 685	-3 838	-2 775

Figure 24. *Annual* import/export of electricity to (+) and from (-) in

Appendix E: Monthly CO_2-emissions for Average Electricity in Northern Europe (2005-2010).

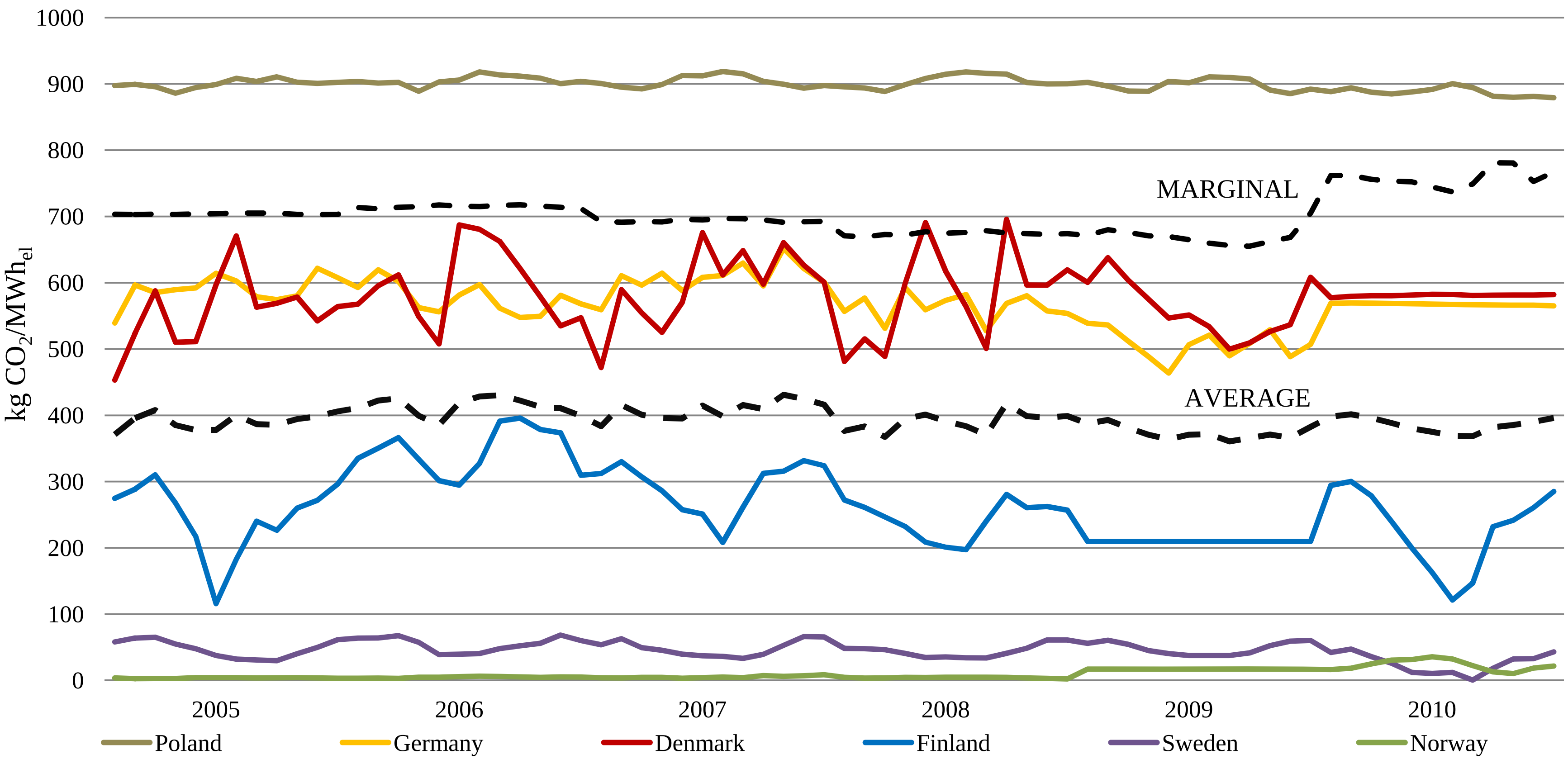


Figure 25. Monthly average CO_2-emissions per MWh_{el} in Northern Europe (2005-2010).

Appendix F: Historic Cost and Emissions of North European Marginal Electricity (2005-2010).

Table 31. Estimated historic price of North European marginal electricity.

Year/Country (SEK/MWh)	2005	2006	2007	2008	2009	2010
Denmark	646	661	694	692	673	673
Finland	650	646	647	650	648	647
Germany	642	485	490	485	475	478
Norway	658	658	658	658	658	658
Poland	640	640	639	640	640	640
Sweden	646	661	694	692	673	673

Table 32. Marginal electricity annual CO_2-emissions.

Country (kg CO_2/MWh)	2005	2006	2007	2008	2009	2010
Denmark	736	785	777	766	766	724
Finland	54	601	560	520	556	556
Germany	878	859	860	853	845	849
Norway	511	511	511	511	511	511
Poland	925	925	924	927	926	922
Sweden	586	570	501	442	525	525

Table 33. Marginal electricity annual SO_x-emissions.

Country (kg SO_x/MWh)	2005	2006	2007	2008	2009	2010
Denmark	0.73	0.89	0.88	0.83	0.86	0.85
Finland	0.26	0.47	0.37	0.25	0.25	0.29
Germany	0.91	0.88	0.93	0.84	0.76	0.86
Norway	0	0	0	0	0	0
Poland	1.56	1.57	1.57	1.57	1.56	1.54
Sweden	0.06	0.07	0.05	0.04	0.06	0.02

Appendix G: Historic and Future Projected Electricity Generation in Northern Europe (2005-2020)

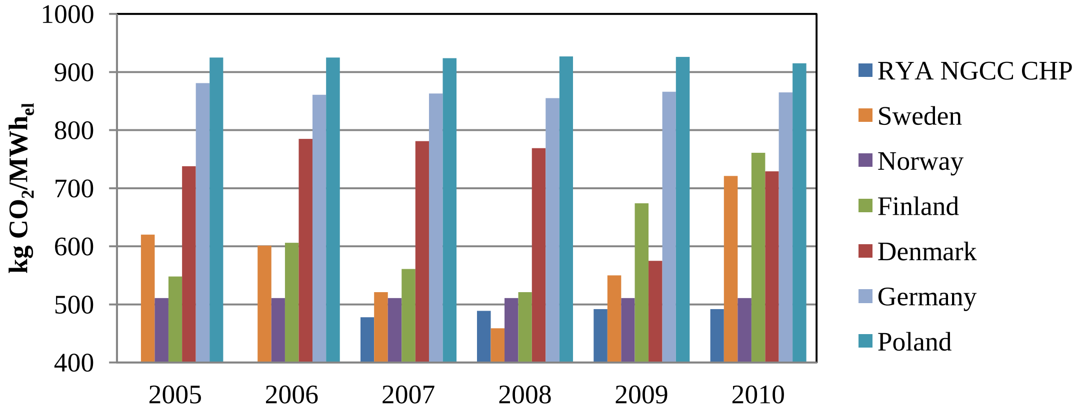


Figure 26. Northern European marginal electricity CO_2-emissions compared with Rya.

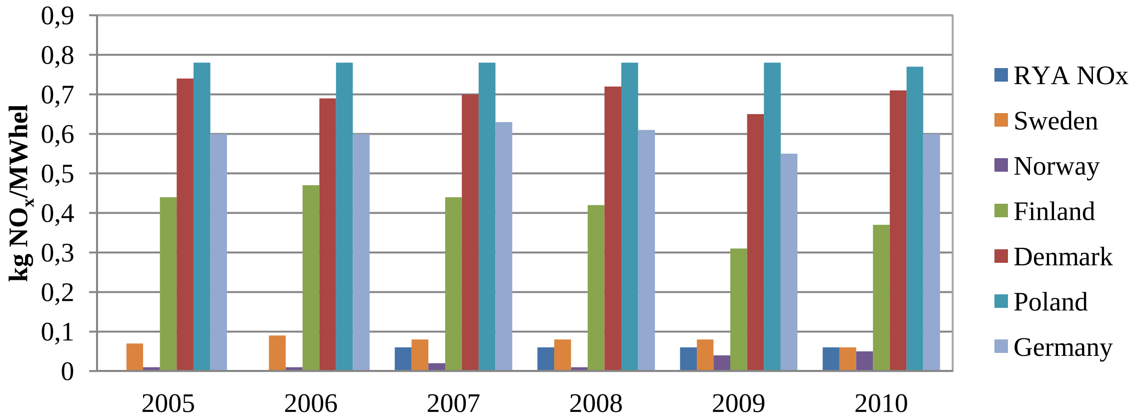


Figure 27. Northern European marginal electricity NO_x-emissions compared with Rya.

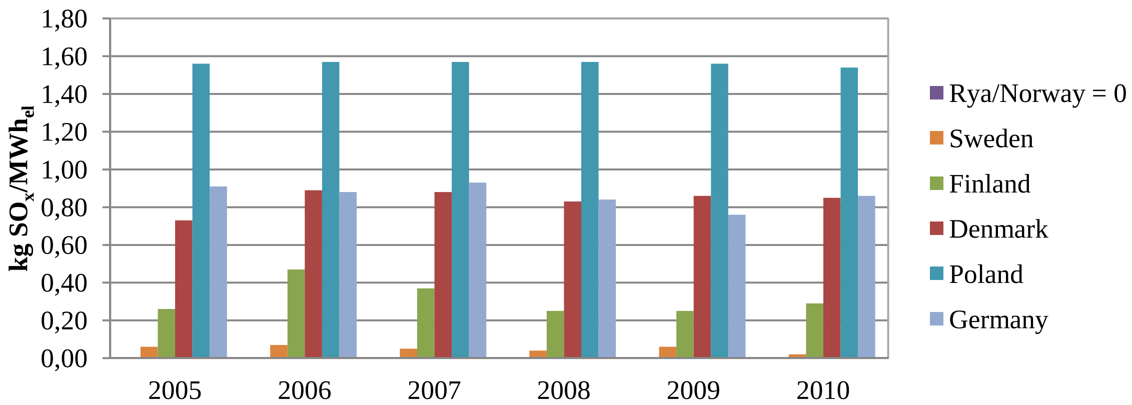


Figure 28. Northern European marginal electricity SO_x-emissions compared with Rya.

Appendix H: Historic and Future Projected Electricity Generation in Northern Europe (2005-2020).

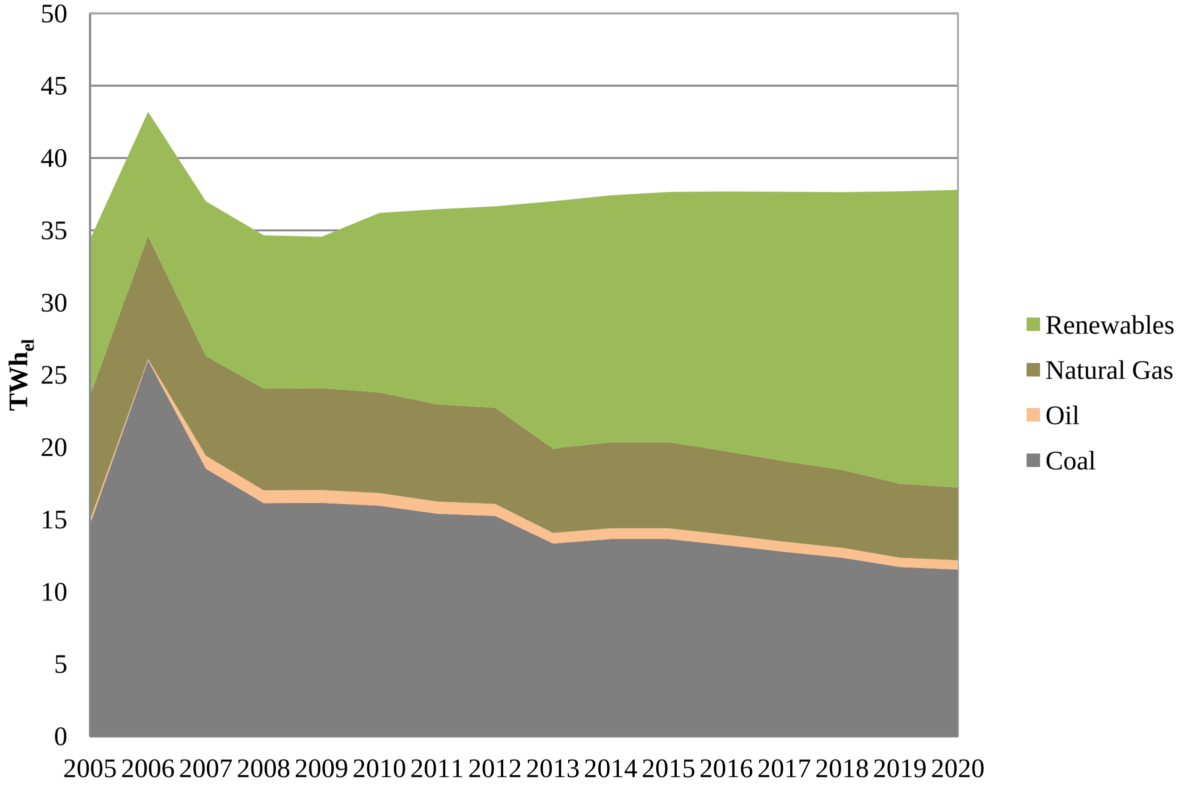


Figure 29. Denmark - electricity generation by source (2005-2020).

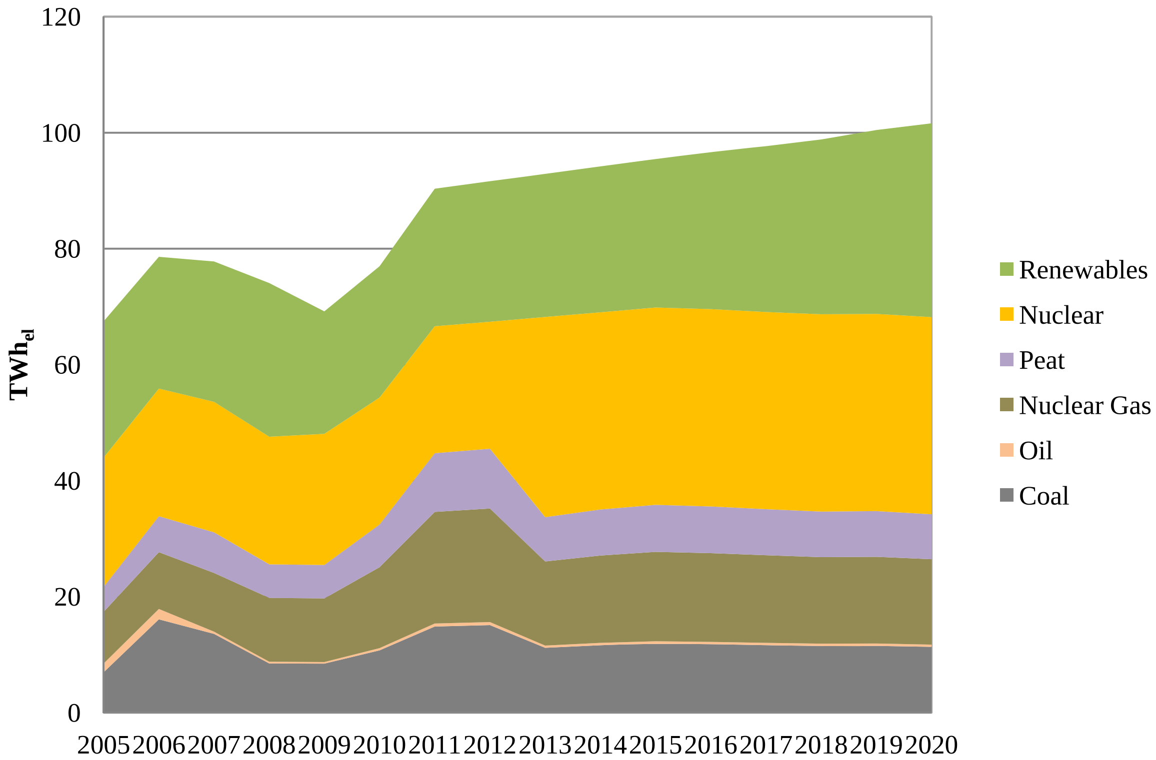


Figure 30. Finland - electricity generation by source (2005-2020).

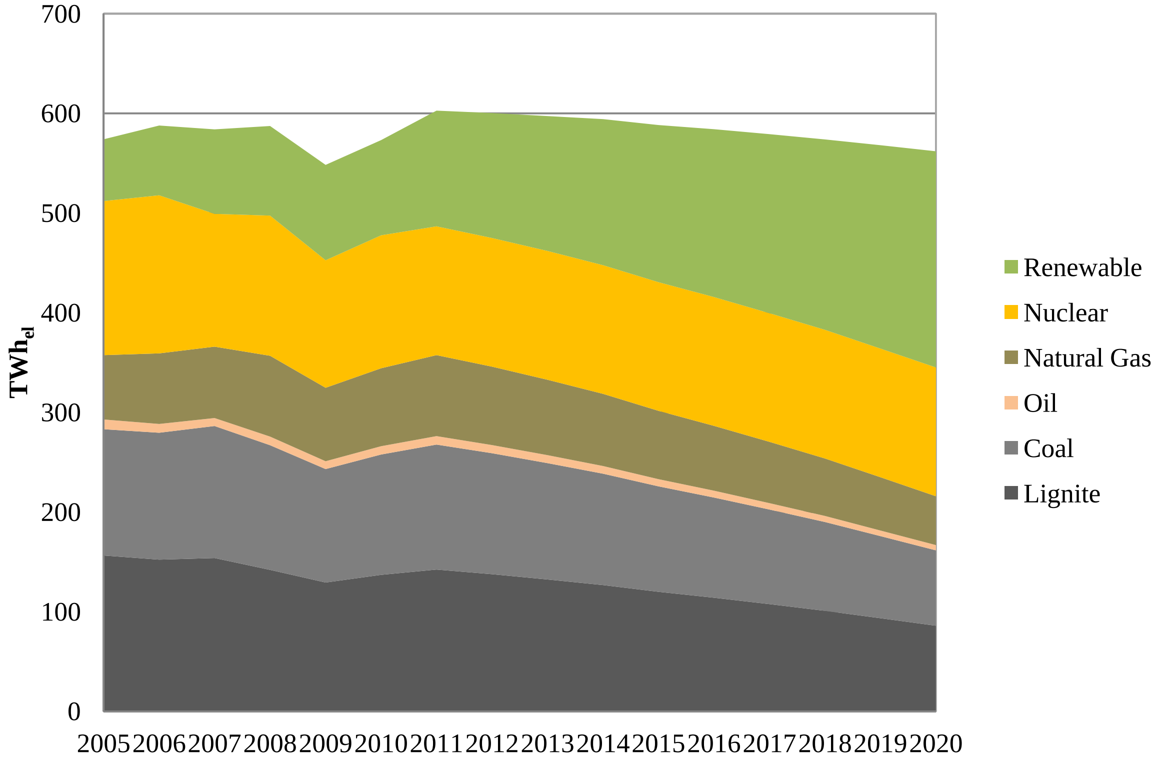


Figure 31. Germany - electricity generation by source (2005-2020).

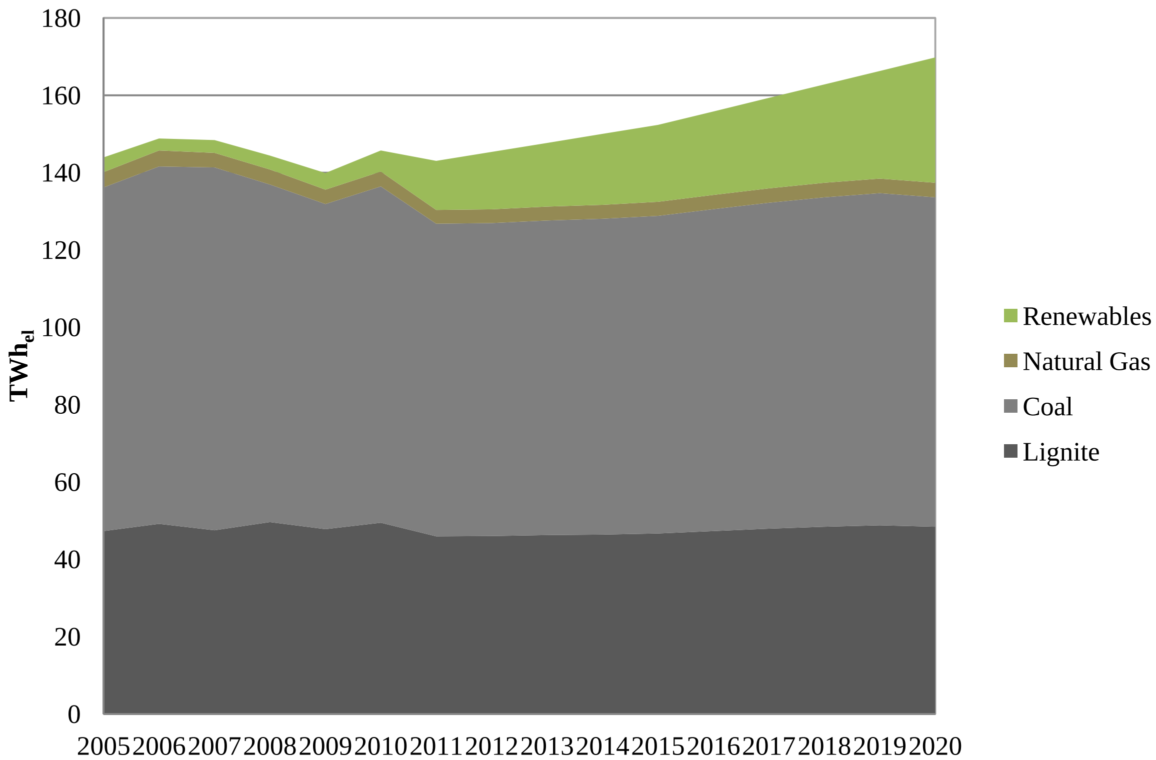


Figure 32. Poland - electricity generation by source (2005-2020).

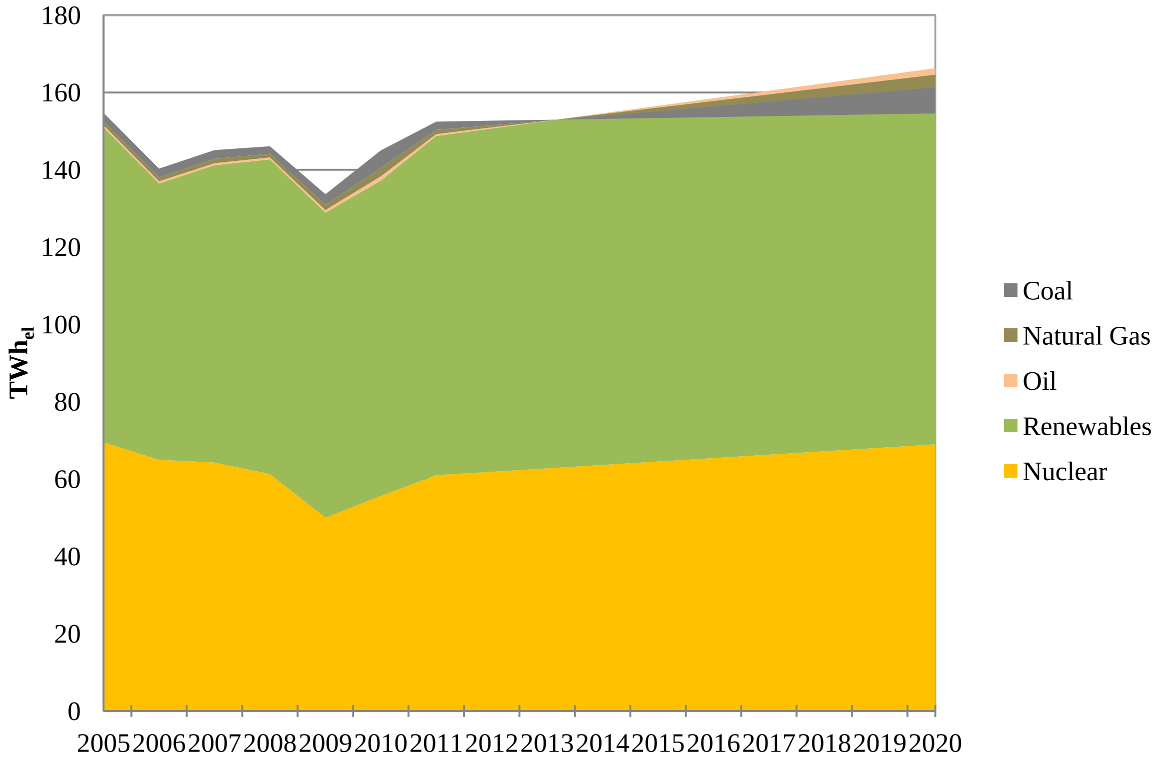


Figure 33. Sweden - electricity generation by source (2005-2020).