UPTEC STS10 029
Examensarbete 30 hp
Juni 2010

Is energy in Sweden secure?

The use of quantitative indicators for analyzing energy security

David Karlsson

UPPSALA
UNIVERSITET

Teknisk- naturvetenskaplig fakultet
UTH-enheten

Besöksadress:
Ångströmlaboratoriet
Lägerhyddsvägen 1
Hus 4, Plan 0

Postadress:
Box 536
751 21 Uppsala

Telefon:
018 – 471 30 03

Telefax:
018 – 471 30 00

Hemsida:
http://www.teknat.uu.se/student

Abstract

Is energy in Sweden secure? - the use of quantitative indicators for analyzing energy security

David Karlsson

The global energy consumption is increasing rapidly and will likely continue to do so for many years to come. At the same time the world's fossil energy resources, today supplying more than 80% of this demand, are in depletion. This means we face the risk of having a shortage in the global energy supply within just a few years. Countries have lately become more aware of this problematic situation, and have come to realize the importance of energy security and securing their supply of energy.

The aim of this thesis is to study energy security from a Swedish perspective. This has been done by comparing the main different energy forms used regarding certain security aspects. The thesis as well presents methods to be used for quantitative comparison of various energy alternatives or suppliers in the energy mix, which could be applied to any jurisdiction.

A division into three main energy services has been done because of their different characteristics; transport, space and water heating, and electricity. Some of the main results from this study are construction of energy security indices for the alternative energy sources used within these services. Also some recommendations for a more secure energy supply are presented and discussed in the thesis, and outlook for the future Swedish energy requirements in 2020.

Handledare: Larry Hughes & Mikael Höök
Ämnesgranskare: Kjell Aleklett
Examinator: Elisabet Andrésdóttir
ISSN: 1650-8319, UPTEC STS10 029

Sammanfattning

En tillförlitlig energiförsörjning är en av grundförutsättningarna för att vårt samhälle skall fungera. Med de mängder av relativt lättillgängliga fossila bränslen som funnits till förfogande under de senaste århundradena har tillgången på billig energi kunnat tas för givet, och i takt med ett ökat välstånd har även energiförbrukningen ökat kontinuerligt. Det ökande globala energibehovet kommer att fortsätta i snabb takt, medan tillgången på fossila bränslen däremot med all sannolikhet kommer att minska samtidigt. Antalet länder med exportkapacitet, och möjligheten att tillgodose detta ökande energibehov, blir allt färre och energiresurserna allt mer koncentrerade till vissa delar av världen. Dessa är några av orsakerna till det ökade fokuset på energisäkerhet under den senaste tiden, där länder nu har börjat inse vikten av att trygga sin energiförsörjning.

Detta examensarbete belyser energisäkerhet ur ett svenskt perspektiv, med bakgrund från tidigare forskning inom området. Studien är formad utifrån fyra särskilt viktiga dimensioner av energisäkerhet, även kallat energisäkerhetens fyra A'n (som är availability, accessability, affordability och acceptability). En modell som använts även inom tidigare studier, men dock inte utifrån svenska förhållanden. Försök har även gjorts att utforma kvantitativa indikatorer av dessa fyra faktorer, vilket också till viss del skiljer sig från föregående studier. Dessa har sedan använts för jämförelse och ranking av olika energialternativ, eller olika exportländer, gällande energisäkerhet och därmed resulterat i ett slags energisäkerhetsindex för de jämförda alternativen. Vidare diskuteras i uppsatsen, utifrån framtidsprognoser av det nationella energibehovet år 2020, vilken potential som finns att förbättra energisäkerheten genom reducerat behov och användande av alternativa energiformer. Resultat som tyder på mycket begränsade möjligheter till att minska energianvändningen, och att en ökad energisäkerhet snarare måste ske genom ökad diversitet i energianvändningen.

Studien sker utifrån tre olika sektorer som har ganska skilda karaktärer. Dessa är transporter, uppvärmning och elproduktion. Denna uppdelning hjälper även till att tydliggöra vilka olika typer av problem som finns och var de kan anses störst. Situationen gällande energisäkerheten inom transportsektorn är det som har kunnat konstateras absolut mest oroande. I skillnad från de övriga två sektorerna är trenden inom transporter en snabbt ökande energianvändning, som samtidigt är nästan uteslutande beroende av importerade fossila bränslen. För elproduktion och uppvärmning finns dock potential att till stor del tillgodose energibehovet ifrån inhemska förnyelsebara bränslen, särskilt ifall den utlovade satsningen på vindkraft blir av som planerat.

Totalt sett går det att konstatera att Sverige i förhållande till andra länder har en fördel i att vara förhållandevis lite beroende av fossil energi och relativt goda möjligheter för användning av förnyelsebara alternativ, men att det jämförelsevis stora importbehovet kan ses som en nackdel vad gäller energisäkerheten. En genomgång av tidigare utförda jämförelser och rankingar mellan länder, vad gäller faktorer relaterade till energisäkerhet, bekräftar också att Sveriges förutsättningar för en säker energiförsörjning kan anses relativt goda.

Preface and Acknowledgements

This project is the final course of my Masters degree in *Sociotechnical Systems Engineering* at Uppsala University. A project that was performed for the *Global Energy Systems* research group in the *Department of Physics and Astronomy* at the university, during the period from late 2009 until spring 2010. Presentation and defense of the thesis was held on April 23rd.

I would like to show my gratitude to all the people who have been helpful and supportive throughout the work on the project. I am very thankful to everyone from Global Energy Systems, for creating a friendly and inspiring working atmosphere during these months. Especially my supervisors Larry Hughes and Mikael Höök, who have given many valuable comments and appreciated guidance during my work on the thesis. And also Professor Kjell Aleklett for his faith and inspiration, and for giving me opportunity to attend several interesting seminars and presentations. It has been a great experience working on this project and I wish to thank everyone that has given me a piece of their time.

Uppsala, May 2010

David Karlsson

Table of contents

1 Introduction

The oil crisis that came to affect the world during the 1970's was one of the first incidents that really made people aware of energy security and its importance. However, during recent years we have been able to see a renewed focus and interest in this issue when the supply of oil has developed as a critical factor, but many others issues also feed current concern with energy security. The high volatility in energy prices, the rapid increase in energy use by developing countries, cut backs in supply due to disputes between countries, need for economic development and poverty reduction just to name a few. While at the same time concern is also fueled by threats of terrorism, geopolitical rivalries and political instability in some of the exporting nations.

Furthermore, what have been even more discussed recently are the problems with climate change caused by emissions of greenhouse gases. Problems which indeed are very much connected to the increasing demand for energy by the world's population, and therefore energy security as well. The fossil energy resources, which are still supplying more than 80% of the world's energy demand (IEA, 2009), are not just limited resources concentrated to specific regions, but also the ones contributing most to the global warming.

1.1 Problem discussion

Ultimately, the interest in energy security is based on the notion that the uninterrupted supply of energy is critical for the functioning of an economy (Kruyt et al. 2009). Right now there is anxiety of whether the resources we have on the planet will be sufficient to meet the world's energy requirement in the future, with a growing population requiring more and more energy. With depleting fossil reserves and production of oil reaching its peak (Peak-oil) we will have to find alternative supplies to fulfill these energy requirements. (Aleklett et al. 2009)

The continuously increasing imports and competition for limited energy resources means the issue of energy security and security of supply will continue to increase its importance to our society. Energy supply failures (when the existing demand cannot be met) are always critical, both in the short-term and long-term perspective. Energy security issues are going to affect national security for the countries around the world, and nations need to find ways of securing supply to meet requirements. Large countries like US, Russia and China have already made substantial investments, not least in military assets, to protect and secure energy supplies. And energy related conflicts have caused fear of a geopolitical cold war scenario with energy security being at center stage. (Jun et al. 2008)

A commonly used definition of energy security is: *availability of sufficient supplies at affordable prices*. (Yergin, 2006) Other, more or less specified, definitions have been made by other authors, but largely having the same meaning. So what is then the situation for Sweden with respect to the problems discussed? Can we consider the fuels in the Swedish energy mix as secure?

1.2 Objective

The objective of the thesis is to study the national energy security in Sweden. This includes analyzing the supply and demand, and comparing the different energy alternatives that are used to meet the national energy requirements. Furthermore the thesis aim to develop and use quantitative indicators as a method for measuring energy security, and construct security indexes for various energy sources or suppliers.

Some of the questions that need to be answered to fulfill this objective are: What energy forms are used and which are the suppliers? What infrastructure, production rates, pollution and costs could be connected to these energy sources and their use? What is to be expected in a future perspective, and what actions could have a positive impact on the Swedish energy security?

1.3 Delimitations

There are a great number of possible energy sources and suppliers that can help meet the energy demand in the future. However, this study will be limited to analyzing the ones that are most important for today's supply. This has the risk of possibly leaving new alternatives that can play an important role in the future out from the discussion, though it is impossible to now know which ones these are going to be. The study also had to be limited to energy security on national level, which means the results and conclusions might not always be applicable to the local or regional level. A more regional approach was discussed in the beginning of the work, but the lack of regional specific data would have made this very difficult. Thus, all data presented is referring to national energy use.

As well there are very many factors that affect energy security, and should be considered in the discussion. The scopes of this thesis cannot fully cover all these aspects. This study can rather be seen as an overview and introduction on how to use quantitative measures to determine and improve energy security within the country. The use of models, which are always a simplification of reality, to such a complex matter, of course means some limitations in itself. This problem is going to be discussed further in coming chapters.

1.4 Disposition

The structure is following general academic principles. This first chapter has given a short introduction to the subject and presentation of the objective. Next chapter will present some previous studies that have been evaluating and comparing countries regarding different aspects of energy security, on national level by using quantitative measures, to give some background to the thesis. The third chapter then will continue with theory and definitions of energy security, and present the literature forming the basis for the thesis. Chapter 4 discusses the methodology and the work approach chosen for the study.

In chapter 5 and 6 all gathered material regarding the Swedish market and the energy use is presented. In chapter 5 the three different services are introduced, and in chapter 6 the main energy sources are analyzed in respect to the 4 A's of energy security. Following this, in chapter 7, the results of quantifying the 4 A's is presented and different ways of constructing indexes of energy alternatives are discussed. Chapter 8 focuses on future outlook and possible scenarios for energy demand in 10 years, and how energy security´s 4 R can be used as a helpful tool in the work to improve security. Finishing the thesis is analyzes of the results, and discussions on what could be considered the main problems or risks to the national energy security. Chapter 10 makes the conclusion.

2 Background

This chapter will present some background to the thesis, including how the project idea evolved and discussion of some previous studies on energy security using quantitative measures and indicators.

2.1 Project background

The idea for the thesis came through a proposal for a Masters project suggested by Global Energy Systems at Uppsala University. Originally a project led by guest professor Larry Hughes from Dalhousie University in Nova Scotia, who has great experience in research on energy security. Professor Hughes is author of several publications concerning Canada's energy security especially and methodologies for use within this research. For example the report *Energy security in Nova Scotia*, which is a study on the regional energy security for one of Canada's provinces. The intention was this study could turn into something similar, but from a Swedish perspective. Thus, studying the energy security for Sweden and for Uppsala län especially, and apply previous research on energy security to the Swedish situation. However, as it turned out, a regional approach was not as well suited for the Swedish energy market as the Canadian one. Consequently the focus on the thesis has been the national energy security of Sweden.

2.2 Previous studies

Attempts to compare different nations and aspects relating to energy security have become more common in the last years. However, there has not been a general way of doing this, but instead several different kind of measures used within these studies. Most of them having quantitative measurable indicators, but often also underlying assumptions of subjective and qualitative character. Here are presented some examples of previous works using different quantitative methods to indicate energy security for a jurisdiction, and the rankings resulting from these.

2.2.1 Import dependence

Import dependence has been a commonly used measure in almost all previous studies and is one of the most simplistic estimates of energy security, with indicators measuring to what extent a country is relying on imports to meet its energy requirements. One of the reports using this indicator for energy security, with calculated values for different countries, is *Streimikiene's (2007)* study on energy supply sustainability in the Baltic Sea region. According to this study Norway followed by Russia and Denmark are ranked the highest in energy independency in this region. Sweden is average in relation to other countries, and is found more secure than the EU average but less secure than BASREC (Baltic Sea region) average in terms of import dependence. See figure 1 for the country rankings:

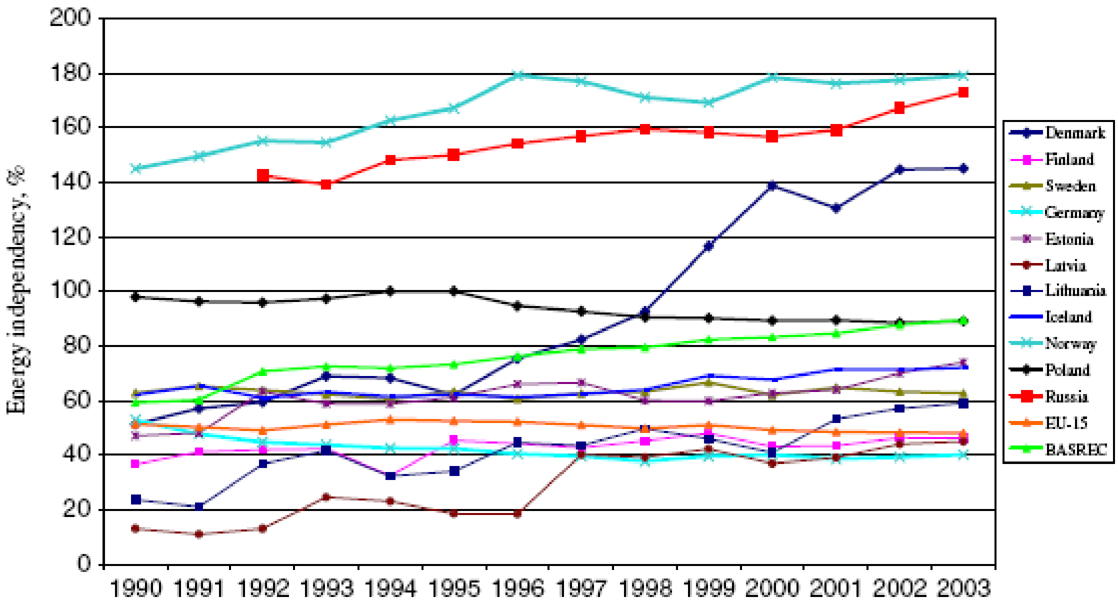


Figure 1: Energy independency (ECO15) in Baltic Sea region (Streimikiene, 2006): Calculated from share of net energy exports in the total primary energy supply.

2.2.2 Oil vulnerability

Oil is an energy resource that is very important to most countries, and therefore also security of oil supply is a commonly used factor in studies of energy security. This has been presented with an oil vulnerability index in a report by *Christos et al (2009),* studying oil vulnerability within the EU countries between 1995-2007, using six indicators that are affecting the security of supply. These six indicators were as follows; Net energy import dependencies, diversification of primary energy demand, market liquidity indicator, political measurement indicator, oil consumed in an economy to its gross domestic product and oil consumption to primary energy consumption. Principal component analysis was applied to develop the index for all EU countries. The results by using this method actually suggest Sweden being the least vulnerable country within the EU in terms of oil supply. One explanation given to this in the report is that Sweden covers a significant part of its oil requirement with imports from Norway, and that the threat of disruptions therefore is very limited.

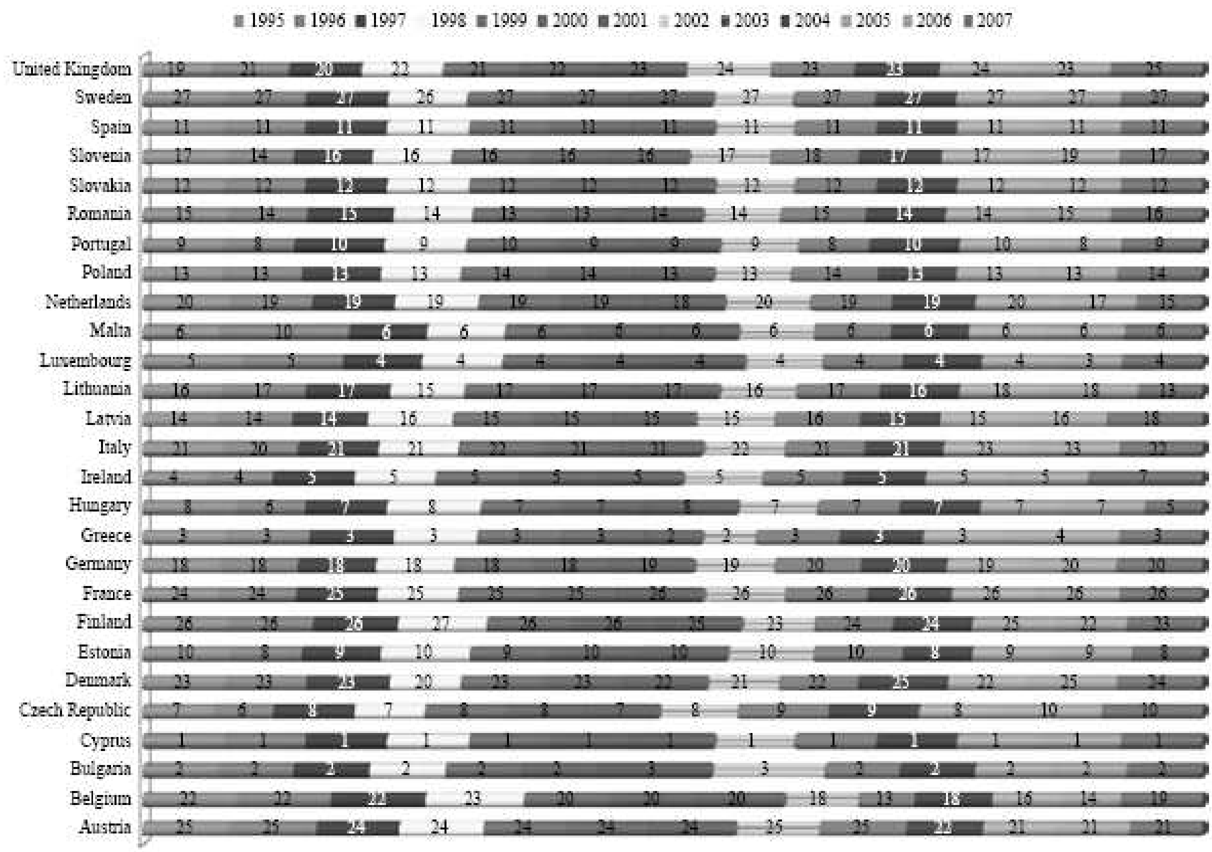


Figure 2: Oil vulnerability index (Christos et al, 2009): EU countries ranked from most (1) to least vulnerable (27) in terms of oil supply for the years 1995-2007.

These results can seem very surprising for a country importing all of its oil, and where imported oil stands for almost a third of the total energy supply. One would expect countries with their own oil resources, like Denmark or United Kingdom, to be ranked more secure in terms of oil supply. Most of the countries in the study do not have any indigenous oil resources though, which to some extent can explain Sweden's relatively high ranking.

2.2.3 Energy vulnerability index

Also an energy vulnerability index has been found in literature, done in Switzerland *(Gnansounou, 2008)* aiming to design an index to monitor industrialized countries with regard to their efforts to cope with long-term energy vulnerability. Five relevant dimensions were chosen for constructing this index and comparing different countries. These were; primary energy intensity of the gross domestic production, energy import dependency, ratio of energy related CO2 emissions to the total primary energy supply, electricity supply vulnerability and non-diversity in transport fuels. For each of the dimensions a relative indicator was also estimated, which was used to compute the composite index I. Sweden, being one of the 37 countries in the study, had the second lowest result on this index (thus being considered the second least vulnerable country after Canada, see figure 3). The main reasons for Sweden's very good result on the ranking are not discussed further in the report though.

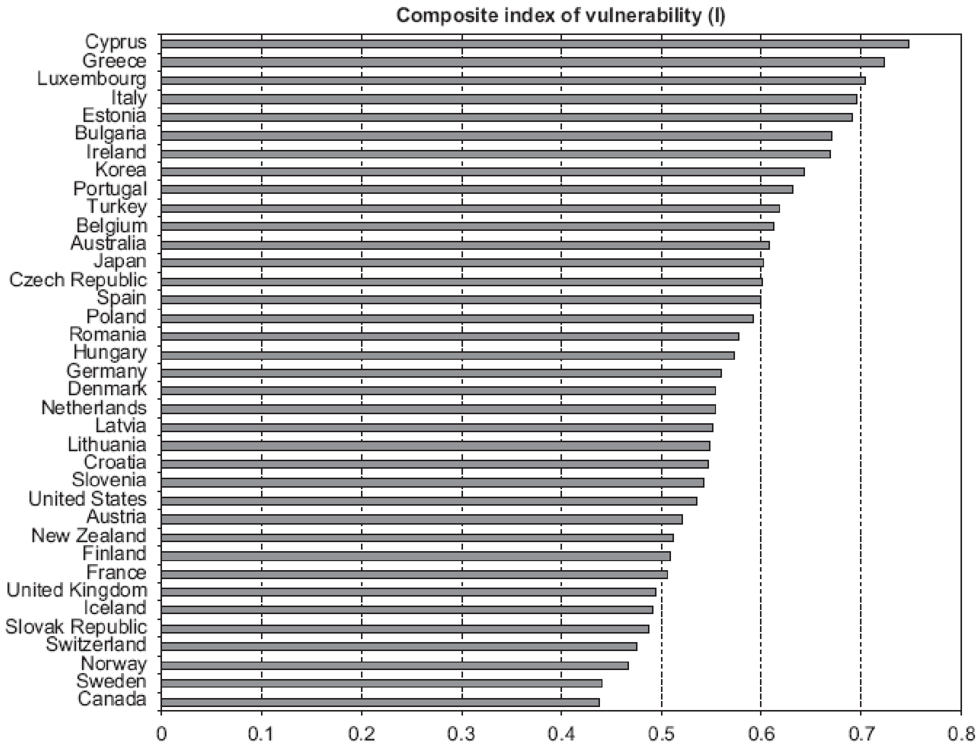


Figure 3: Energy vulnerability index (Gnansounou, 2008)

2.2.4 Supply/Demand index

While many approaches to studying energy security tend to zoom in on the supply side, a Supply/Demand index also covers demand aspects. The structure and intensity of national demand, supply elasticity, inland supply chain, conversion infrastructure and physical environment affecting needs for fuels and electricity also plays a big role in energy security. Therefore the S/D index sets out to integrate major underlying supply-side with demand-side factors, ranging from 0 (very insecure) to 100 (extremely high security). The index has the potential to cover factors like final energy demand, energy conversion and transport, and primary energy sources supply. (Jansen & Seebregts, 2009)

In *Jansen and Seebregts (2009)* the supply/demand index for the European Union is calculated. For the 27 member states the unweighted average of the index value is 56, and ranges from 25 (Cyprus) to 82 (Denmark). Sweden is here placed 4th on the ranking with 70 on the index, thus in comparison with rest of EU (average 65) showing relatively high security. The authors conclude that member states importing oil and gas mainly from EU or Norway and deploy renewables and/or combined heat and power also are ranked relatively high on their S/D index. The upper part of the ranking is shown in figure 4 below:

Figure 4: Supply/Demand index for EU countries (Jansen & Seebregts, 2009)

2.2.5 Energy policy index

An energy policy index has been constructed by *Röller et al (2007),* and is suppose to give an overview of current state of energy policy in the European Union. Thus focusing more on the goals and objectives of the country's energy strategies. This index is being measured for three different objectives; competitiveness, security of supply and environmental sustainability (the three policy objectives set for EU by the Commission). For each of the objectives the EU countries were given a value from 0 to 6 (6 being best possible). These results show Sweden having average levels regarding security of supply and competitiveness, and being placed in the middle of the scale (given 2.7 and 2.3 respectively). And doing second best among the countries in sustainability (5.0). The analysis of supply security has here been limited to supply-side factors (such as limited resources, investments in infrastructure and new exploitation, blackouts, political blackmail or terrorism), and divided into operating reliability and resource adequacy. Figure 5 shows the results with sustainability on the vertical axis and supply security on the horizontal axis:

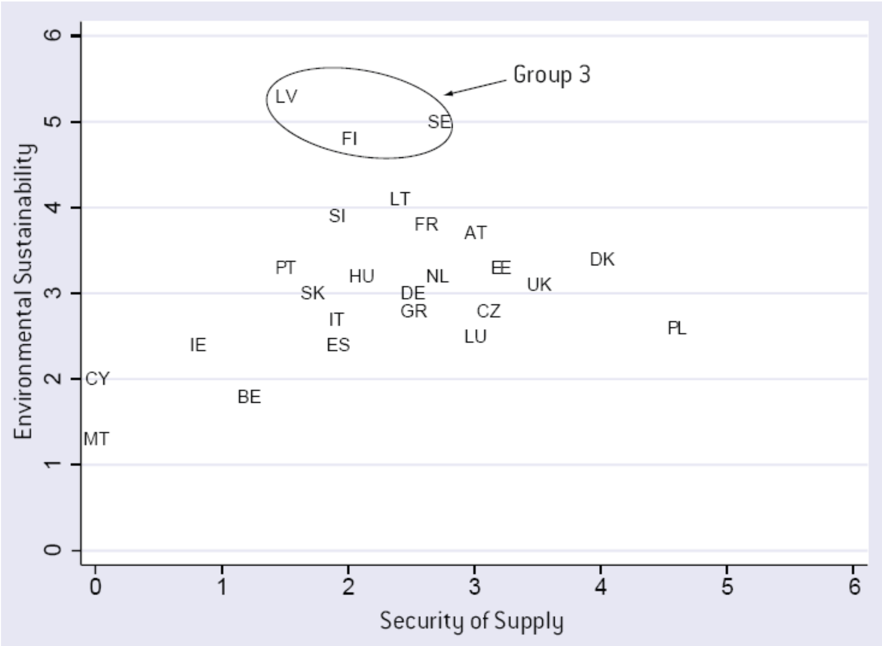


Figure 5: Energy policy index for security of supply and environmental sustainability (Röller et al, 2007)

Other types of indicators that are sometimes included in studies of energy security are different risk indices, political stability indices or similar. For example, like *Jun et al (2008)* in studying of Korea's energy security, using a geopolitical instability index (derived from the *Global Peace Index*) to compare supply security from different import countries. When comparing Sweden's main import countries in such a ranking, you will likely find some in the top (Norway, Denmark) and some in the bottom (Russia, Venezuela), indicating that the first ones are secure suppliers while the latter ones are not.

2.2.6 Concluding remarks on previous studies

As been proved in this chapter, there are number of different ways energy security issues can be measured and illustrated. However, indices like those presented only indicate one jurisdictions security in comparison with others. They do not give much direct guidelines on how energy security can be improved for a specific jurisdiction, and no measures of what fuel supplies and energy sources can be considered more or less secure to those. A discussion very important to the individual countries, and a problem that will be discussed further in this report.

Commonly for these indexes though is that Sweden, despite its lack of indigenous fossil energy resources, is to be considered fairly secure compared to other countries. And points that Sweden at least, no more than others seem exposed to the various security risks. One main reason for the high ranking likely is Sweden's relatively small share of fossil energy in the energy mix and sustainable production. Common for the studies as well, and also contributing to the high ranking, is the consideration of Norway (and European countries in general) as secure and reliable oil supplier compared to other oil producers.

3 Theoretical framework

This chapter aims to define some of the important concepts and terminology used in the study, and present some of the basic quantitative indicators.

3.1 What is energy security?

In general energy security and energy policy are concepts which are quite poorly understood among the populace (Hughes, 2009). Maybe not very surprisingly since energy security can be seen as a rather vague concept, and traditionally associated mainly with securing access to oil supply. Reasons for this can be found in the oil crises that occurred in the 1970's, which are examples that made the dependence on oil exporting countries very evident.(Kruyt et al. 2009)

There are different ways to look at energy security depending if you are an importer or exporter of energy. For importing countries, security of supply is going to be the main issue. Although for an exporting country reliant on income from exports, security of demand is going to be just as crucial. The developing countries also have to be very concerned about what affects changes in energy prices will have on their balance of payments. And for countries where energy demand is increasing very fast, such as China and India, the ability to rapidly adjust to a new dependence on global markets will be important to their energy security. (Yergin, 2006)

Considering a net importer, such as Sweden and many others, energy security should neither be limited to the supply and imports of fossil fuels. Several power blackouts in the US, Europe and Russia, as well as chronic shortages of electric power in China, India and many of the developing countries, have also raised worries about the reliability of electricity supply systems.(Yergin, 2006) Furthermore, energy security is often discussed just in terms of energy imports, overlooking other important factors such as domestic supply and infrastructure.

To this situation, governments in different parts of the world are responding by formulating policies to improve the security of supply. In most cases however, this does not include formulating quantifiable goals. Security of supply is still seen as the major objective for most energy policies, although energy security should be seen also in relation to other policy issues that concern the energy system (for example economic and environmental policies), which implies that it is important to study energy security consequences of different development pathways. But for doing this, it is important that we have indicators of energy security.(Kruyt et al. 2009)

International Energy Agency, IEA, some years ago defined energy security as *reliable supply of energy at an affordable price* (IEA, 2001), but has since then restated their definition a few times. A very similar definition comes from Bielecki (2002) and says *a reliable and uninterrupted supply of energy sufficient to meet the needs of the economy at the same time, coming at a reasonable price*. This definition was also used by the European Commission (EC) when suggesting their four dimensions of energy security; physical, economic, social and environmental. (Jun et al. 2009) Another, more general, way to describe it; *Energy security exists if the energy sector does not cause welfare-reducing frictions in the economy at national and global levels*. (Löschel et al. 2009; Bohi & Toman, 1996)

The concept and definitions of energy security generally seem to have widened over time. In later definitions there are often four main elements identified. First element being the availability of energy to an economy. The element of accessibility, due to large spatial discrepancy between consumption and production of resources. Third the element of cost, and finally an element including environmental sustainability. This broad classification scheme has been used by Asia Pacific Energy Research Center (APERC, 2007) among others, and can be summarized in 4 A's; Availability, Accessibility, Affordability and Acceptability. Their definition of energy security consequently is: *the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy*.

The definitions and ways to achieve energy security can vary between countries and within countries however, usually depending upon the state of development and availability of energy supplies. The priorities of industrialized, net-energy importing countries (like Sweden) could for example be (Hughes, 2007):

- Avoiding disruption of energy supplies
- Diversification of energy supply sources
- Security concerns for infrastructure
- Technological solutions to reduce dependence on imported supplies

3.2 How can energy security be measured?

A concept that is not defined very clearly can of course be difficult to measure. The growing importance and interest in energy security makes the question relevant to ask though. A number of different indicators and possible measures have also been discussed in literature. Chapter 2 discussed some of the methods used in previous studies to produce rankings and indexes. Here are some of the basic and commonly used formulas presented further:

Diversity is often one of the main measurable factors being mentioned as important to energy security. Two common and quite simple indexes used for measuring this are the Shannon-Wiener index and Herfindahl-Hirschman index (Bazilian & Roques, 2008):

Shannon-Wiener: $$H = -\sum_{i=1}^{I} (p_i \ln p_i)$$

Herfindahl-Hirschman: $$D = \sum_{i=1}^{I} p_i^2$$

Where p_i is representing the share of fuel i in the energy mix, or the market share of supplier i.

These have been the basis for many other refined measuring methods. For example, a further development of the Shannon index to take the share of imported resources into account as well (Jansen et al. 2009):

$$I = - \sum c_i p_i \ln p_i$$

Where $c_i = 1 - m_i \ (1 - S_i^{m} / S_i^{m,max})$ and $S_i^{m} = -\sum h_j m_{ij} \ln m_{ij}$

m being the number of primary energy sources, and m_i the net import share of energy source i. S_i^m is the Shannon index of import flows of resource i, where m_{ij} represents the share of imports from region j in total imports of source i. (Kruyt et al. 2009)

Derived from mentioned formulas are also some of the energy security indicators used by APERC (2007). The first indicator measuring diversification of primary energy demand, DoPED:

$$D = -\sum_{i=1}^{T} (p_i \ln p_i) \qquad \Rightarrow \qquad DoPED = \frac{D}{\ln T}$$

Where D is result from the Shannon index, and T the number of utilized energy sources. A high result means a diversified energy mix. DoPED is normalized to show a maximum value of 1.

The Shannon Index is also being utilized to measure the economy's net energy import dependency (NEID) altered to reflect the impact of both diversification and imports on the energy supply security. NEID of an economy is weighted by the consumption intensity of each primary energy source, and is presented as:

$$D = -\sum_{i=1}^{T} (c_i p_i \ln p_i) \qquad \Rightarrow \qquad DoPED_{import\_reflective} = \frac{D}{\ln T}$$

$$\Rightarrow \quad NEID = 1 - \frac{DoPED_{import\_reflective}}{DoPED}$$

c_i (= 1-m_i) represents the correction factor for p_i, where m_i is the share of net imports in primary energy supply of source i. A result close to 1 implies that the economy is highly dependent on imports to meet its primary energy demand.

A third indicator used by APERC is measuring the efforts being made to switch away from a carbon intensive fuel portfolio (NCFP). Thus calculating the share of hydro, nuclear and renewable energy:

$$NCFP = \frac{(HydroPED) + (NuclearPED) + (NRE\_PED)}{Total\_PED}$$

A fuel portfolio consisting of only renewable energy and nuclear power would get a result very close to 1.

Also net oil import dependency can be calculated with similar formulas. (APERC, 2007) These energy security indicators are just some basic examples, but do show some main factors important to include when studying energy security; diversification, import dependence and the share of fossil/renewable energy sources to meet the energy demand.

In one of the reports from Asia Pacific Energy Research Centre, *A quest for energy security in the 21st century* (2007), these indicators are presented and calculated for 21 different countries. Sweden was not a part of the study, but with the formulas above values for Sweden easily can be calculated and compared to the others. The results for Sweden with the current energy supplies would be (see appendix 1 for calculations):

Diversification of primary energy demand: $ESI_I = 0.72$

Net energy import dependency: $ESI_{II} = 0.67$

Efforts to switch away from carbon intensive fuel portfolio: $ESI_{III} = 0.63$

Numbers that probably do not say much to the reader at first, but can be put in perspective by comparison to the other 21 countries that were analyzed (using data from 2004 however). For the first indicator results ultimately would be close to 1. Sweden's result 0,72 is a little above average compared to the other countries. While for the second indicator one would seek for a lower value (to be less dependent on imports). In this calculation all energy produced from nuclear has been included as imported energy. The result 0,67 is higher than most of the other countries. For the third indicator though Sweden is showing a very good result and actually better than any other countries studied.

3.3 The 4 A's of energy security

Another approach for studying energy security would be to find ways of measuring the 4 A's that were mentioned briefly in 3.1. A challenging task that will be one of the main focuses of this thesis. These are 4 A's that are not really isolated from each other though, but instead subject to a complex interplay. How to define these A's, and indicators that can be used, is discussed below. Later will also be discussed possible ways to calculate quantitative values for each of them.

To examine energy security we must look at the whole life cycle for the energy used, which can include reserves, production, conversion techniques and efficiency, infrastructure to access the energy, associated costs, effects of its use etc. The 4 A's can be used as a tool helping to do this.

Availability

This would naturally mean the physical availability and actual (geological) existence of the energy source, which of course is crucial and an indicator of direct importance for the security of energy supply. Data that has been well used previously in different ways to determine availability is: estimations of reserves, production data, R/P ratios, depletion of production fields, predicted undiscovered reserves etc. The "reserve" concept seems to be very much connected to fossil forms of energy however, and is not really applicable to renewables in the same way.

Accessibility

An available resource might not always be accessible. Reasons for this can be barriers of many various kinds. Technical, geographical, political, economical or environmental constraints to name just a few (though the last two will be discussed under affordability and acceptability).(APERC, 2007) The accessibility factor can be referred to as the level of access that the consumer or a service has for a particular energy alternative, and the means of how to access the energy available.(Hughes, 2010) A typical example could be the infrastructure that exist to make the energy accessible (e.g. pipelines to deliver natural gas), or technical and economical constraints that are making many renewable energy forms less accessible than fossils. But could also depend on restrictions imposed by governments, exercise of market power etc. (Jansen, 2009) The importance of the various accessibility aspects might be different for the various fuels and services.

Affordability

Affordability is referring to the economical elements of energy security. Looking at costs for energy use, volatility in prices and the amount of money a country spend on the energy resources are possible ways to study affordability. High costs and fluctuations for a fuel would imply low security. Although determine peoples ability to pay and how important the cost of energy is to them might be a more correct measure, but also much more difficult. Energy production costs will be composed differently depending on the type of energy resource, and dominated by capital costs, operational costs or fuel costs etc.

Acceptability

Acceptability is commonly focusing on the environmental concerns related to the energy industry, but could also be social, cultural or political barriers inhibiting supply because of negative perception among the population (Jansen et al. 2009). In general acceptability refers to a jurisdictions acceptance of an energy alternative. Some factors that could be considered important to environmental acceptability are emission of greenhouse gases and other pollution caused by the energy use, deforestation and land use, waste from production, production efficiency etc. Problems to social or political acceptability can be that some countries are considered unacceptable as trading partners, or some fuels that are not considered acceptable by the population.

One way acceptability could be reflected is through taxation or emission charges, where in general taxes or charges are higher on those sources that are deemed by society to be less desirable or acceptable than others. (Hughes, 2010)

3.4 The 4 R's of energy security

The 4 A's can be seen as a way of reviewing the energy security for different energy sources or energy supplies to a jurisdiction, which naturally would be the first step to achieve or improve security. One methodology to explain and achieve energy security has been presented by Hughes (2009) and consists of the 4 R's, which are presented below:

Review

The first part is to understand the problem. This means reviewing the existing energy sources, the suppliers and infrastructure, including methods for ranking the different energy sources in terms of security. Energy services should be reviewed by sector as deeply as possible, to find potential secure energy supplies for these that can substitute less secure ones. Which essentially means examining the various available energy supplies as carefully as possible.

Reduce

Using less energy is likely to have a good impact on energy security (especially if the reduction target insecure sources). This can be accomplished through energy conservation or energy efficiency. The first one can be introduced rapidly and with little cost typically. The second usually takes more time and money to implement. Rising energy prices is one possible way to induce energy reduction, but also government policies that encourage reduction may have impact. (Hughes, 2009)

Replace

Shifting to secure sources and replace insecure energy supplies with more secure ones. In general this can be done by diversification of energy supplies or changing the infrastructure to allow alternative energy sources. An example of significant replacement programs that is being established in most major economies is within the transportation sector. Because of its high energy requirements and reliability on fossil fuels, programs for introduction of renewable fuels in transportation will be necessary to improve energy security.

Restrict

Replacement is referring to already existing demands, therefore a 4th R was introduced for limiting new demand to secure sources. Jurisdictions often will experience demands for new supplies of energy. Restricting those to secure sources might sometimes be problematic though, due to lack of enough secure energy sources or infrastructure to fulfill the demand. (Hughes, 2009)

4 Methodology

The study, and the structure of the report, is based on the 4 A's and 4 R's discussed in 3.3 and 3.4. An approach differing from the presented previous studies in chapter 2, but still covering many of the same important aspects. It represents a general and dynamic method which is suitable for comparing energy alternatives or different energy suppliers by various criteria. The method can be applied to any jurisdiction and be used as a tool to improve its energy security, and also has the advantage of including both supply side and demand side factors.

The methods used within the study have been qualitative and quantitative. However, the goal has been to find quantitative indicators which as good as possible can describe the 4 A's of energy security. The reliability of such approach could of course be criticized of favoring measurable indicators and being very simplified, but is also necessary to meet the objective of creating a ranking and index of different energy sources. But also factors that are not as measurable and contain less precise metrics have been taken into consideration and included in the discussion.

Energy requirements have been divided in three different services, having different characteristics. These are transportation services, space and water heating, and electricity. Reasons for making this division are primarily to make comparison of alternatives easier and more relevant (there is no need to include all possible energy sources for all kinds of use). As was mentioned in the theory as well, the available energy sources preferably are reviewed by sector as deep as possible.

4.1 Data sources

Much of the work in the thesis has been to collect and process data material from various sources and databases. The sources used for this have mainly been government agencies, especially Statistiska Centralbyrån and Energimyndigheten. These have been able to provide much of the national energy statistics, especially regarding supply and use of energy. Also an important data source is the annual reviews from British Petroleum, which very well covers the different countries reserves and production of fossil fuels. Other important data sources have been the Swedish Petroleum Institute, Energy Information Administration, International Energy Agency, European Forest Institute for example.

The objective initially was to find data allowing a more regional approach, and study the energy security for Uppsala län. However, it turned out that the national approach was going to be more feasible and give more relevant results. Much of the data that in the end has been used could not be found on regional level. And in the cases they do exist, there were still doubt whether they were more appropriate to use than the national data.

4.2 Constructing an energy security index

Finding quantitative measures of the A's is the first part of constructing an index. This can be done in several different ways. Everything from having a relatively simple model with one indicator representing each criterion, to a very complex model with many equations including several indicators. The alternative chosen for this study is closer to the first one. Including several measures for each criteria might be a more comprehensive approach, but will also lead to further difficulties how to weight the indicators against each other, how much more important one is compared to the others etc. However, the same type of problem is showing up when adding the 4 A's to a security index, where different weightings may have to be applied (this will be discussed more in 7.1)

Other difficulties have been finding indicators that can be measured in similar ways for all different types of energy sources (which is also setting a limit to the number of indicator that can be included). A more detailed description on how 4 A's have been measured and calculated will be discussed further later on. The software used for most calculations and illustrations has been Excel.

4.2.1 Decision matrix and ranking vector

Numbers and data for all alternatives can preferably be collected in a matrix, to allow ranking of the alternatives in a ranking vector. This type of matrix is called a decision matrix, and has been used to produce the results presented later in chapter 7.

Table 1: Decision matrix

	w_1	...	w_c		
	C_1	...	C_c		
A_1	$r_{1,1}$		$r_{c,1}$	V_1	$V_1 = w_1 \times r_{1,1} + \ldots + w_c \times r_{c,1}$
...				...	...
A_a	$r_{1,a}$		$r_{c,a}$	V_a	$V_a = w_1 \times r_{1,a} + \ldots + w_c \times r_{c,a}$

Here, A_i represents the different alternatives (energy sources available) and C_i are the different criteria (the 4 A's). Weighting of the criteria can be applied by choosing the value of w_i, who's vector is of the same size as the number of criteria. A uniform weighting means all w_i has the same value. The final ranking of the alternative then is obtained by the formula for V_i, and the vector contains the index of the alternatives. For the alternatives being different energy sources this means vector V is a form of energy security index, indicating the security associated with the alternative energy sources. (See appendix 3 and chapter 7 for the results and calculated values) The table below, just to illustrate an example, shows the decision matrix for heating services, assuming equal weighting of the criteria:

Table 2: Example of decision matrix for space and water heating

	Availability	Accessibility	Affordability	Acceptability		Ranking vector
weighting	0.25	0.25	0.25	0.25		
Biomass	$r_{bio,ava}$	$r_{bio,acs}$	$r_{bio,aff}$	$r_{bio,acp}$		$V_{biomass}$
District heating	$r_{dh,ava}$	$r_{dh,acs}$	$r_{dh,aff}$	$r_{dh,acp}$		$V_{district\ heating}$
Electricity	$r_{el,ava}$	$r_{el,acs}$	$r_{el,aff}$	$r_{el,acp}$		$V_{electricity}$
Fuel oil	$r_{oil,ava}$	$r_{oil,acs}$	$r_{oil,aff}$	$r_{oil,acp}$		$V_{fuel\ oil}$
Gas	$r_{gas,ava}$	$r_{gas,acs}$	$r_{gas,aff}$	$r_{gas,acp}$		V_{gas}

The methods and indicators described above were used for ranking the fuels between each other in relation to the different A's. All of the values have been normalized (showing a value from 0 to 1).

In the following chapters the different types of energy resources in the Swedish energy mix is going to be studied further and compared. The 4 A's will be discussed for each of them. Similar to the Supply/Demand index both supply and demand side aspects will be covered. The method presented can be used as an analysis tool, studying how different parameters can influence energy decisions and policies.

5 Swedish energy market's main services

Swedish energy use and requirements are discussed in the chapter, in total and divided into three different services. Data comes from Energimyndigheten (Swedish Energy Agency) if no other source is referred to.

Sweden's total supply of energy has during the last 20 years quite constantly been around 600 TWh (see figure below). For the last year of data, 2008, the total supply was 612 TWh (about 2200 PJ) for the country. Although the final use of energy was amounted to less than two-thirds of that number, 397 TWh. This is due to the losses in distribution and conversion (especially for nuclear power where around 2/3 of the energy produced is heat, that is not used for any purpose), as well as the use of fossils for non-energy purposes and international marine bunkers, which accounts for about a third of the total energy supply altogether.

The major energy sources used in Sweden are petroleum products, electricity (from hydro and nuclear) and biomass. Nearly 200 of the 612 TWh supplied energy came from petroleum products, 123 TWh of the energy counted as biomass, and 264 TWh connected to the electricity production (including the losses). Figure 6 shows the total energy supplied by the different energy sources. As seen, oil has been a very dominant energy source until the 1970's, but was after the oil crises partly substituted with the newer nuclear power. The use of oil has now almost been phased out in all sectors but the transportation sector, where it is actually increasing quite significantly.

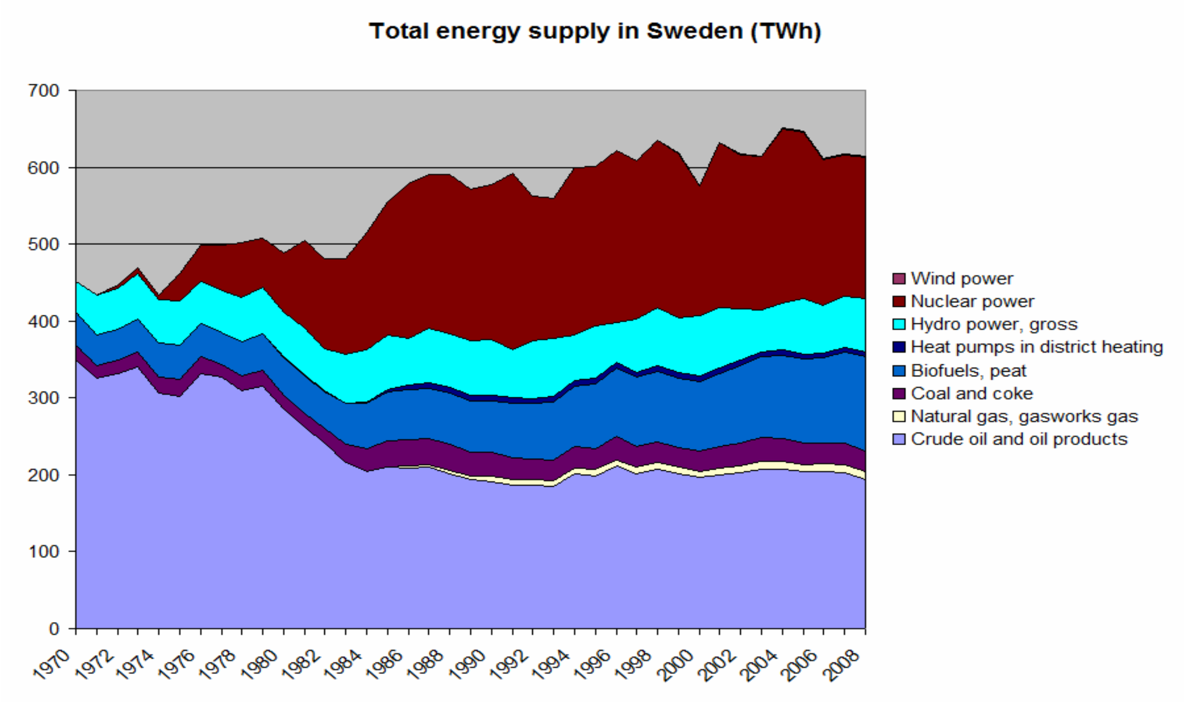


Figure 6: Energy supply in Sweden by energy source (Energimyndigheten, 2009)

Sweden´s final energy use is shown in figure 7. Thus, with the losses in nuclear and the international marine bunkers accounted for and illustrated in the graph.

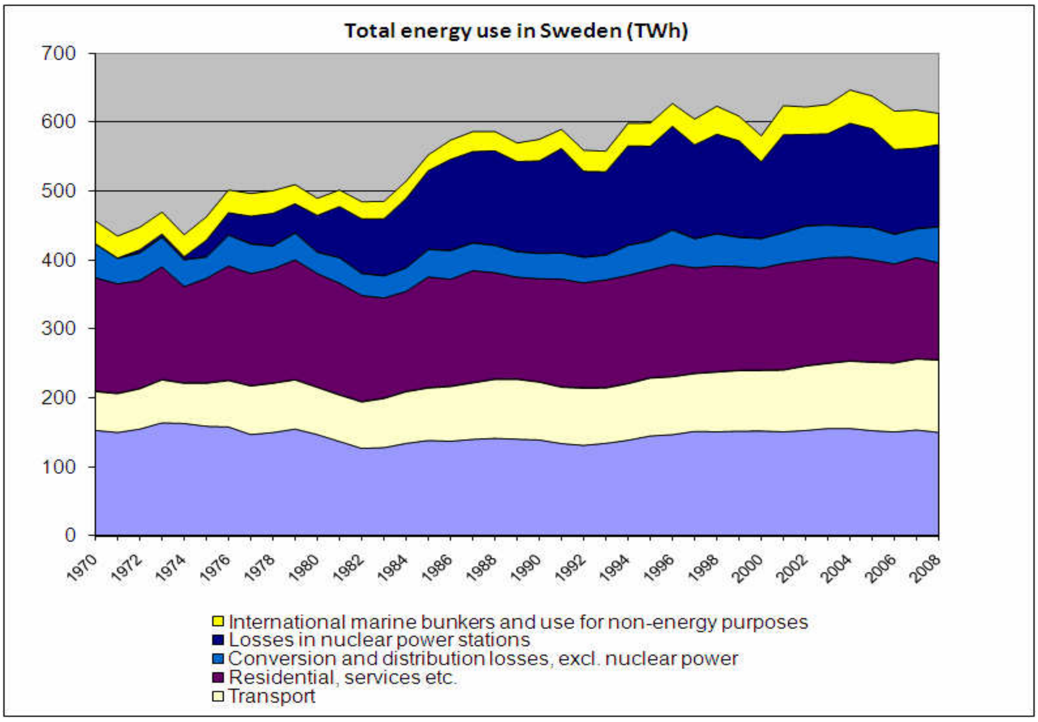


Figure 7: Sweden's final energy use (Energimyndigheten, 2009)

Compared to other countries around the world, the share of fossil fuels in the Energy mix of Sweden is very low. In total 37% (EC, 2004) of the primary energy demand was met from fossil fuels, where the world mean was as much as 87%. (EIA, 2008) The main reasons for this are the possibilities to produce electric power almost without any fossil fuels (if not counting nuclear energy as fossil), and that biomass can be used to meet a large part of the heating demand. The share of renewables is actually the largest within the EU and has risen from 33,3% in 1990 to 44,1% in 2008.(Energimyndigheten, 2009:28)

5.1 The transport sector

As mentioned above, the transportation sector is where the energy use has continued rising constantly, and consequently also the use of fossil fuels. Since 1970 the energy use has almost doubled (see figure 8). In 2008 the energy requirement in the sector was 128,7 TWh (105 TWh if excluding bunker oils). Although a small decline has been shown in the use of petroleum during the last years, this has been more than compensated by increased use of diesel and bunker oil. Renewable alternatives for transportation fuels are also increasing though, but have not yet had a real breakthrough on the market. Just a few percent of the energy used comes from renewable sources, and most of it being ethanol mixed into regular petroleum.

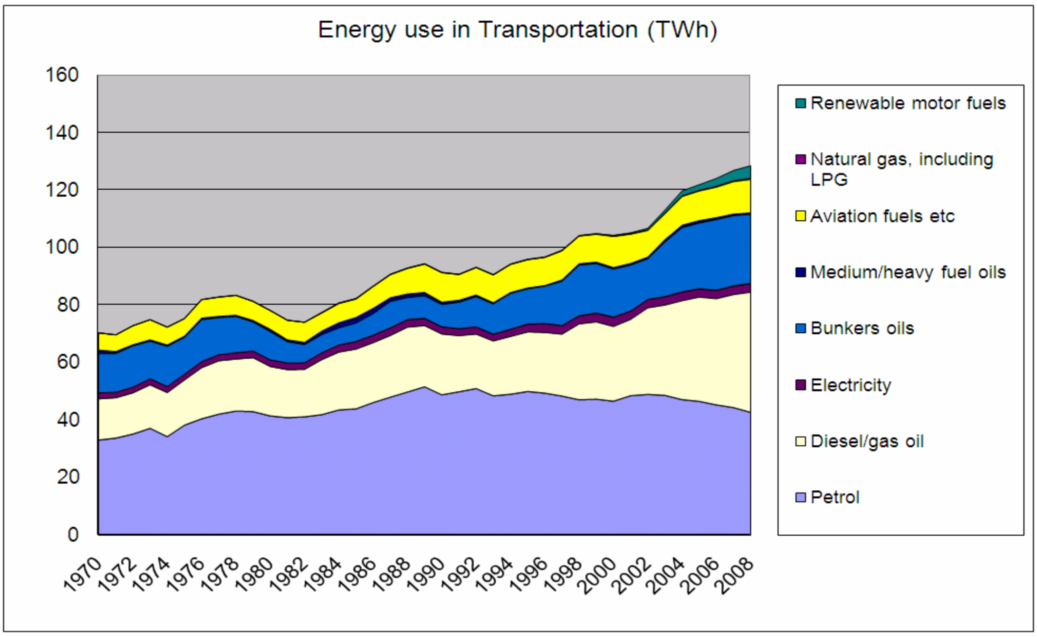


Figure 8: Energy use in transportation (Energimyndigheten, 2009)

Of one year's total domestic transports (137,3 billion personkm) road traffic accounts for 87%, rail 9%, plane 3% and less than 1% on water.(Energimyndigheten, 2008:15) Thus, cars and trucks make up a huge part of the energy consumption. The amount of Ethanol mixed into petroleum and FAME into diesel has grown and now become standard, and been the main reason for the renewables slowly increasing their share. But also the law that was implemented in 2006 that means the big stations must offer a renewable alternative fuel has had an impact, especially for ethanol use.

The big share of fossil fuels in the sector also means high emissions. About a third of the greenhouse gas emissions, ~21 million tonnes, within Sweden come from the energy use in the (national) transport sector. If international transports also are included the number will be higher. (Naturvårdsverket, 2008)

5.2 Space and water heating

Total use of energy in residential and service sector was 141 TWh in 2008. Of this amount 61% (86 TWh) was used for heating purposes (space heating and hot water production). However, the energy that goes for heating always is a lot affected by temperature conditions. Therefore corrections for climatic conditions, calculating the energy demand compared to a statistically average year, are normally being made to allow comparison between years. Thus, since the temperature in 2008 was higher than the average year (+14%), the corrected heating requirement also become higher (ca 91 TWh).

86% of the total energy used for heating falls under the category dwellings and non-residential premises. This equals about 75 TWh of actual energy use in 2008, and 81 TWh in corrected value (a decline compared to previous years). The energy use for this category has been accurately measured for every year by the Swedish energy agency, covering a total heated area of 581 million m^2 from which almost half is houses, and apartment buildings and premises have equal shares of the other half. Figures on energy demand in heating will mainly be referring to data presented in these reports. (Energimyndigheten, 2009:10) The trend in energy used for heating purposes is shown below:

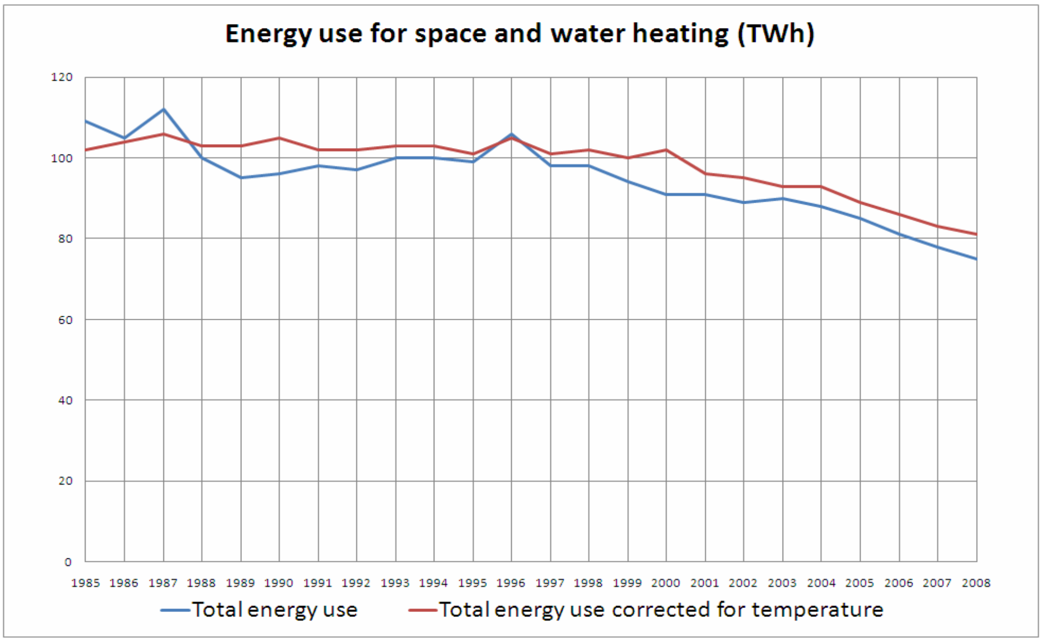


Figure 9: Energy use in heating (data from Energimyndigheten)

The figure shows a continuous decline in energy use. Given that the heated area likely has increased over the period as well, the energy use per m^2 would show an even more obvious trend. However, the studies cannot clearly report any significant changes in the estimation of heated area for the last years. Different methods used for estimating heated areas as well make comparison to previous years sometimes difficult and uncertain regarding this.

District heating systems are now very well developed in Sweden, reaching out to a large share of the buildings in cities. Although, studies show also that a significant part of the heating still is done electrically.(Energimyndigheten, 2008) Even in the houses that don't primary have electric heating system, a significant part of the electricity used in the household goes for some sort of heating (e.g. even if a house is connected to district heating some parts such as bathroom-, floor heating etc. are often heated electrically). Figure 10 shows the last years changes in how space and water in houses and buildings are heated. As seen, district heating and use of wood fuels are becoming more popular, on the behalf of heating oil and electric heating.

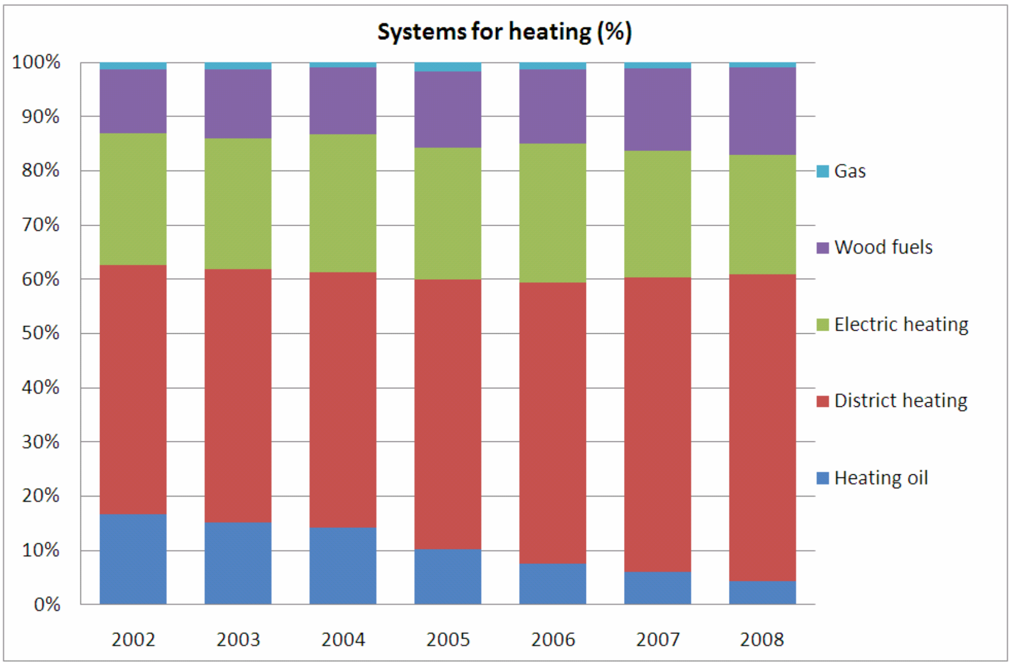


Figure 10: Heat supply in houses and buildings (data from Energimyndigheten)

In district heating the fuels used are mainly wood fuels (25 TWh) and waste (10 TWh). District heating production has had a huge increase, going from delivering 10 TWh in 1990 to 48 TWh in 2008 (Energimyndigheten, 2009:28). The quantities of waste in district heating increased a lot when dispose of unsorted combustible waste in landfills was forbidden.

5.3 Electricity

In total 2008, close to 144 TWh of electricity was used in Sweden. The residential and service sectors stands for about half (72,4 TWh). Except the 21,2 TWh that was used for electric heating, 19,5 TWh was electricity for household purposes and 31,7 TWh for common purposes. The rest of electricity used was mainly within the industry (55,5 TWh), where especially pulp and paper industry requires a lot of electric power (22,6 TWh). The demand within transports so far is limited to just about 3 TWh. Distribution losses account yearly for around 11 TWh.

The production is almost entirely from hydro or nuclear power, 68,3 TWh and 61,3 TWh respectively. Combined heat and power and Industrial back-pressure power together produced almost 14 TWh, which is most of the remaining part. Electricity from nuclear is the base power in the grid with relatively constant production. While hydro power also can have an important function as a regulating power source, and will become even more so if the planned increase of other renewable production come in place. But at the same time hydro power is an energy source which production can vary a lot depending on if it’s a wet or dry year.

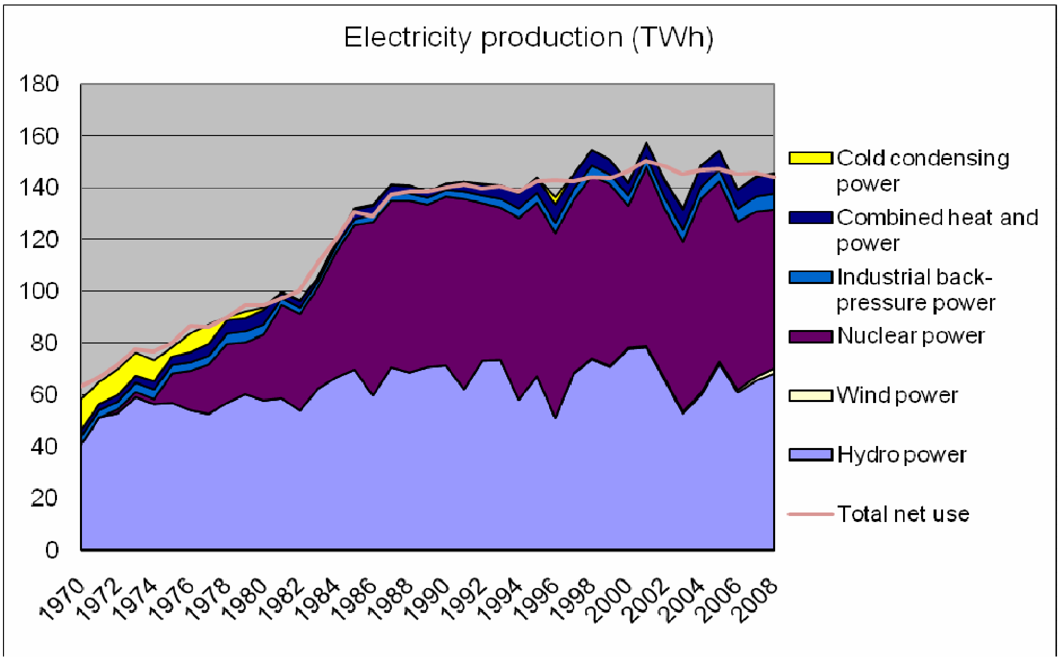


Figure 11: Production and use of electric power (Energimyndigheten, 2009)

The markets in the Nordic countries are becoming more and more integrated. One big reason to this is the Nord Pool Exchange, which is the common Nordic market where the trading takes place and where the spot price for electricity is decided. Since Norway produces almost all its electricity from hydro, the precipitation volumes do have a very big impact on the market prices. The electricity is being imported and exported like other forms of energy, and naturally these trades are made with our neighboring countries. However, Sweden in general is self-sufficient in producing electricity, and the net import/export usually just adds up to a few TWh annually.

5.4 Import flows

One important question that needs to be asked, when looking at energy security, is where the energy comes from. Energy resources are not evenly distributed around the world, which means some countries will be more important than others for the energy supply. And very few countries today have possibility to completely satisfy their energy demand with indigenous resources. Figure 12 shows a map illustrating where the main import flows are coming from. The arrows are made to scale to symbolize which imports are the largest, and include nearly all of the fossil energy resources (around 95%). The figure shows how Sweden especially is reliant on a few supplying countries, with Russia clearly the most important one, to meet the energy requirements. Note that all produced nuclear energy has been counted as originally imported, and that the energy imports equal to less than 5 TWh not are included in the figure.

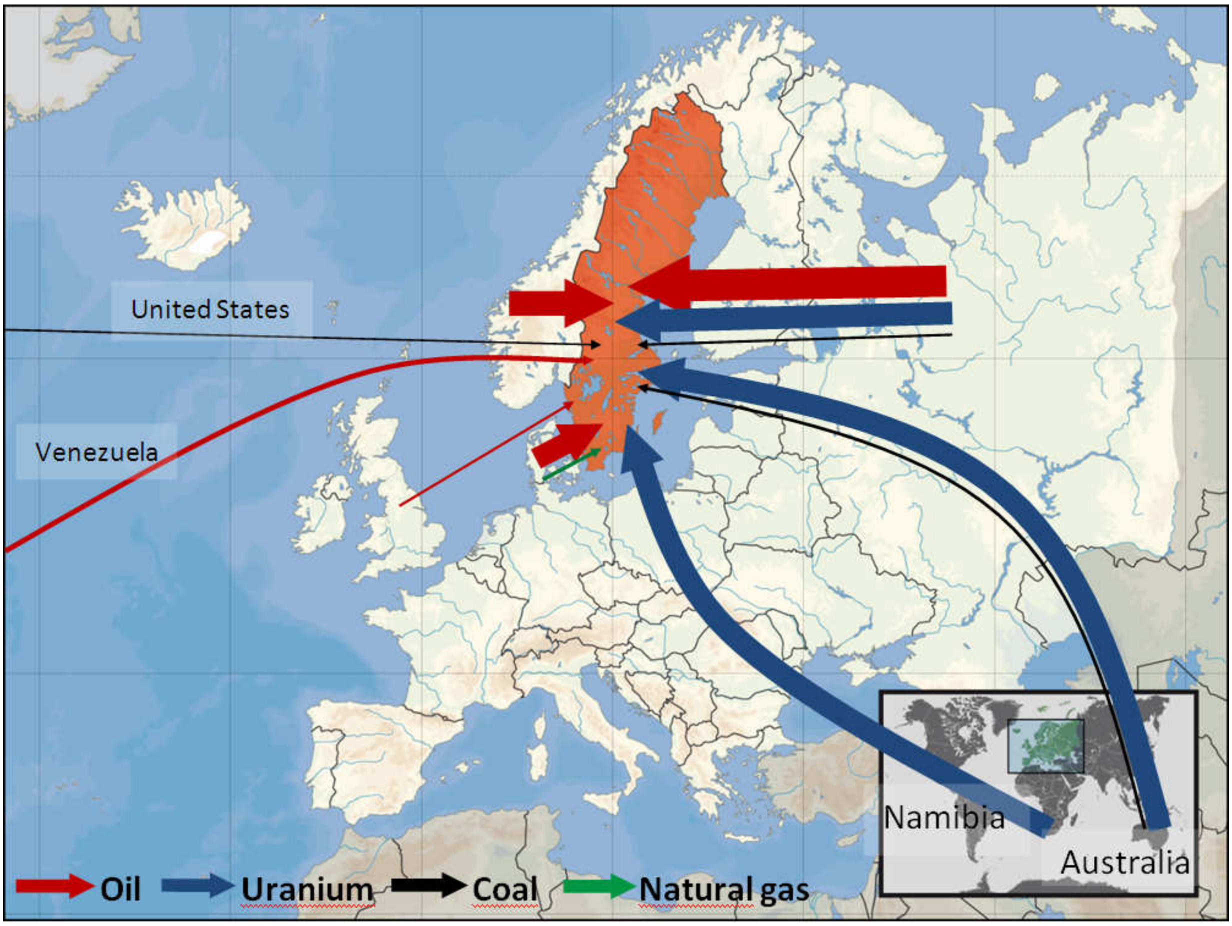


Figure 12: Import of energy products (data from SPI, SCB, Energimyndigheten, Vattenfall)

The imported energy resources will be analyzed in respect to the state of supplying countries (availability, accessibility etc for the resource). It's also possible to argue that it wouldn't matter from where we import since the energy can often be imported from any of several exporting countries, and in case of supply disruptions from one supplier it's possible to just turn to other suppliers. But with rapidly rising energy demand, mainly for limited resources with reserves and production that are in decline (BP, 2009), the world's demand will have to be met by fewer and fewer countries. This equation will be practically impossible to solve, when many countries today already are producing close to maximum from their oil fields.(Aleklett, 2006) As well, results from previous energy security studies have pointed out the important role the suppliers play for a country's security.

From the security perspective, it could also be uncertain to assume that the global market will work well for all future. After all we've seen some historic examples of markets collapsing. (Hammoudeh, 2005) And some of the countries with large energy requirement and economic and military power already fighting to protect supply of oil from all parts of the world, while more producers are struggling to maintain their production. (Jun et al. 2008)

5.4.1 Crude Oil

There are especially three countries critical to our supply of crude oil. These are Russia, Norway and Denmark, each accounting for around 30% each of the Swedish supply. Imports from Iran made a big share of the total just 10 years ago, but is already down to almost nothing. Instead the share of Russian crude oil import has increased rapidly and become the most important supplier. Figure 13 shows the import of crude oil to Sweden divided by country.

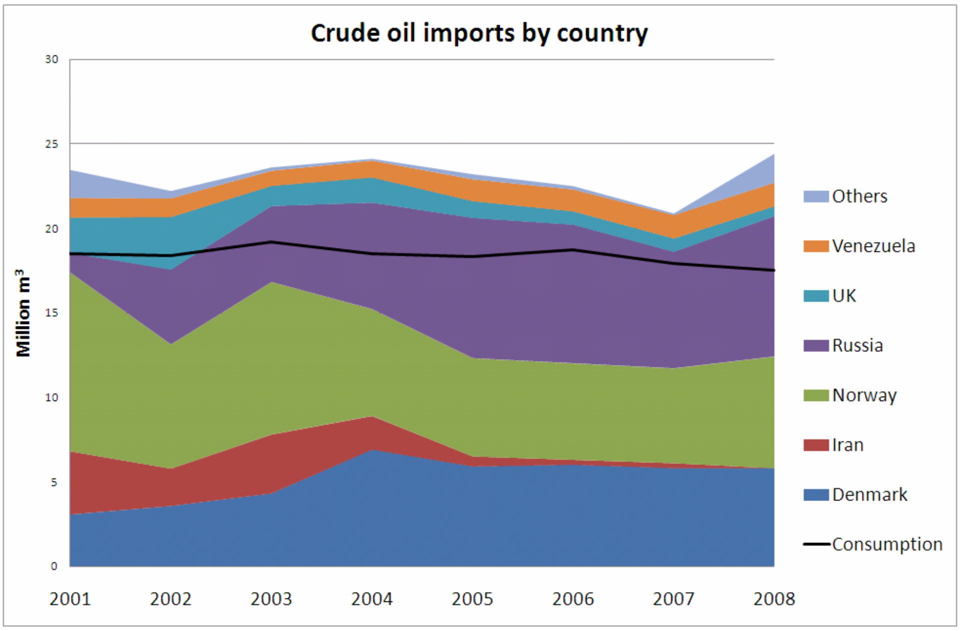


Figure 12: Crude oil imports (data from BP, SPI, SCB)

Additionally a lot of refined petroleum products are being imported, although Sweden has a large domestic refinery capacity and is a net exporter of refined products. During 2008 the refinery production was 21.6 million m^3 of oil products and the net export over 6.2 million m^3(SPI, 2009). The large refinery capacity, as the figure shows, has had the effect that the crude oil imports normally have been well above the Swedish demand for oil products.

5.4.2 Natural Gas

The Swedish natural gas grid is connected to the Danish one, which means almost all the natural gas comes from the Danish production. The amount of natural gas supplied to the Swedish market is still very small though, not more than about 10 TWh. Norway as well has production of natural gas, but no connection to the Swedish grid.

Total in Europe 38% of the total net supply came from indigenous production, and approximately 23% of the imports came from Russia. Forecasts says Europe's reliance on natural gas is expected to increase 2-3 times until 2030, and consequently then also the imports to the region will increase.(Constantinini et al. 2005) Russia is responding by expanding their pipeline systems for natural gas, via the north stream line through the Baltic Sea for example. This means Russia soon could be the main supplier of natural gas to Europe, since the European reserves are in depletion. However, there are questions whether Russia's export capacity actually will be able to supply Europe with sufficient amount of natural gas in the future. (Söderbergh, 2010)

5.4.3 Coal

Coal as well is a very important energy source globally supplying more than a quarter of the world's primary energy (IEA, 2009). In Sweden there are no power plants running primarily on coal, and therefore demand is rather limited. Most of the coal used in Sweden is hard coal, which can be the metallurgical coal used in iron and steel industries or steam coal used for energy purposes. For industrial production processes coal is a very crucial resource though, since there are not really any good alternatives that could be used to substitute this use. China and USA are the main producers of coal (together having over 60% of the world's production), and are also the countries consuming most coal. (BP, 2009) The share of coal that is traded internationally is much lower compared to oil. A major share of Sweden's imports of coal comes from Australia (1.14 million tonnes). Other important import countries are Russia and United States (0.76 and 0.57 million tonnes respectively), who together with Australia are accounting for more than 75% of the total coal supply to the Swedish market during 2008. (SCB, 2009).

3.3 million tonnes of hard coal was used in Sweden during the year. Totally 1.3 million tonnes was used directly for energy purposes, the other 2 million tonnes were industry coking coal (Energimyndigheten, 2009:28). In total energy this equals close to 27 TWh.

5.4.4 Biofuels

Biofuels can consist of many different kinds of biomass and come in many forms. Wood fuels, black liquor, cereals, peat, combustible waste, ethanol, FAME, biogas are some of the most used energy resources that are usually categorized as biofuels. Biofuels now makes about one-fifth of the energy supply, which means it has almost doubled its share since the 1980's. Much of the increase has occurred in district heating and the industry sector. Most of the demand is met by domestic resources, and Sweden also has some export of biomass. However, for imports Latvia is an important supplier country of wood products, and delivering a major part of the fuel wood, wood residues, and wood chips. Norway is second biggest in this respect. Some of the other countries exporting to Sweden are Finland, Russia and Canada. (EFI, 2006) Imports have increased a lot during the last decade, but also the export volumes are increasing. Figure 14 illustrate imports of wood residues, fuel wood and wood chips taken from the *forest products trade flow database*.

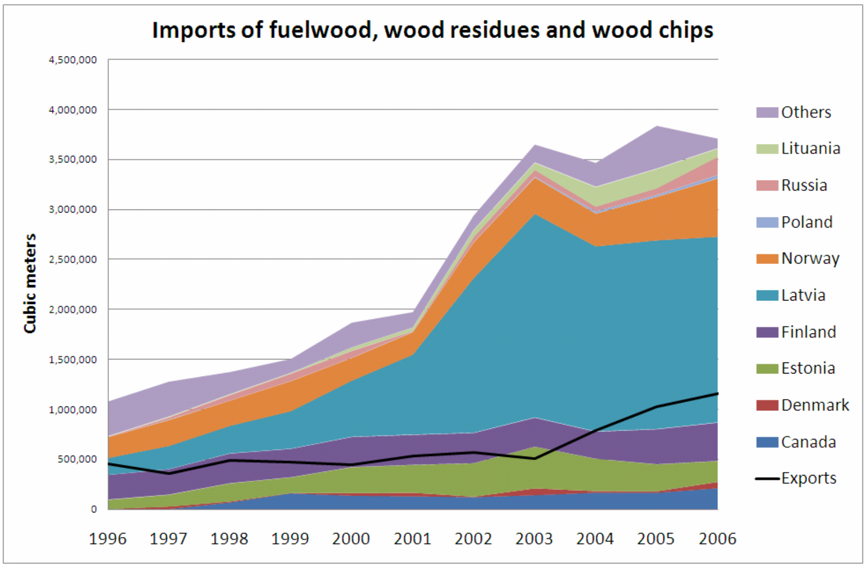


Figure 14: Biomass imports by country (data from EFI, 2006)

Other relatively big biofuel imports, that are not shown in the graph though, are ethanol imports from Brazil and peat imported from Belarus.

5.5 Energy policy

Ways to improve energy security for a jurisdiction are varied. A document that should be a guideline for this goal is the energy policy. Sweden's energy policy is built on the same three pillars as EU's energy cooperation, which are **ecological sustainability**, **competitiveness** and **security of supply**.

As the policy say, the dependency on fossil energy will have to be broken, and "Measures to promote renewable energy and more efficient energy use will strengthen Sweden's security of supply and competitiveness in Sweden and give Swedish research and entrepreneurship a leading role in the global transition to a low carbon economy." (Regeringskansliet, 2009)

Some of the national targets set for 2020 are:

- 50% renewable energy
- 10% renewable energy in transportation
- 20% more efficient energy use
- 40% reduction in greenhouse gas emissions

Ways to achieve this, according to the policy, could be through advanced economic policy instruments, and possibly increased taxes on energy and fuels. The heating sector should phase out the use of fossil fuels by 2020, and significantly improve energy efficiency. By 2030 the Swedish vehicle stock as well should be independent of fossil fuels. For electricity generation nuclear power will remain important, but a third pillar that reduce the dependence on just nuclear and hydro power should also be developed. For example wind power and cogeneration could together fill this function. Increased production from hydro power will be limited with the continued protection of the large rivers in north of Sweden. For wind power a new planning framework of 30 TWh by 2020 (20 TWh from land and 10 TWh offshore) will be established. New construction of nuclear power will be allowed at existing sites within a framework of maximum ten reactors. Current reactors will be possible to replace as they reach the end of their technological and economic life. Peat is also being mentioned as a nationally available energy source significant for Sweden's security of supply, which under certain conditions can be used with positive net climate impact. (Regeringskansliet, 2009)

6 Applying 4 A´s on the Swedish energy supply

Discussed in this chapter are the main categories of energy sources in the Swedish energy supply, concerning their availability, accessibility, affordability and acceptability. The supply of energy has been divided into five main categories.

6.1 Availability

First availability, and data that can be used for measuring this, is analyzed for the different types of energy sources. Concluding the chapter (in 6.1.6) is the attempt to find a representive quantitative availability indicator that can be applied.

6.1.1 Oil products

Saudi Arabia is the country having the greatest oil reserves in the world, and stands alone for 21% of the world's oil. Together with the other Middle East countries as much as 60% of the world oil reserves are included. Africa, South America and Europe/Eurasia each have about 10% of the world reserves (BP, 2009). As was seen in figure 13 the countries that during recent years have been important for supplying Sweden with oil is mainly Norway, Denmark, Russia, UK and Venezuela. This means oil reserves and production in these countries most likely will be important also to energy security in Sweden. In the chart below the crude oil production (million tonnes) over the last ten years for these current suppliers are presented:

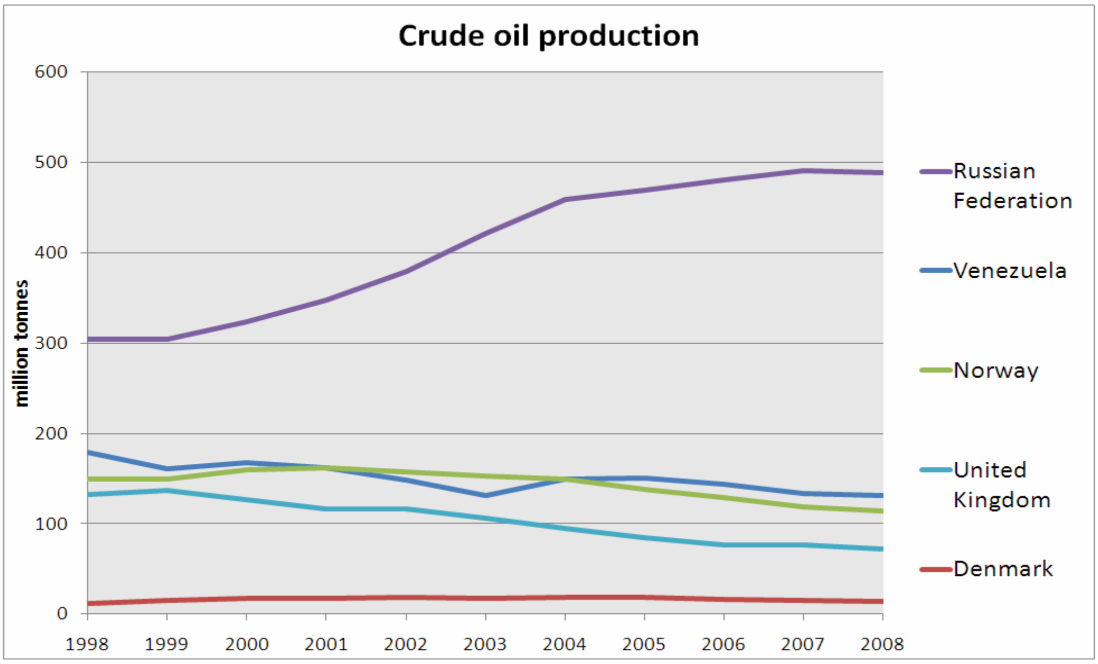


Figure 15: Oil production in supplying countries (data from BP, 2009)

The chart shows oil production that is in decline for most, or maybe all, of the suppliers. Also it illustrates well how little oil Denmark is producing, and that both Norway and Denmark most likely have had their peak in production many years ago (2001 and 2004 respectively) and since then are in decline. Denmark uses around 9 million tonnes of oil themselves (out of 14 million tonnes production) in a year, which means that the volume exported to Sweden equals their whole surplus production and that the production decline therefore likely will have a direct effect on our oil supply. United Kingdom is in a similar situation, where they have gone from being a net exporter to net importer of oil during the last few years. Norway still produces more than 100 million tonnes a year, but the depletion from the peak of production seems to be going quite fast. Research made on all known oil fields in Norway shows this trend is very likely to continue unless any new giant oil fields are discovered.(Höök & Aleklett, 2008) Russia is the world's second largest oil producer (after Saudi Arabia), and had in 2008 a production that was around 20 times larger than the whole Swedish imports. They probably reached their production peak already in 1987 when producing almost 570 million tones, but might have had a second peak in 2007 leading to a decline in production the coming years. (BP, 2009)

One method that has been used in literature to reflect availability of oil is the reserves/production ratio (R/P). This method uses data on known reserves and production of oil to estimate how many years production can continue. A simplified and somewhat misleading way of determining for how long oil will be available since it assumes a constant production rate and reserve capacity. When instead the production rate will continue to show a more gradual decline (if not many new oil fields are found and put in production). However the R/P can give us an idea of how much oil is known to be available. The table below presents the reserves and associated R/P values for Sweden's main import countries:

Table 3: Proved reserves and R/P ratio among Swedish crude oil suppliers.

Oil: Proved reserves	at end 2008		
	million	Share	R/P
	tonnes	of total	ratio
Venezuela	14319.9	7.9%	*
Denmark	108.3	0.1%	7.7
Norway	921.4	0.6%	8.3
Russian Federation	10828.7	6.3%	21.8
United Kingdom	452.0	0.3%	6.0

(Data from British Petroleum)

This also shows proved reserves in the countries, and their share of the global reserves. Thus, Russia has close to 11 billion tonnes of oil which would last over 21 years with current production rate. Norway's reserves are ca 900 million tonnes and Denmark´s reserves are even smaller with just 100 m tonnes (corresponding to 0.1% of the global oil reserves). Venezuela has a small production in relation to their very big reserves, meaning their oil could last more than a century with this production rate. However, the oil from Venezuela is usually of lower quality, and most of it therefore is used for non-energy production rather than fuel.

Notable with the R/P value still, is that they show Denmark, Norway and UK (supplying more than half of Sweden's oil) will be among the first oil producing countries to "run out" of oil. Thus, the availability of oil should not be considered secure. Worth mentioning as well though, for availability of oil products, could be Sweden´s refinery capacity which is more than 24 million tonnes a year. This is actually more than both Norway and Denmark, which shows that the countries having the oil resources not always have the possibility refining it into oil products. (BP, 2009)

6.1.2 Natural gas

Natural gas is important to many European countries, but relatively little is used in Sweden. The Swedish consumption of natural gas during 2008 was just about 10 TWh, which made up about 10% of the Danish production (from where we import) of 9,1 million tonnes oil equivalents. Denmark's export capacity during recent years has normally been around half of their production. The statistics shows Denmark's production of natural gas likely had a peak during 2005/2006. And the reserves/production ratio is expected to no more than 5.5 years (BP, 2009).

A more detailed study on the Danish oil and gas fields argue that no clear peak so far has been seen in most of the gas fields. But also points out how dependent the production will be on the behavior of their only giant field, and that the reserves in many of the smaller dwarf fields are very small. And even considering an optimistic forecast of the gas production Denmark seems to face a steep decline during the next years. (Höök et al. 2009)

Expanding the Swedish grid for natural gas, and making the gas more important to the Swedish energy market, therefore mean that we have to find more secure sources to import gas from. Because of the pipeline distribution this likely would mean countries close to Sweden with big gas reserves. Naturally this would be Norway or Russia, which mean we would also for this energy source eventually be relying mainly on the same countries supplying the oil. (Söderbergh, 2010)

6.1.3 Coal

The 27 TWh supplied to the Swedish market in 2008 stands for less than 0.7% of the European Union's total use of coal. The availability of coal resources are high compared to other fossil fuels, and global production rate has been going up for the last ten years. Proved reserves globally are estimated to 826 billion tonnes, which with current production rate would last for more than 100 years. (BP, 2009) About half of this amount is reserves with anthracite and bituminous coal (hard coal), which is the type that is most common on the global market and the type of coal Sweden imports.

Completely opposite to the oil production discussed earlier, coal production shows a continuous increase in all three of Sweden's main import countries (see figure). Thus, no production peak has been seen yet. The figure is from data including both hard coal and brown coal/lignite production. A major share (80-90%) of the production consists of hard coal however, but only around 16% of the production in 2008 was traded on the international coal market. (World Coal Institute, 2009) This shows that coal is a resource that is primarily used locally.

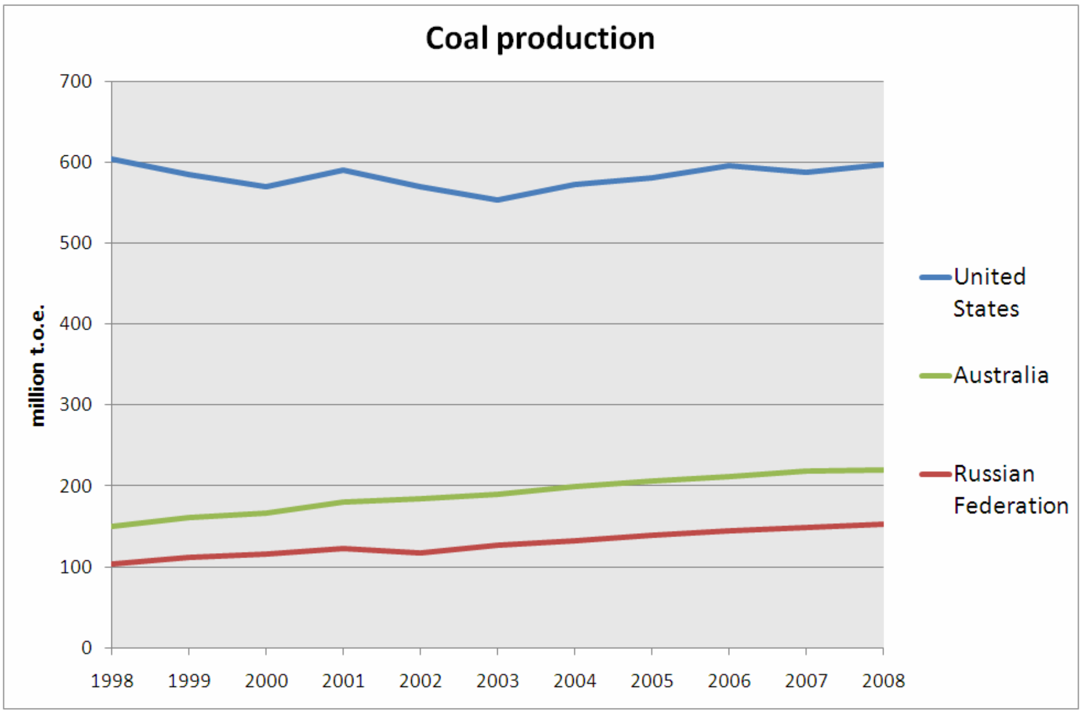


Figure 16: Coal production in main supplying countries (data from BP, 2009)

Coal is a very concentrated energy resource. Looking at the proved reserves over the world, United States has the biggest with 238 billion tones (or 29% of the world reserves). 19% of the reserves are in Russia, 14% in China, 9% in Australia and 7% in India. This means five countries have almost 80% of the worlds proved resources of coal, thus being the most centralized of the energy resources. (BP, 2009) Only comparing anthracite and bituminous coal will show similar results, but more equally distributed between the same five countries. Regarding availability, coal must be considered more secure than oil or gas, but instead have some disadvantages with accessibility and acceptability (which will be discussed more below).

6.1.4 Biofuels

A large quantity of the biomass comes from the forest industry in form of felling residues, firewood, bark, sawdust and so on. Of the 123 TWh, about 85% comes from forest industry somehow. The agriculture supplied only about 1% of the energy, and most of the remaining part comes from waste or peat (Bioenergiportalen, 2010). Most of the biofuels used in the country are of indigenous origin, but some is also imported. Especially for renewable fuels in transportation. Swedish ethanol production currently is far from meeting the demand in transportation sector, and the increased use means more imports. The Brazilian production of sugar cane ethanol is expanding fast to meet the world´s increasing demand. During the last ten years production has doubled, and was in last year 27,5 million m^3 (BSIA, 2009). Swedish use in 2008 was 2,5 TWh, equal to 0.4 million m^3 or 1.5% of Brazil's production.

About 30% of the peat used in district heating, 363 000 tonnes, is imported. Most of it from Belarus, but also from Estonia and Finland. However, also the exports of peat from Sweden is increasing, and was 251 000 tonnes in 2008. The peatland density in Sweden is considered among the world's highest, almost one fourth of the land area is covered with peat. Of this area an estimated 350 000 ha has been determined as suitable for extracting peat for energy use. (SCB, 2009)

From the wood fuels used for energy purposes more than 87% comes from the Swedish forests. (KVA, 2007) And with the huge indigenous biomass resources, Sweden cannot be regarded as much dependent on imports (with the exception of ethanol). Reasons for importing forest fuels have likely been more connected to cheap supply so far. The Swedish forests have continuously increased in volume for centuries, meaning biomass availability should be ranked high. Figure 17 shows the growth of Swedish forests volume during the last century:

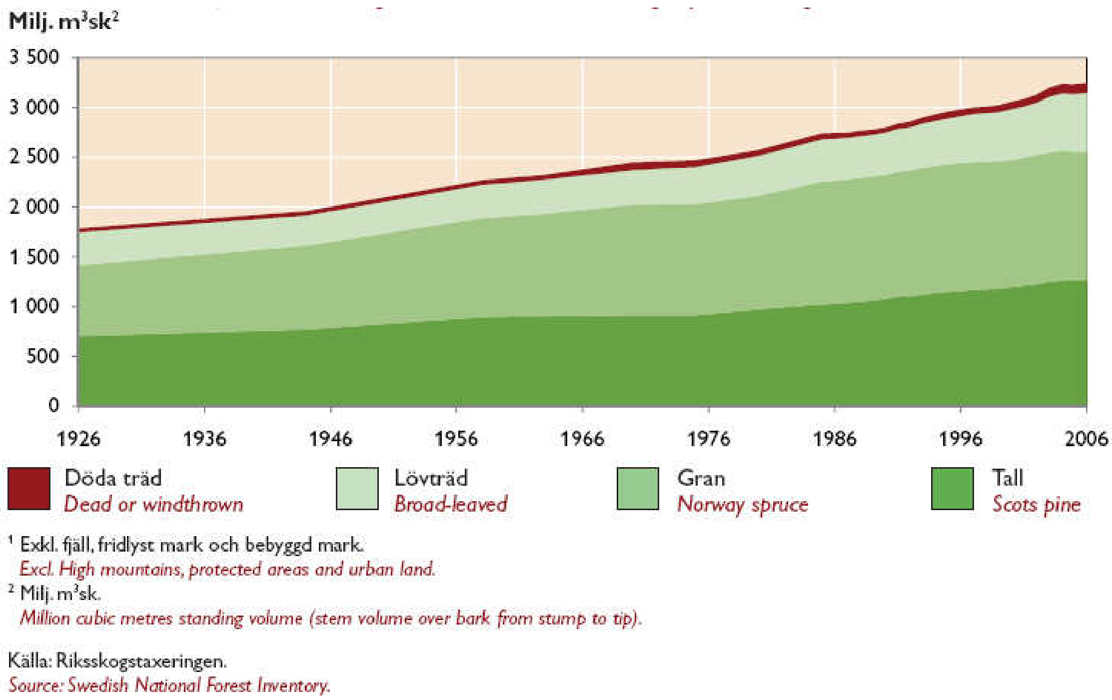


Figure 17: Volume of Swedish forest (Swedish national forest inventory, 2009)

6.1.5 Electric power

The availability of electric power can be discussed in terms of installed capacity. However it is important to remember that the production from every installed watt will vary a lot depending on which type of electric production is discussed. Installed **hydro power** capacity in Sweden is 16 195 MW (2008). Lule älv is the river with most installed capacity, 4 196 MW (Elåret 2008). The total production in the hydro stations reached up to 68,3 TWh during the year. How much hydro power that can be produced depends on rainfall and the water available in the reservoirs (if water availability was infinite, Sweden would be able to produce all its electricity from hydro power). Studying historical data tells us water availability is unpredictable though, and can vary a lot from one year till the next. During 2008 the supply of water to the hydro stations were less than for a normal year, see figure 18.

The availability of hydro power also is different depending on season. The reservoirs normally fill up after the spring flood in april/may(see figure 18, right), and can then produce at full capacity. All year though, hydro power function as a regulating power in the Swedish power grid, and the reservoirs have capacity to store water corresponding up to 33 TWh of energy. (Elåret 2008)

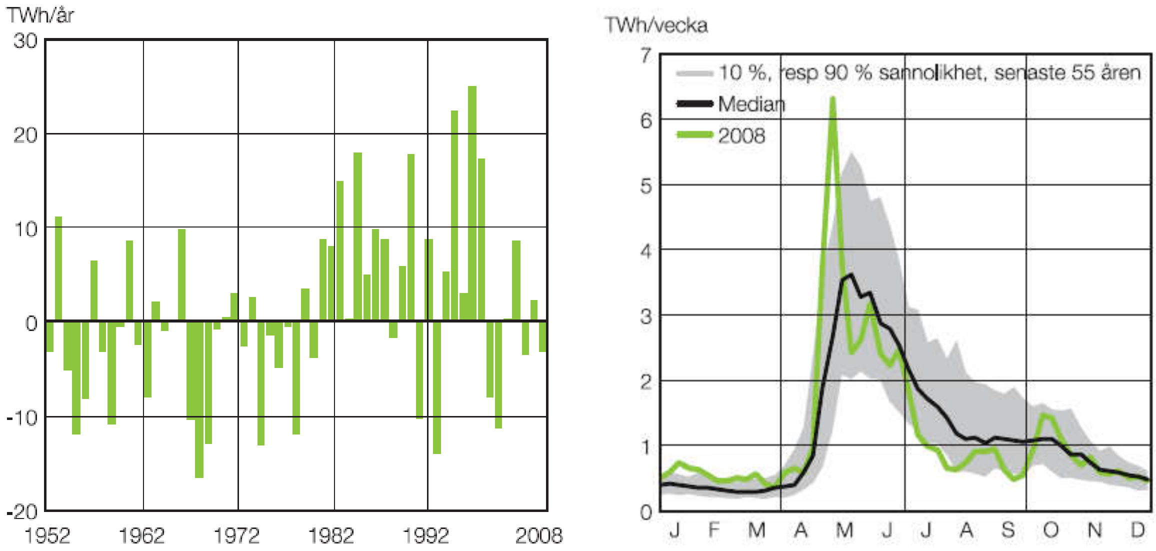


Figure 18: Hydro power availability, deviation from normal year and monthly variations (Elåret 2008)

Sweden has 10 **nuclear** reactors with a total capacity of 8 938 MW(small decline compared to the year before). The nuclear power function as “base power” in the electric grid, with its relatively high availability and constant production. During 2008 the energy availability from the reactors varied from 62% - 91% (percentage of maximal capacity, average 82,3%), and the production (61,3 TWh) was the lowest in many years. A lot of this has to do with unplanned downtime in some of the reactors during the year (Elåret 2008), but also the planned upgrading measures in the reactors have caused this declining trend in electricity produced from nuclear power during the last years. The nuclear reactors have entered a development phase which makes the availability lower than it normally is.

Uranium to the nuclear reactors is imported, and comes mainly from mines in Australia, Russia and Namibia.(Vattenfall, 2010) Other big producers of uranium are Canada and Kazakhstan. The biggest known recoverable resources can be found in Australia, Kazakhstan and Russia. However, the actual availability of nuclear fuel is compared to other fossil resources harder to estimate. Mainly since the scale of exploration hasn’t nearly been the same as for oil and gas. And also because of several secondary uranium resources such as recycled uranium and plutonium, re-enrichment of depleted uranium, civil stockpiles and nuclear weapons, which could cover parts of the supply. (World nuclear association, 2010)

In end of 2008, 1080 **wind power** turbines (with minimum 50 kW) were delivering electricity to the grid. In total the installed capacity was 1 021 MW, and producing 2 TWh(40% increase from the year before). The produced electricity from wind power in relation to installed capacity thus is much lower for wind compared to hydro and nuclear. A major expansion of the wind power capacity is planned to continue in the coming years, and increase its share of electricity production. It’s important choosing appropriate locations for new wind turbines, where availability of wind is good. Normally wind power is more available during the winter months compared to rest of the year, which is illustrated in figure 19 showing production by month. Actually the availability of wind power quite well fit the electricity demand curve.

(Elåret 2008) Which could make it a good compliment to hydro power that produces more during summer and less in winter.

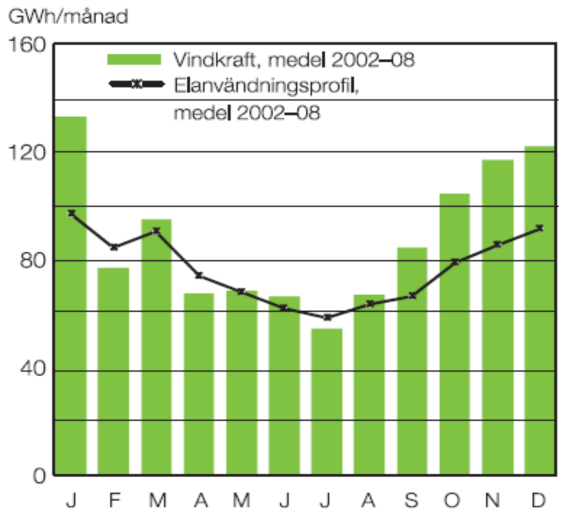


Figure 19: Wind power, monthly variations (Elåret 2008)

Installed capacity in combined heat and power (CHP) in general is determined by which primary fuel is used. The total effect in district heating-CHP was 2 995 MW and in industrial-CHP 1 194 MW. Although biomass is the main fuel in most CHP-systems, others often can be used as well.

In total, the effect in all the different power stations is more than 34 000 MW. The production in 2008 was 146 TWh, which means a net export of electricity. The biggest import of electricity was from Norway (9 TWh) and biggest export to Denmark (7 TWh). (Elåret 2008)

6.1.6 Quantitative indicator (AVA)

Somehow these availability characteristics need to be represented by an indicator. The method suggested to do this is by calculating production data from the supplier. These data can show the trends in production, if it is in decline or depletion. Using production data instead of, for example, reserves data makes the same kind of measures possible for renewable as for fossil energy. These data can also be seen as more accurately measured, while reserves estimations can be exaggerated in one way or another. Production is assumed to reflect availability of the source, since production is likely to increase for resources that are abundant and decrease for resources in depletion. For resources not available within Sweden data will refer to production trends in the exporting countries.

Still though, there are number of ways to calculate a value on availability from a production curve. The most simple way would be to just make a linear regression over a specific time period. Another way would be to go back to an inflection point, peak or trough, on the curve and fit a regression line from there. With curves showing a steady increase or decrease in production since many years back (for example the coal production in figure 16) both of these methods very well can be used, but the problems can be with production curves showing very high fluctuations (for example hydro power production shown in figure 18). Or that the starting year of the time period goes back to a year with abnormal production, for some reason, and then show values that can seem unreliable. (Hughes, 2010)

Therefore the method used was to fit a regression line from production in all of the latest years, and then calculate an average. This will prevent temporary drops or peaks in production to affect the availability value too much. There are still the difficulties though to decide how far back the data should be studied. You could argue that if it goes just a few years back you can't really see any trends. But on the other hand, chose a starting year to long back means production that has peaked will still show good availability. In following calculations year 2000 has been chosen as the starting year. The aggregated value for fuels supplied by different producers have been calculated by the share supplied to the Swedish market (how much of the production is exported to Sweden) to receive a total availability value for the specific fuel.

Thus, the indicator reflects the production trend for various supplies between 2000 and 2008. Since values are normalized, zero availability does not mean no production at all. It only shows that availability has been estimated as lowest among the compared fuels, and is caused because of a continuous decline in production.

6.2 Accessibility

How accessible an energy source is can be reviewed from a supplier perspective as well as from a demand side perspective. Both of these are discussed briefly for the different energy forms.

6.2.1 Oil products

Almost all of Sweden's main oil suppliers are neighboring countries (or within close geographical distance) and close trading partners, which in many ways can limit problems with supply access. This especially goes for Norway and Denmark (together more than half of the oil supply), who just like Sweden is part of an already very well integrated Nordic energy market. Also when using indexes relating to geopolitical risks for different countries (GPI, 2009) gives no reason to expect geopolitical implications with access from the Nordic countries or UK. However, Russia and Venezuela, according to the same index, are some of the countries where the risk of implications is the highest. In the case of Russia, tendencies of "using energy as a weapon" has also been observed (Christos et al. 2009).

To meet national energy demand, the oil products (petrol, diesel, heating oil etc.) should be considered as very accessible fuels. This especially goes for the transport sector, where practically all vehicles can (or must) access petroleum products of some sort (trains being the exception). Oil was representing almost a third of the total supply of energy to Sweden in 2008. And more than two-thirds of the oil products came to use in the transport sector. (Energimyndigheten, 2009:28) In the heating sector oil is indirect an accessible fuel, meaning it can be used as fuel in the district heating system. However the direct accessibility is not as high since it has been phased out as a primary fuel in district heating, and now only used as fuel in a few percent of the sector. The accessibility for oil as fuel in power production is very low. Just in extreme situations, like very cold weather, the few power plants running on oil are in use.

6.2.2 Natural gas

In Sweden the pipeline distribution system for natural gas is not very well developed so far, and therefore demand as well is quite limited. Only some parts in south of Sweden is connected to the grid at present, where the gas pipelines enter Sweden from Denmark in the very south and goes along the west coast of the country (EON, 2010). The undeveloped infrastructure for delivering gas to consumers means big accessibility problems for the rest of the country. Some of the industries and households in south of Sweden can access the gas and use for heating or power production, but in total natural gas makes up just a few percentages of the required energy in the sectors, and is not very accessible from a national perspective (however, in a study made locally in these areas it would have to be assigned a greater accessibility and importance). Increased production of liquid natural gas (LNG) has the opportunity to make the gas more accessible, though this is more expensive and also needs other techniques.

The use of gas in transports however is being promoted, and becoming more accessible with the extension of infrastructure. The number of gas stations where you can fuel your car with gas are increasing, as well as the vehicles that can drive on gas.(OKQ8, 2010) Although, gas still has a very small share of the market for fuels in the transport sector (less than 1 TWh).

6.2.3 Coal

Even though availability is estimated very high, it doesn't mean the resources have to be accessible. The fact that a huge share of the world's coal resources are concentrated to just a few countries, means accessibility could become a problem. Even in the countries where the resource is available, there might be problems to access the coal because of different reasons. Much of the coal in US can prove to be inaccessible due to geographical constraints and regulations for example. (Aleklett, 2009)

In Sweden coal as energy source is accessible mostly for heating and production in the industries. It is possible using also for residential heating in some parts of the district heating systems, but has since many years now not been used as a primary fuel. Some coal still is regularly used though in cogeneration, CHP, for simultaneous heat and electricity generation. In transports coal has very low accessibility, and practically can't be used as fuels for vehicles if it's not liquefied.

6.2.4 Biofuels

Biomass is available and accessible in many forms, and more or less in countries all over the world. And with almost 90% of the biomass coming from domestic production, access to the primary sources can't be considered a big issue. Possible implications to accessibility of biomass rather should be discussed in terms of infrastructure in the different sectors, or conversion techniques. For example, even though Sweden has the available resources, the technology for converting it into fuel for transportation is missing. Such technology would mean more secure access, compared to relying on Brazil for 70- 80% of the imports (Naturskyddsföreningen, 2009).

Also, the previous dependence on oil products means the infrastructure mainly has been developed to support these types of fuels. For example just a small percentage of vehicles today can access biomass fuels like ethanol or biogas. However, gas stations are starting to make ethanol and alternative fuels more accessible to the consumer by having the alternatives to conventional petroleum products.

The heating sector to a wide extent now uses biomass as fuel, meaning it's accessibility in the sector is high. And the district heating systems, fueled mainly by biomass, are well developed by now and accessible to a large part of the residential buildings. For many of the big companies within the forest industry it's natural to use byproducts from the wood for generating heat or electricity. Most of the supply of primary fuel in Swedish electricity production actually is biomass, although this is because of the big dominance of hydro and nuclear power that doesn't demand much input.

6.2.5 Electric power

Electricity as energy carrier is very accessible to the society, except for transportation purposes. The Swedish power grid is well developed and reaches almost every household in the country, meaning everyone has access to electricity. It can also easily be converted into heat, even if not used as primary heating source. In transportation, energy in form of electricity is accessible almost only to train and rail traffic (around 3% of the transport sector). For transportation on roads it is becoming an alternative, but so far not many vehicles powered by electricity exist. This in turn is linked to the problems with storing electric power effectively, which becomes an accessibility barrier (especially for very energy consuming objects such as motor vehicles). It also means the power grid needs to be working all the time, and effects from disruptions or blackouts always become very serious.

For renewable power production like hydro and wind power, access to the primary fuel is not a problem of course (although the wind might not always be accessible at the same time as the energy is needed). For nuclear however, this could be the case since uranium production is concentrated to a small number of countries, and is distributed through other countries. First the mining of uranium is done in Australia, Namibia or Russia. Then enrichment of the uranium could be made in France, Germany or Holland for example. Before it is imported to Sweden for production of nuclear rods to the reactors. (Elåret 2008) Still though, uranium is not that sensitive to supply disruptions since the nuclear rods can be used over a long time, and can be reprocessed.

6.2.6 Quantitative indicator (ACS)

The quantitative accessibility indicator is to focus on the accessibility to the end consumer, considering whether the infrastructure and techniques exists for the consumer to apply and access the available energy source. One way of reflecting this is using the percentage of the total energy used in a sector supplied by each alternative. For example in heating, the percentage of the total energy used for heating supplied by each of the fuel sources (percentage of households accessing heat through district heating systems, fuel oil, electricity etc.). Or for transports, how much of the required energy is being met by petrol, diesel, ethanol etc (reflecting the share of the transportation sector and vehicles that actually can access the different types of fuels). Unlike other factors connected to accessibility, such as implications of geopolitical elements, these are indicators that are more measurable.

6.3 Affordability

This chapter refers to costs associated with the various types of energy sources. Prices for energy in different forms are presented with and without taxes, and in SEK/kWh to make the comparison between alternatives easier. All prices are average for 2008.

6.3.1 Oil products

When discussing oil prices, usually the spot price on crude oil per barrel is meant. Oil has during many years been a very cheap fuel source. Until just a few years ago the average price had never been more than 30$/barrel (except for the beginning of 1980's after the oil crisis). (EIA, 2010) But since that the price has shown drastic changes and very high fluctuations. During 2008 the average price reached the peak so far with a price close to 100 $ for a barrel crude oil. And when the price was at its highest during the year it was close to 150 $/barrel (EIA).

Many factors influence the price for oil and its volatility (availability and accessibility being some of them). Imbalance between demand and supply of course, but also the major oil companies investments in oil and gas upstream exploration and development. The major companies capital expenditures are dominated by their exploration costs, 74% in 2005 (APERC, 2007). The source of the oil imported does not have a significant influence on price though. The price difference between different suppliers is very small. (EIA, 2010)

According to national statistics (SCB) the average price for the oil imported to Sweden in 2008 was 0.40 SEK per kWh of energy. Commercial prices (excluding taxes) for the refined products were 0.55 SEK/kWh for petrol and 0.63 SEK/kWh for diesel. For medium-heavy fuel oil price was cheaper (0.37 SEK/kWh) and gas oil cost 0.59 SEK/kWh (Energimyndigheten, 2009:28).

Oil and the refined products are subjects to very high taxation however, and usually 60-70% of what the consumer pays for petroleum is taxes. (SPI, 2009) Diesel and other refined products have some lower taxes but still quite high. The taxes added specifically for the fuel (VAT excluded) per kWh was for petroleum 0.58 SEK, for diesel 0.41 SEK, gas oil 0.37 and medium-heavy fuel oil 0.35 (Energimyndigheten, 2009:28). Some exceptions though are fuels used for international aviation and bunkers, which according to international regulation can not be taxed. (see appendix 2 for historical trends in oil prices)

6.3.2 Natural gas

The natural gas price is, like other energy sources, linked to oil price and therefore has shown a similar upward trend in recent years. A growth in production of LNG will probably mean even more similar price trends between the fuels. But since most of the gas is still delivered through pipe-line systems, regional differences are more likely to occur than for oil. The Swedish, and Nordic, gas market is under development and has just recently opened the Nord Pool gas exchange. Following also the liberalization of the Swedish gas market in 2007 this will lead to increased competition on the market.

During the first year (2008) on The Nord Pool gas exchange the average spot price was at 25.9 EUR/MWh (Nord Pool Gas, 2010), being equal to about 0.25 SEK/kWh then. The taxes and end use price for consumers depends on if it is used in the residential sector, in industry or in transports. The industry just paying very low taxes of 0.04 SEK/kWh and in total 0.42 SEK for the gas delivered. While for residential use taxes of 0.22 SEK/kWh is added giving a total average price of 0.67 SEK for a delivered kWh. (SCB) The emission tax on natural gas for fuel in vehicles was 0.12 SEK/kWh. The prices for VAT or connection to grid has not been included. In petrol station the gas sold is usually a mix of natural gas and biogas.

6.3.3 Coal

Coal is the most cost competitive of the fossil fuels. Although prices are also likely to vary much more, depending on where it is mined and the quality of the coal. There is no global market, and prices are usually discussed directly between supplier and buyer. But similar to prices for oil and natural gas the coal price reached a very high level during 2008. The average price of Australian thermal coal from the Newcastle port, from where we import most of the coal, was during 2008 about 136 $/ton (Index Mundi, 2010). Close to double of the price during 2007, and also much more than in 2009.

According to SCB, the average price in Sweden per kWh coal bought during 2008 was 0.16 SEK/kWh. Thus, still a lot cheaper per energy unit compared to oil or gas. Taxes added to the use of coal represent more than 70% of the price though, 0.40 SEK/kWh. Making the total energy price 0.56 SEK/kWh.

Global investment costs for coal production is very low compared to other energy sources (estimated 5% of cumulative energy investments in APEC region 2003-2030), which has led to its cost competiveness. In future harder constraints on carbon emission might enforce the use of capture and storage (CCS) for industries using much coal energy. This will mean the price advantage that coal currently has will decrease. (APERC, 2007)

6.3.4 Biofuels

Different types of biomass fuels show big price differences, much depending on the amount of energy it contains and how it is processed. For persons heating their home with forest from their land, it can be practically for free. While buying refined products such as pellets would cost much more. In general though, biomass is very affordable fuel for heating purpose, but expensive when it’s processed for use as fuels in vehicles. Most biofuels are showing some increase in price, but not showing the same volatility as fossil fuels has done recently.

The average price for forest fuels delivered to district heating plants was 0.17 SEK/kWh in 2008, and since it’s a renewable energy source no emission taxes are added. Peat cost 0.15 SEK/kWh and being taxed with 0.018 SEK/kWh because of the sulfur emissions during combustion, thus being about the same price as forest fuels. The price for the heat delivered from the district heating plants to households however, in average was 0.52 SEK/kWh (VAT subtracted) although big variations exist around the country. Pellets are also free from taxes, but more expensive compared to forest fuel because of the production process, and had the average price of 0.38 SEK/kWh (Energimarknadsinspektionen, 2009).

6.3.5 Electric power

Average spot price on the Nordic power market (Nord Pool Spot, 2010) for the year was 0.43 SEK/kWh. Although there are several different ways electricity is produced, the price to the consumer is not directly connected to how it is produced (same price for hydro, nuclear, wind etc) but dependent on who uses it. For industry use the average price was at 0.66 SEK, plus taxes on 0.006 SEK/kWh. While the average household paid 0.86 SEK/kWh, plus energy taxes on 0.28 SEK/kWh (1.14 SEK in total + VAT). However, also some of the households pay lower taxes depending on where in the country they live (Energimyndigheten, 2009:28).

The cost for production however, is usually not the same for the different power sources. A comparison of specific overnight construction costs and generation costs gives an idea of the differences in production costs:

Table 4: Costs for electricity generation including overnight construction cost

	Specific overnight construction costs[i]	Generation costs[i]		External costs[ii]
	US$/kW	5% discount US$/MWh	10% discount US$/MWh	US$/MWh
Coal	1000 - 1500	25 - 50	35 - 60	85
Gas	400 - 800	37 - 60	40 - 63	25
Nuclear	1000 - 2000	21 - 31	30 - 50	4.5
Hydro	1600 - 6800	40 - 80	65 - 100	5
Wind	1000 - 2000	35 - 95	45 - 140	2.5
Photovoltaic	3000 - 11000	150	200	6

(APERC)

This shows renewable energies usually cost more than fossils for construction and generation, but if external costs also are considered the renewable energy can also be beneficial. Furthermore, the big gaps in construction and generation costs between the options will be narrowed when costs for renewable gradually is decreasing.

6.3.6 Quantitative indicator (AFF)

Affordability would ideally be a ranking of the user's ability to pay for the service. This could be difficult to measure, and not likely to be the same for all individuals in the population. Therefore, the price for the energy of the different energy sources will have to be the quantitative value used. It is very much reasonable however, to expect energy at a lower price to be more affordable. (Hughes, 2010) But also measuring the prices can be done in several ways. The fuel prices can be compared with or without taxes, with or without distribution costs, with or without including efficiencies in combustion, prices for companies or to private persons, in average prices or measures of volatility and price increase.

The prices used onwards will be average prices for the year 2008, and is being presented in price per kWh without taxes but including distribution costs (price for connection to power grid, district heating etc). In the case that prices still show big differences depending on users, an average price has been calculated. In heating and transport service an estimate of efficiencies in energy use has been included (see estimates and calculations in appendix 3). For electric power affordability will reflect production costs instead of cost to the consumer, since price for buying usually does not depend on how it's produced. Price changes are not reflected in the model.
Here a high value however would mean an insecure energy source, which is why the reciprocal of the price has to be calculated.

6.4 Acceptability

The 4th factor of energy security could be referring to various acceptability aspects, but will here (like the APERC definition) be discussed mainly in terms of environmental acceptability and especially the emissions from combustion.

6.4.1 Oil products

Oil is a finite energy source with high emissions of carbon dioxide. Between 640-750g/kWh of CO_2 is a fair estimation, depending on the product and burning efficiency. (IEA, 2009) It also releases emissions of NOx, SO_2 and particulate matter. Vattenfall (2005) calculates CO_2 emissions from their oil-fired back-up power plants to 910g/kWh, but being lower for combined heat and power production. Thus, environmentally oil has low acceptability as a fuel, which also is reflected in the high taxes added to oil products.
Also leakages from oil tanks or accidents like the recent oil rig explosion in the Gulf of Mexico (BP, 2010) are incidents that are causing unacceptable problems to the environment and ecological systems.

6.4.2 Natural gas

Natural gas can regarding the environmental aspects be considered more acceptable than oil since emissions are not as high and it can be used more efficiently, but it's still a finite fossil resource however. The amount of CO_2 emissions from natural gas is around 380-410g/kWh. For gas liquids (LNG) it is higher. The emissions of NOx and SO_2 are much lower than for oil. (IEA, Vattenfall)
Systems for use of natural gas can also be seen to facilitate future expansion of biogas, since same systems and infrastructure often can be used. Natural gas can be an important energy source in transition from carbon intense energy to renewable. (Byman et al. 2008)

6.4.3 Coal

Acceptability is one of the main barriers to coal as secure energy resource. It is damaging to the climate and has the most emissions of the different fuels if no capture and storage (CCS) is used. Clean coal technologies are being developed for a cleaner use though. The possibilities to almost entirely reduce the emissions of NOx, SOx and particulate matter already exist. CCS is an attempt to tackle the problems with CO_2, but is not yet effective neither from cost or environmental perspective. (APERC, 2007) The CO_2 emissions depend on the type of coal and its energy content, and can be somewhere in between 700-950g/kWh. Publics' acceptance to coal mining also tends to be low because of the very big land areas damaged at the location of a coal mine.

6.4.4 Biofuels

Biomass is considered an environmentally acceptable fuel option, since it is regarded neutral for emissions of greenhouse gases (even though the combustion does cause emissions). Also the biomass do not cause the security risks or risk of environmental damages that fossils do (leakage during produktion, transportation etc.). Emissions per energy unit from a bio fueled combined heat and power plant can be low as 16g CO_2/kWh. Instead using peat as fuel however, means CO_2-emissions could count up to 660g/kWh. (Vattenfall, 2005)

What could be negative to acceptability is the large land area needed to produce the energy. And always there is the competition with alternative use of the product (with food, industry etc). Especially using food and agricultural products for producing energy can mean acceptability problems when a growing population also will demand more food products. Production usually seems to be more accepted from some materials than others as well, think of ethanol production for example. The refining/production process of biofuels also can include use of other (less acceptable) energy forms, which is not always taken into account.

6.4.5 Electric power

Acceptability in terms of environmental effects from power production is mainly positive. Swedish electricity mix is very clean from emission of CO_2 and other greenhouse gases. Looking at the production mix for whole Nordic market the emissions are a little higher. According to Vattenfalls own life cycle analyses, their production releases less than 5g CO_2/kWh both for nuclear and hydro power, and just a little more for wind and CHP.

Negative for the acceptability is the risks that by many are associated with nuclear power. This includes the problems with long-lived radioactive waste products, security threats, fear of nuclear weapons etc. It's an energy source that is considered unacceptable to some and most acceptable to others.

6.4.6 Quantitative indicator (ACP)

An indicator of acceptability should measure how acceptable the energy source can be considered by the public. The environmental impact caused by using the fuels is a major factor here, but acceptability can also refer to social or political factors. Greenhouse gas emission from combustion of the fuel is one possible measurable indicator. Another alternative is taxes and emission charges connected to use of different fuels. Taxes can be considered a good indicator of a society's acceptance of different products, and energy sources that are deemed from society to be less desirable or acceptable than others usually are associated with higher taxes. Therefore this will be chosen as indicator for acceptability.

As for affordability the unit used will be SEK/kWh. It's also the same problem with high taxes and emission charges actually meaning less secure energy source, and since biofuels sometimes has 0 taxes the reciprocal can't be used. Instead then, the ranking has been reversed by subtracting each of the values from the value of the fuel with highest taxes.

7 Results

Chapter 6 discussed the main different fuels used in Sweden in relation to four important security aspects, the 4 A´s. As well, an alternative for quantifying these 4 A was put forward. Doing so makes it possible to illustrate the results and compose an index of various alternatives. This chapter will show the results generated from such approach, and by using the indicators described. However, in some cases another indicator than described in chapter 6 might have been used for a certain reason. Explanations and motivation for this will be given in those cases of course.

7.1 Ranking of the 4 A's

Is the availability, accessibility, affordability or acceptability the most important security factor for an energy resource? This answer is not obvious, and even more difficult would be trying to decide how much more important one factor is than the other. However, to produce a ranking vector of alternative sources (from the decision matrix presented in 4.2.1) this question needs to be addressed. If it is assumed they all have same importance for energy security in total, the ranking could be done by simply adding the alternative's results for each of the 4 criteria. If they are expected not to be equally important though, constructing the ranking would be more complex. Different weighting of the 4 A's have been used to compare results of different scenarios. Some examples of this are presented below.

The various weightings of criteria are presented in table 5. The sum of the values assigned to the 4 criteria has to be equal to 1 (100%).

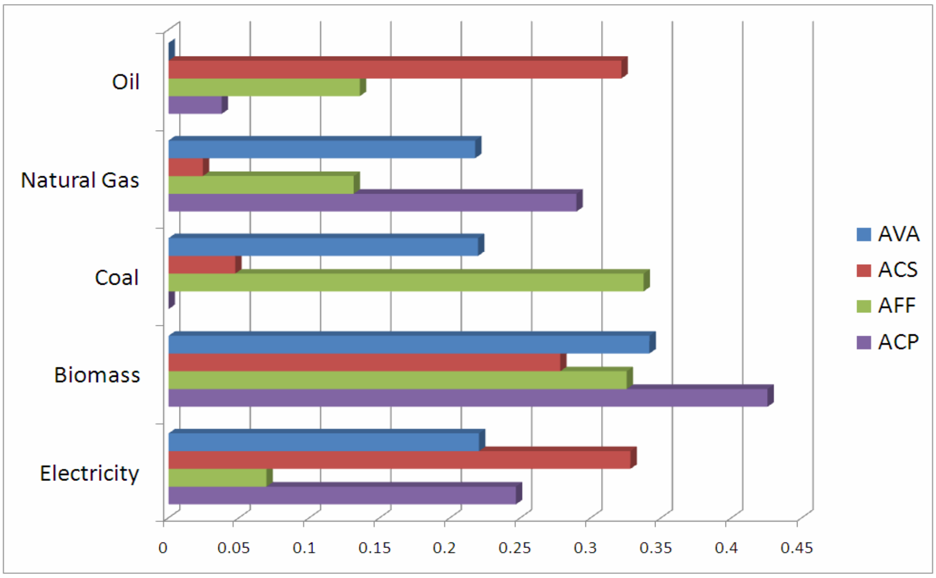
Table 5: The 10 different scenarios studied and their weighting of the 4 A's

Scenario	Weighting	AVA	ACS	AFF	ACP
1	Availability most important	70%	10%	10%	10%
2	Accessibility most important	10%	70%	10%	10%
3	Affordability most important	10%	10%	70%	10%
4	Acceptability most important	10%	10%	10%	70%
5	Availability/Accessibility most important	40%	40%	10%	10%
6	Availability/Affordability most important	40%	10%	40%	10%
7	Availability/Acceptability most important	40%	10%	10%	40%
8	Accessibility/Affordability most important	10%	40%	40%	10%
9	Accessibility/Acceptability most important	10%	40%	10%	40%
10	Affordability/Acceptability most important	10%	10%	40%	40%

Thus, depending on what criteria would be considered most important to a jurisdiction, different weighting would be applied to determine security of different energy sources. The ranking vectors, or energy security index, for the ten scenarios presented above is summarized in the tables.

It is important to remember that values for all A's have been normalized (with a number between 0 and 1). For example this means, a value of zero for availability should not be interpreted as no availability of the alternative. It just illustrates that the alternative is considered least available among the options compared (meaning it has a more negative production trend in comparison with other alternatives). To find out more in detail how calculations have been done, see appendix 3.

An overall comparison, not divided into different services, for the main category fuel types could be illustrated as follows (see figure 20). The table next to the graphs shows the energy security index for the alternatives if a uniform weighting of the criteria is applied.



Index
0.124
0.166
0.151
0.343
0.216

Figure 20: 4A ranking for the main categories of fuel

It illustrates that biomass could be considered being the most secure alternative when it comes to availability and acceptability. Electric power and oil are being the most accessible alternatives and coal the most affordable. Thus different benefits with different types of primary energy sources. The energy security index to the right gives the total ranking where all A's are summarized, and shows that biomass with these measures is ranked as most secure from the alternatives. Oil has the lowest ranking on the security index, mainly due to the low availability and acceptability.

For the different criteria weightings in table 5, the ranking vector would show the results below (Table 6). For every scenario the most secure alternative is highlighted in green, and the least secure with red color, to make the overview of the ranking easier.

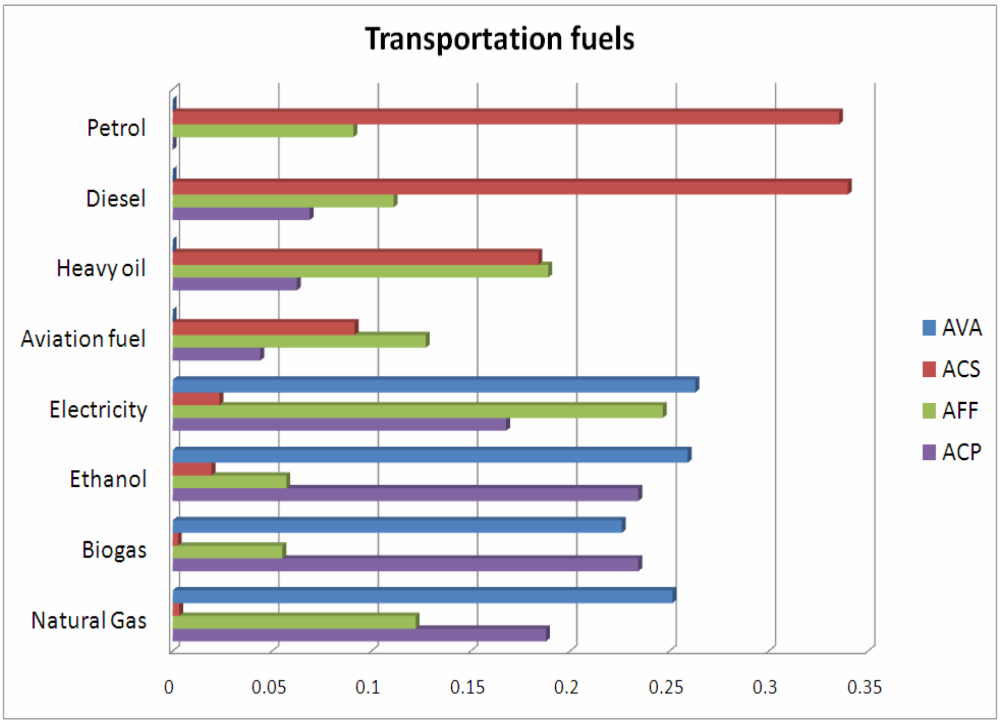
Table 6: Indexes for different weighting scenarios

	1	2	3	4	5	6	7	8	9	10
Oil	**0,049**	0,243	0,131	0,072	0,146	**0,090**	**0,061**	0,187	0,157	**0,102**
Gas	0,197	**0,081**	0,145	0,240	**0,139**	0,171	0,219	**0,113**	0,161	0,193
Coal	0,192	0,089	0,263	**0,060**	0,141	0,228	0,126	0,176	**0,075**	0,162
Electricity	0,219	0,283	**0,128**	0,234	0,251	0,173	0,227	0,206	0,259	0,181
Biomass	**0,342**	**0,304**	**0,332**	**0,392**	**0,323**	**0,337**	**0,367**	**0,318**	**0,348**	**0,362**

For example then, scenario 1 suggests biomass to be most secure followed by electric power, natural gas, coal and last oil. In scenario 2 oil would instead be ranked third, coal fourth and gas fifth. Biomass is in all scenarios ranked as most secure. Oil is least secure in 4 scenarios, Gas in 3 and Coal in 2.

Aggregated values have been calculated in the example above. However, as discussed previously, a better comparison might be between the fuels used within each specific service. To do this some of the categories need to be broken down further (into specific oil products, biomass products and different sources of electric power for example). This is shown in the next chapters. For example comparison between alternative transportation fuels would look like following:

7.2 Transports



Index
0.107
0.130
0.109
0.066
0.175
0.143
0.129
0.141

Figure 21: 4A ranking of transportation fuels

These results are illustrating oil products major accessibility advantage within transportation, and that renewable fuels' advantage especially is that they are more acceptable. Electric power show to be most available and affordable, the latter because of the generally much higher energy efficiency in electric engines (since the price per kWh electricity is the most expensive as previous diagram showed). It is also ranked as the most secure energy source in total on the index. The oil products advantage in accessibility evens out their disadvantage in availability, and vice versa for the renewable fuels. Which means though, biofuels could potentially be a much more secure alternative if we just could manage to make them more accessible for transportation vehicles.

The high AVA-value for renewables could be questioned and discussed further though since production of renewable transportation fuels usually is still quite low in comparison to fossils. But on the other hand they can seem correct as well since they, unlike fossil fuels, not are showing a trend of depletion. Also a reason for ethanol being considered more available is that suppliers during the last year's has shown a large increase in production.

Since affordability measures the prices excluding taxes, biogas and ethanol are ranked very low (reflecting the relatively high production costs). Although prices for the consumer (taxes included) usually is about the same as for oil products. Regarding biogas and natural gas the distinction can be hard since it is usually sold as a mix at the stations.

The ranking for different weightings show these results:

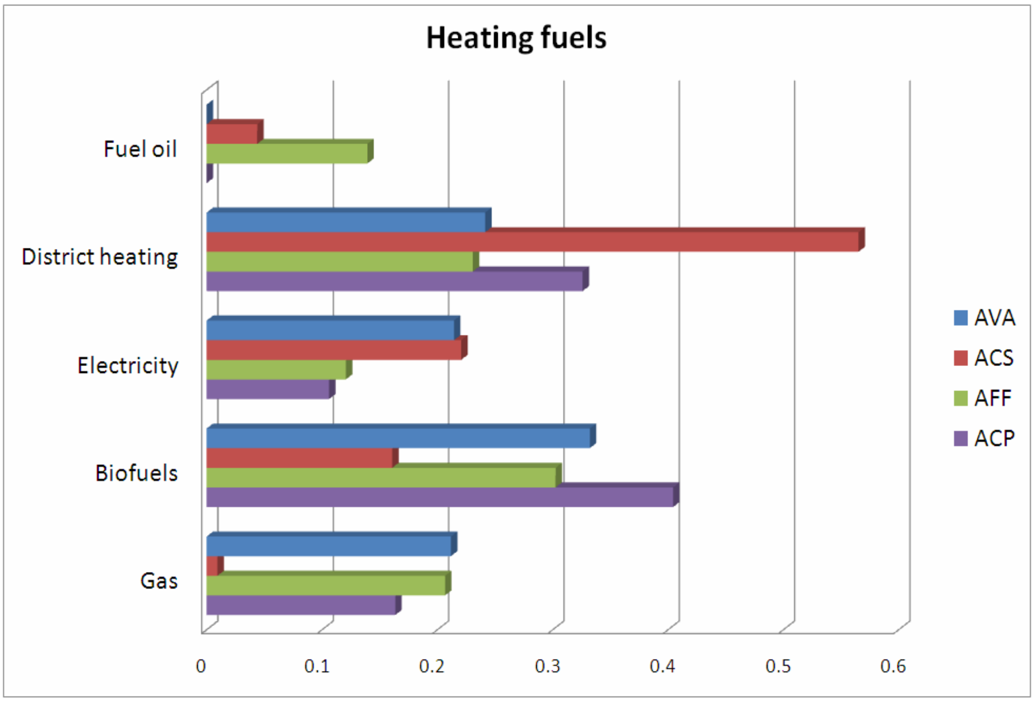
Table 7: Indexes for different weighting scenarios

	1	2	3	4	5	6	7	8	9	10
Petrol	0,043	0,244	0,097	**0,043**	0,143	0,070	0,043	0,171	0,143	**0,070**
Diesel	0,052	**0,256**	0,119	0,093	0,154	0,085	0,073	**0,187**	**0,175**	0,106
Heavy oil	0,044	0,154	0,157	0,081	0,099	0,100	0,062	0,156	0,118	0,119
Aviation fuel	**0,026**	0,081	0,103	0,053	**0,054**	**0,065**	**0,039**	0,092	**0,067**	0,078
Electricity	**0,228**	0,084	**0,218**	0,171	**0,156**	**0,223**	0,199	0,151	0,128	**0,195**
Ethanol	0,213	0,069	0,091	**0,198**	0,141	0,152	**0,205**	0,080	0,133	0,144
Biogas	0,187	**0,053**	**0,084**	0,192	0,120	0,136	0,190	**0,069**	0,123	0,138
Natural Gas	0,207	0,058	0,130	0,169	0,133	0,169	0,188	0,094	0,114	0,150

These rankings show more differentiation than previous table. Electric power is being ranked as most secure in half of the scenarios, diesel in 3 of them. Aviation fuels most insecure in 5 of the scenarios and Petrol and Biogas in the others.

7.3 Space and water heating

For heating purpose district heating is regarded most accessible (since half of the energy used for heating is delivered via the district heating systems), while biofuels are ranked highest in any other criteria. What has to be noted though is that district heating is no primary energy source (in same way as electricity) and that the results therefore are very much affected, especially for acceptability and affordability, by the fuels used in the system. During recent years this primary fuel has mainly been biomass of some sort. If oil were to be used more in district heating, acceptability and affordability would likely be lower.



Index
0.046
0.341
0.165
0.300
0.148

Figure 22: 4A ranking of fuels for space and water heating

Fuel oil has the lowest availability and acceptability, but also low affordability and accessibility. This gives the alternative a very low ranking on this security index, meaning oil would be a relatively insecure fuel to meet the national heating requirements. Heat supplies from biomass or district heating are more secure energy sources for this purpose.

Table 8 shows the alternative ranking results:

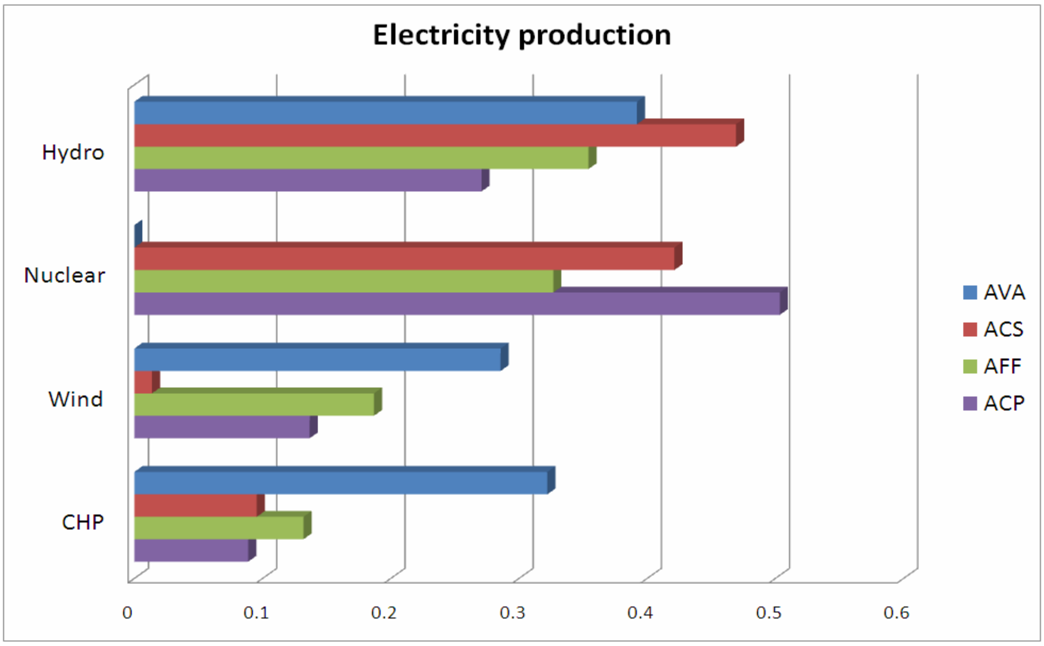
Table 8: Indexes for different weighting scenarios

	1	2	3	4	5	6	7	8	9	10
Fuel oil	**0,018**	**0,045**	**0,102**	**0,018**	**0,031**	**0,060**	**0,018**	**0,073**	**0,031**	**0,060**
District heating	0,281	**0,475**	0,275	0,332	**0,378**	0,278	0,307	**0,375**	**0,404**	0,303
Electricity	0,195	0,199	0,139	0,130	0,197	0,167	0,162	0,167	0,164	0,134
Biofuels	**0,319**	0,216	**0,301**	**0,363**	0,268	**0,310**	**0,341**	0,259	0,290	**0,332**
Gas	0,186	0,065	0,183	0,157	0,125	0,185	0,172	0,124	0,111	0,170

As were to be expected from the chart, fuel oil is ranked lowest on all indexes. District heating is ranked most secure in 4 cases, and biofuels in the others.

7.4 Electricity

Looking at the production of electricity, hydro in general would be the preferred energy source. Affordability in the chart is representing estimated production costs instead of price for buying (unlike other graphs), and acceptability instead refers to estimations of CO_2 emissions from the production. This since neither prices nor taxes for buying electricity can be directly connected to the alternative production methods.



Index
0.372
0.313
0.156
0.160

Figure 23: 4A ranking for electricity production

Availability of nuclear, as seen in the figure, is actually considered lowest among the alternatives. An explanation for this is downtime and continuous decline in production during the last years (decrease for every year since 2004, in total 14 TWh, which made a big influence on the calculations). However, the main reason for the declining production has been because of the upgrading of the nuclear reactors, which means the production trend very likely will be turned around within the next years. As well it could be surprising that it is considered most acceptable, which stresses some of the difficulties with quantifying acceptability. All of these alternatives could be seen as (almost equally) acceptable in terms of CO_2 emissions, and even though nuclear shows a little better values it might not be seen as more acceptable than others by people in general.

Unfortunately there’s no straightforward way to include the intermittency problem of some of the renewable fuels, such as wind. With the criteria weighted uniformly however, hydro power is ranked as the most secure source of electricity production. Nuclear, although low availability, also is estimated fairly secure. Combined heat and power generation (CHP) is lower on the index, but has good availability and the advantage of also producing heat.

For other weightings the rankings would be similar:

Table 9: Indexes for different weighting scenarios

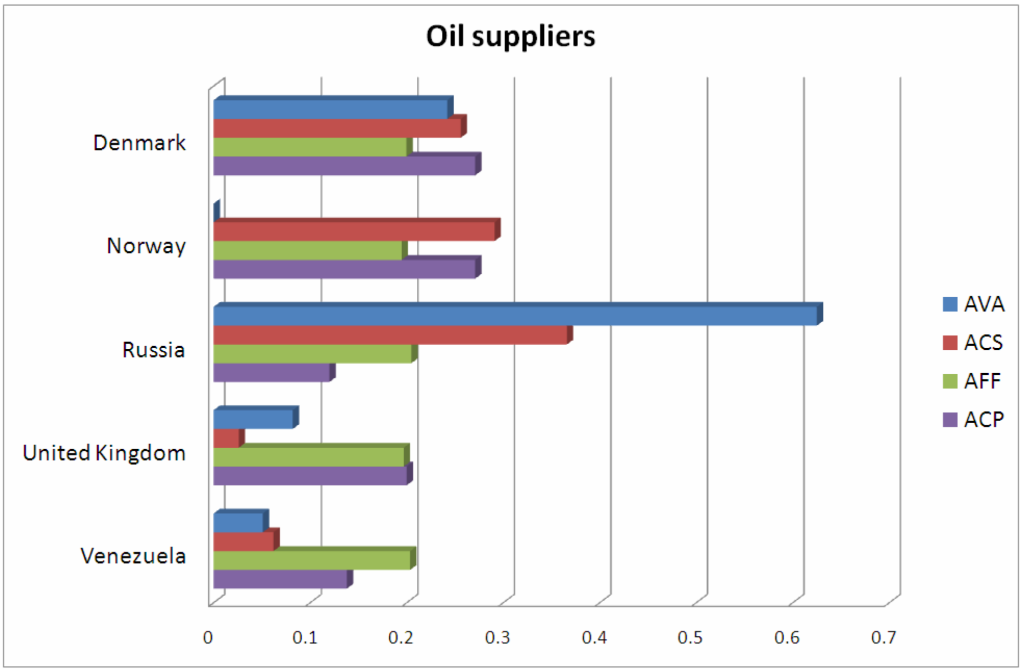
	1	2	3	4	5	6	7	8	9	10
Hydro	**0,384**	**0,430**	**0,361**	0,311	**0,407**	**0,373**	**0,347**	**0,396**	0,371	0,336
Nuclear	**0,125**	0,378	0,321	**0,427**	0,252	0,223	0,276	0,350	**0,403**	**0,374**
Wind	0,234	**0,071**	0,175	0,144	**0,152**	0,204	0,189	**0,122**	**0,107**	0,159
CHP	0,257	0,121	**0,143**	**0,117**	0,189	**0,200**	**0,187**	0,132	0,119	**0,130**

7.5 Oil supply

Oil stands for a major share of Sweden's imported energy. This means secure supply of oil is of great importance to Swedish energy security, and that a more detailed study of the different suppliers would be needed. Even though high oil dependence is likely to be one of the biggest threat to energy security, it is not likely we will see any major changes in the use of oil products (within near future) at the same time as transportation is expected to increase. Therefore oil imports need to come from secure suppliers, and different suppliers somehow need to be compared in terms of how reliable they are.

The Swedish crude oil supply here is divided by the main exporting nations. Availability is determined by the average decline or increase in export capacity, production minus consumption, in supplier countries during recent years (the previously used aggregated availability for oil and oil products was determined by the average increase/decline in production, and the share of production exported to Sweden from each supplier).

Acceptability (environmental) as measured in previous graphs would be the same for all of the alternatives in this case, and not very interesting to compare then. Therefore acceptability here instead will refer to political/social acceptability, determined by the GPI (Global Peace Index) ranking of different nations. (More information on the GPI is presented in appendix.)



ESI

0.242

0.189

0.329

0.126

0.114

Figure 24: 4A ranking for oil suppliers

In terms of political acceptability, Denmark and Norway can be seen as most secure oil suppliers and Russia least secure (which seem to agree with the general opinion on energy security). On the other hand the available resources give Russia a huge advantage and Norway the status as a very insecure supplier. Prices on oil do not show any great differences, because of the much globalized market, meaning affordability will be almost the same for all suppliers (average price in 2008 was between $95 and $100 for all markets). Thus, in total the index show Russia to be ranked most secure supplier of oil, and Venezuela most insecure.

If applying other weightings Russia still do well because of their available resources:

Table 10: Indexes for different weighting scenarios

	1	2	3	4	5	6	7	8	9	10
Denmark	0,242	0,250	0,217	**0,259**	0,246	0,229	0,251	0,234	0,255	**0,238**
Norway	**0,075**	0,250	0,193	0,238	0,163	0,134	0,157	0,221	0,244	0,215
Russia	**0,507**	**0,351**	**0,254**	0,204	**0,429**	**0,381**	**0,355**	**0,303**	**0,277**	0,229
United Kingdom	0,100	**0,066**	0,169	0,170	0,083	0,134	0,135	**0,117**	0,118	0,170
Venezuela	0,076	0,083	**0,168**	**0,128**	**0,079**	**0,122**	**0,102**	0,125	**0,105**	**0,148**

An interesting detail however, is some of the new exporters that came to supply the Swedish market in 2008. Examples of these are Angola, Libya and Nigeria. Still accounting for smaller share of the imports than the countries studied above, but on the other hand having relatively big reserves (together almost 8% of the global proved oil reserves). Angola, especially, is a country where oil production during last years has had a big increase.

7.6 Discussion on the criteria ranking

Can some of the scenarios be regarded as more correct or realistic to use in Sweden's case, or for national energy security in general?

One way to think about it: For example, availability could very well be considered the most important of the four since it wouldn't really matter how accessible, affordable or acceptable an energy source is if it's not available for use. Also the opposite could be argued about acceptability. If other fuels would not be usable due to availability-, accessibility- or affordability reasons the "less acceptable fuels" would continue being used (or be considered more acceptable to use). As well, opinions on what's acceptable can vary widely. Affordability could likely be more important to poorer countries than those regarded as rich. In Sweden (which should be in the latter group) energy prices would have to change very drastically before leading to serious affects on society. Just as an example, even doubling the price on petrol is expected to have just a small impact on how much we drive. (Dagens Nyheter, 2008). A fuel that is not accessible would of course be a serious problem, but usually a problem with possible solutions to. Thus important, but not more important than availability.

This means, a subjective ranking of the different A's importance to energy security in my case likely would be the same order they have been presented so far in the paper. But finding an exact quantitative weighting of them would be an impossible task. It also depends if having a long- or short-term perspective on energy security. Availability may be regarded less important in short-term perspective.

The results presented in this chapter can preferably be used together with some of the other presented security indicators to reach the goal of a more secure energy mix. For example the energy security indicators by APERC, mentioned before in 3.2. Indicators that can be calculated for possible replacement of energy resources, to see whether exchanging one type of energy supply to another also has positive effect on diversification, import dependency or the carbon intensity of the fuel portfolio. Ideally these indicators would change in the right direction when replacing an energy source.

8 Achieving energy security

The 4 R's (presented in 3.4) represent an approach to improve security in energy services. The first R, a review of energy requirements, alternative energy sources and suppliers, has now been done in chapters 5-7. This chapter will focus more on the reduction and replacement potential within the services. To improve energy security insecure supply should be targeted for reduction and replacement. The energy security index presented above with ranking of alternative fuels can give some guidance on what replacement is needed to improve the energy security. The 4th R, restriction, will not be studied here. This because of its focus on arising new demand that a jurisdiction is likely to experience, which I have not tried to predict in this study.

Projections made by Swedish Energy Agency point to an increased energy use in Sweden 2020 compared to 2005. The 396 TWh that was used in 2005 will rise to 412 TWh. Although some reduction and more efficient energy use already are accounted for in these numbers, there is good potential to further reduce the demand and even decrease the required energy. (Energimyndigheten, 2009:14) Figures below show some possible scenarios, and what can be achieved within the different services.

8.1 Transport services

8.1.1 Reduction potential

Good technical potential to reduce energy demand in transportation do exist because of the generally high energy consumption in existing vehicles. Current trend for vehicles is they are becoming less fuel consuming but at the same time growing in number and weight, which unfortunately leads to an increase in total energy demand. Estimation of the final energy use for domestic (road) transports in 2020 with the use of today's technology is 105 TWh, thus an increase by 14 TWh compared to 2005. However, more efficient energy use and reduction in total energy demand are very much likely to occur. Just accounting for spontaneous improvements driven by already implemented economic instruments will make the increased energy use in 2020 much lower, ca 94 TWh. (SOU 2008:110)

The potential exists for further significant reduction in the energy demand though. By only including actions that are considered profitable another 11 TWh of the final energy demand can be reduced until 2020. In total the reduction potential for the energy end-use is then at least 22 TWh, and in primary energy about 27 TWh. Some of the actions proposed in the study to achieve this are better techniques and fuel efficiency, taxation, binding emission requirements, eco-driving etc. (SOU 2008:110) The fuels that should be targeted for this reduction or replacement would according to the security index (see 7.2) especially be petrol and heavy oil, but also diesel.

8.1.2 Replacement potential

Even if we assume all these reduction potentials will be taken advantage of, transport services would still require more than 80 TWh of energy in 2020. For many more years the major part of this energy demand will most likely be met with oil products, and how much of it that will be replaced is difficult to estimate. Predictions say diesel will continue to grow more popular than petrol, and that biofuels also will grow in popularity (SOU 2008:110). The target set for

2020 is 10% biofuels (about double of today's share), and is also the minimum requirement by European Union. On the other hand more ambitious goals exist, both among producers and politicians. For example, biofuel producers saying 20% being possible, and some people arguing for even much larger capacity. This shows how difficult the estimation of the existing replacement potential is to do in this case. The graph below show remaining demand for oil when including the reduction plus replacement potential of 10%/20%. This would still leave us with a demand for more than 60 TWh of oil within the sector. Note also that this is just final demand and does not include the energy that is used to produce the biofuels replacing oil.

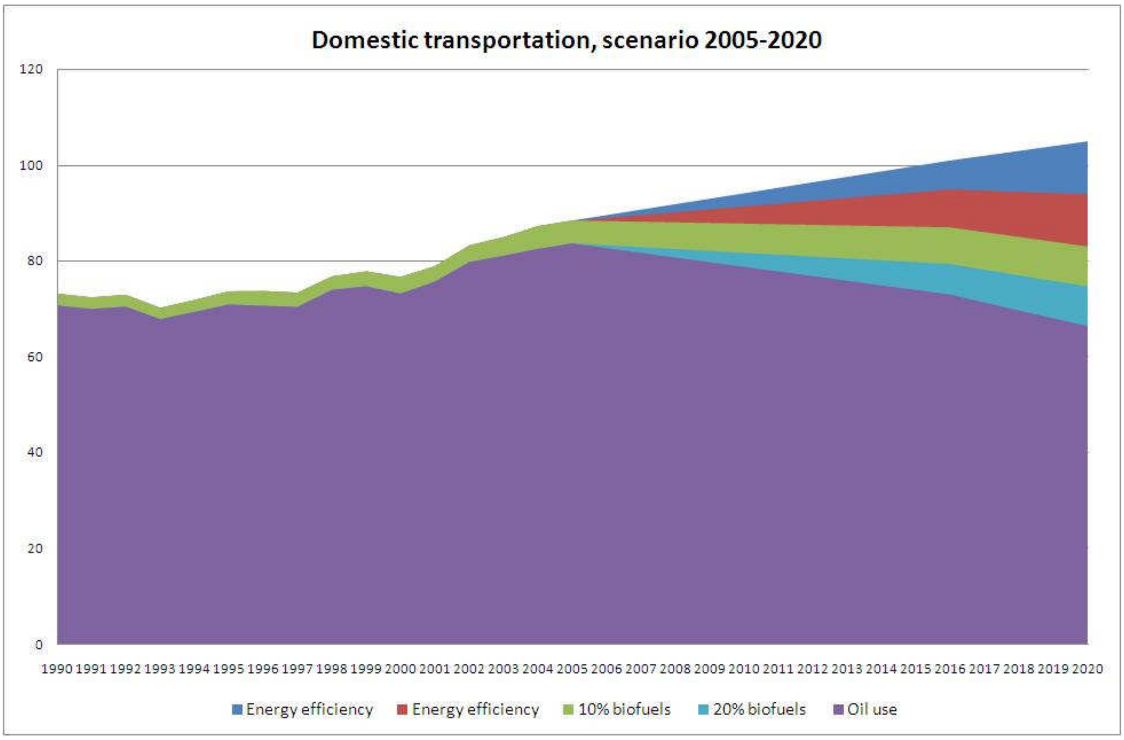


Figure 25: Outlook, energy use in transportation until 2020

Since the Swedish energy policy says the vehicle stock should be independent from fossil fuels by 2030 (Regeringskansliet, 2009), these reduction and replacement of oil products probably are the least we have to do until 2020. The target to replace just 10% until 2020 seems very low then.

8.2 Space and water heating

8.2.1 Reduction potential

The energy demand in the buildings and service sector is expected to be quite constant for the next years, 149 TWh both for the year 2005 and 2020. (Energimyndigheten, 2009:14) However, the value in 2005 corrected for temperature would be 154, which then is showing a small future decrease. The energy used directly for heating is projected to decrease from 95 TWh to 88 TWh, while electricity use is expected to increase. This is with some efficiency actions already taken into account. Since the population, and also apartments and buildings, is expected to increase with around 10% during the period, the energy demand would otherwise also be increasing without any efficiency actions. (Energimyndigheten, 2009:14)

The potential, technical and economical, for more efficient heating is much bigger though. Studies show potential for reducing total requirement by as much as 29,7 TWh just for heating. How much of the potential actually will be met though depends mainly on the acceptance for making these energy efficient actions, 100% is not realistic to presume for these kinds of studies. And even though the report claims all the actions discussed to be profitable, it is going to depend on factors such as transaction costs, split incentives, interest rates etc. (SOU 2008:110) 15% acceptance has been considered a more realistic assumption, and is shown in the graph as well. (IVA, 2009)

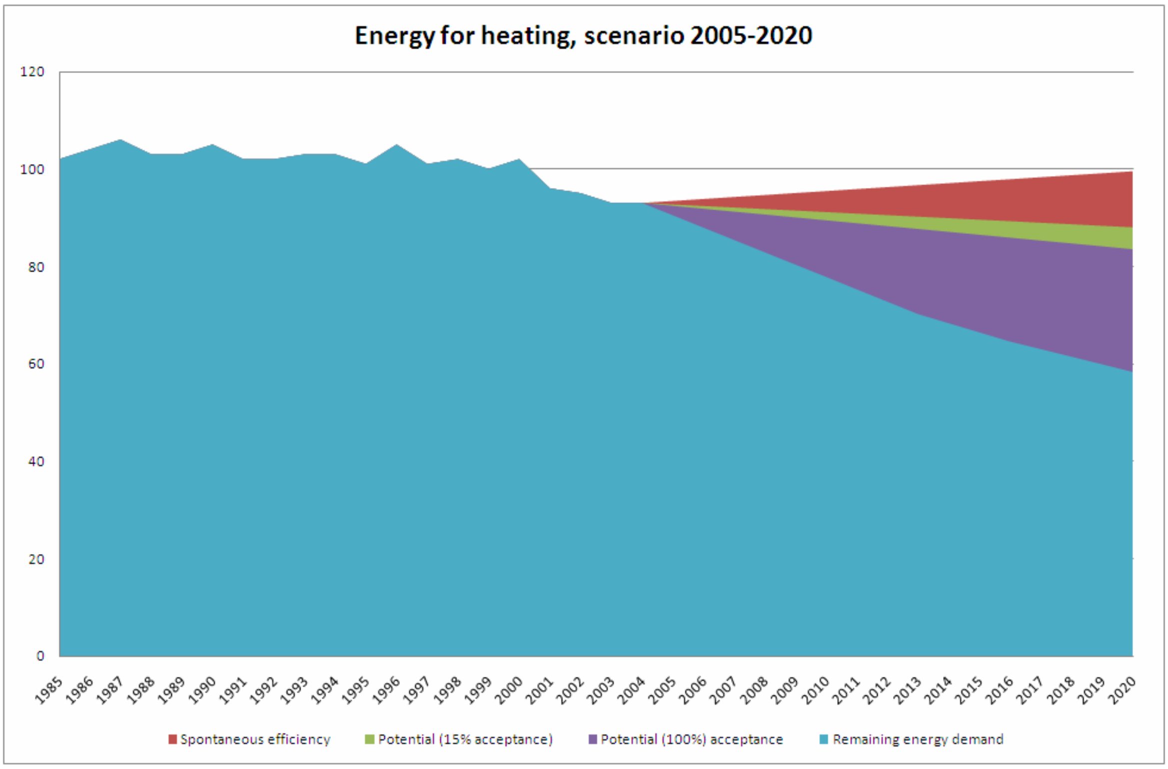


Figure 26: Outlook, energy use in heating until 2020

Although, while these reductions are not especially for insecure energy resources, its direct effect on the energy security is not as obvious. But taking advantage of reduction potential that exist would be enough to phase out the most insecure heating fuels, if these are targeted.

8.2.2 Replacement potential

The review of the 4 A's clearly showed oil to be the least secure fuel to use in heating, but the replacement of this fuel has mainly been done already during the last years. Just a small amount of oil is still left to be replaced in the sector. The use of direct electric heating could be another target for replacement. Of the remaining energy demand (after reducing energy use) alternative sources like solar heating, geothermal heating, wind heating etc could be considered options for replacement, or to be combined with the ones already in use. Probably it will take much time though before these heating sources will replace a significant part of the heating demand. The availability of indigenous biomass resources from the forests on the other hand is likely more than enough to cover the energy requirement for heating services. (KVA, 2007)

8.3 Electricity

In the main scenario from Swedish Energy Agency, the production of electricity will increase much more than the consumption. In 2020 Sweden is expected to have a production of 167 TWh, from which we can export 23 TWh. This means the consumption should be around 144 TWh, which is the same as 2008 and 3 TWh less than 2005.(Energimyndigheten, 2009:14) From this, electricity used for heating will become lower but electricity for other use will most likely increase instead. But also here there's a potential to reduce the consumption. Estimated 10,9 TWh reduction potential exist from the electricity use in buildings, and additional 2,3 TWh can be saved within industry use. (Jagemar & Pettersson, 2009) The needs for replacement of insecure alternatives are relatively small however, but a greater diversity would still be preferable.

The production of wind power will be extended a lot the coming years. This can have both positive and negative effect for energy security. Mainly positive since it reduces reliance of only hydro and nuclear power and gives the opportunity of more local production, but maybe also some negative effects because of its intermittency. Higher capacity in power grids could be needed to support this huge increase in production. A great advantage with electricity though, is that it can be produced from such many various primary sources.

8.4 Indigenous resources

For an improved national energy security a higher use of indigenous resources, to replace the large import volumes, should be one of the overall goals. What is the potential to do this? Biomass and electricity are the main domestic energy resources available, meaning these are the main alternatives for an (import-)independent energy production. The calculations and graphs in previous chapters also confirmed that these in general are considered secure options. Estimations of the potential in available resources has been done by many different agencies, and therefore showing a wide range of the possible energy extraction. Here is a summary of some of the estimations presented:

The big resource in Sweden is the **forest** of course. The yearly increase in volume is over 100 million m^3. About 80% of this is harvested, leaving 20% (or energy equal to 76 TWh) in increased forest volume. 36%, or 137 TWh, of the harvested biomass is left as felling residues in the forest. (KVA, 2007) Especially for the residues potential exist for use in energy production. A summary of studies made by various organizations, and their estimations of the potential energy supply, has the wide range of 20-74 TWh extra supply of biomass energy that could be used in a future scenario. (Björklöv & Karlsson, 2009)

Residues from **agriculture** has potential to be used for energy production and can yield 17 TWh if all technically harvestable residues are used (Johansson & Liljequist, 2009). There are

4 different possible scenarios presented in the report though, giving a range between 4 and 15 TWh of energy depending on different circumstances.

The amount of energy from agriculture can be much larger if more energy crops are grown as well. Energy crops today just stands for about 3% of the areal in agriculture and has the advantage that it can be grown on land not suitable for food production(Björklöv & Karlsson, 2009). Until 2020 production could be increased significantly and according to various estimations theoretically yield energy somewhere inbetween 10-30 TWh.

The **wind power** potential is mainly decided from the public's acceptance of wind power stations. If people would be more willing to accept having wind power in their surroundings the potential would also be greater. However, production of 30 TWh by 2020 is already planned, which means the potential should be anything above this number.

Solar energy has a good theoretical production potential as well, but is likely to remain as a small contributer to the energy supply because of climate for example. If all small houses in Sweden were to use solar panels the size of 15 m^2 this would be enough to produce a total of up to 14 TWh energy, just as an example. (SCB, Andrén)

Geothermal energy (another energy source with great theoretic potential) can be used for heating of residential although seismic activity is very low in the country. Very deep holes are needed which usually makes it an expensive alternative. Still Sweden is one of the countries where heat pumps actually are most popular.

Thus, potential for indigenous and diversified increase of renewable energy does exist. But most of these estimations are theoretical however, and its actual potential will depend on many other factors as well.

9 Discussion

This chapter will discuss the results presented and some of the main problems related to the national energy security that have been identified throughout the report, as well as the methods of measuring it and what can be seen as potential risks for a long-term secure supply of energy.

9.1 Model discussion

The methods presented in this thesis give examples of how energy security can be determined by quantitative indicators, and especially discuss how the 4 A's of energy security can be measured. Of course it is a very simplified way of looking at energy security and probably not enough comprehensive, but still delivers some interesting results that can be used in the discussions. As been experienced while working with this report, there are a huge number of ways in which the 4 A's can be represented. And more complex models do not always deliver more credible results. Studies of energy security, and especially with help from quantifiable indicators, is something that just during the last years has became a focus in research. And we will see more developed methods to study this being presented in the next years.

The results in general have to be considered reasonable, meaning this way of illustrating and quantifying security of different fuels is one possible method that can be used. And depending on which criteria is considered to be the most important, a corresponding weighting can be chosen to produce a ranking of different energy sources according to this. Others doing the same analyze maybe would favor other weightings of the different criteria. But as the examples shown, small changes in weighting will not have much effect on the total ranking. Choosing one criteria much more important than others also means a reliable and representive way of measuring this criteria becomes even more important.

The analysis of reduction and replacement potential over the next ten years (chapter 8) showed that no significant reduction in energy use is to be expected. Potentials for some reduction do exist, but more likely is that energy requirement in total will continue to increase. This makes replacement potential more important. Some of the energy resources need to be replaced by more secure ones. A first step towards this is starting to replace imported energy forms with indigenous resources, and replace finite fossil resources with renewable. Available resources do exist within the country for a significant increase in the use of domestic renewable energy, for various alternative sources. If affordability for these are good as well needs to be studied further though.

To be able to also keep or improve diversity in the energy supply, various diversity indicators can be used together with the ranking. Like the energy security indicators that was presented in chapter 3.2. Before deciding on how to improve security by replacing insecure fuels these can test whether diversity or import dependence will be affected positive or negative by a choosing certain types of energy sources.

9.2 Secure suppliers?

The summary of previous energy security studies and comparison between different countries (chapter 2) was showing Sweden to be among the most secure countries in many respects. However, many of these studies seem to build on the assumption that supply from Norway and EU countries in general can be regarded as more secure than others, which naturally would be good for Sweden but can be discussed whether it's correct. It might be a true assumption if you compare risks of accessibility problems or factors like political acceptability (lower risk for supply disruptions). Looking more at long-term implications or actual available resources though, the situation is rather the opposite. Availability of oil in these countries, which include three of the five main suppliers of Swedish oil, is very low compared to other oil producers (having the highest depletion rate among all oil producing countries). Thus, if ranking resource availability high, these suppliers would not be considered secure.

On the other hand, Sweden´s largest supplier of energy resources, Russia in many cases has been considered an insecure supplier because of current risk for supply disruption being higher. Although, in terms of production and available reserves they could be considered a relatively secure alternative. This means the opposite situation to above. (most secure regarding availability but least secure for acceptability). This example shows the problem to decide which criteria should be the most important, and how this weighting seems to have been decided in other studies. During 2008 Sweden increased crude oil imports from both Russia and Norway compared to the years before. And the trend is that Russia currently is becoming a main supplier for all Sweden's fossil fuels, which means the question whether they are a secure supplier or not definitely needs to be asked.

Overall Sweden is a very import dependent country when it comes to energy resources, and therefore having a disadvantage regarding the security of supply. The importance of having secure suppliers hence becomes high. But as discussed, the definition of a supplier as secure or not depends mainly on what criteria is used. A fact that further shows why diversity in supply should be regarded as important. And now that oil production is in rapid decline in the countries traditionally supplying our oil, we should examine possible alternative suppliers that can substitute these.

However, many of the previous work found might have been a little too much focused on the supply-side of energy security, and not really considering much of the demand aspects. In this study the goal has been to include both of these sides. The division of energy use in different services has helped to do this.

9.3 Transports

By making the division of the energy use into these three different services, we notice they have problems of different kind regarding security. Heating is done mainly by indigenous biomass resources or electricity (which are relatively secure), while transports rely heavily on imported crude oil and oil products (less secure). Energy use for transportation continues to go up, while heating demand goes in the opposite direction. Capacity of Swedish power production is expected to increase, though the demand likely will be quite constant. This shows how crucial transportation, and the introduction of alternative energy resources in the sector, will be to energy security. Any actions made to improve Sweden's energy security first of all should focus on transportation, and it´s use of fossil fuels.

The lack of fuel diversity and need for import of deficient resources are the main problems for the sector. This means a serious shortage in the oil supply would threaten almost the whole transportation system. In turn this could affect the other services and the whole society, since transports are such an important factor for a functional society of today. For example, most district heating systems are relying on working logistics and transports to be fueled with biomass and waste from the surroundings. If the district heating systems cannot supply enough heat, people are going to use electricity for heating their homes. Many people doing this could cause a shortage of electricity in the power grid, leading to further problems. An example showing how the services are well connected, and how problems in one of them will affect the others. A complete disruption in oil supply is not a likely scenario though. But it is definitely possible we will experience more oil crises similar to previous ones, and have new price shocks on oil. To be very dependent on oil supply is not a secure situation then.

The existing target of 10% renewable fuels in transportation by 2020 seems rather low if the high goal of a fossil free vehicle stock in 2030 is going to have credibility. On the other hand the target of producing 30 TWh from wind power by 2020 seems very high, judging from how it has developed so far (since 30 TWh means expanding wind power capacity ten times over the next ten years). Looking at these two existing goals together, a possible scenario could be a transportation sector driven mainly on electricity within 10-20 years. A scenario that could have great impact on energy security, but could be questioned as well how realistic it is. The scenario for 2020 anyway points to an abundance of power production, meaning different ways of storing the energy or exporting it will be needed.

Breaking the dependence of oil as much as possible maybe is the most obvious way to improve energy security, but as mentioned in the 2020-scenario oil will likely continue to be the main fuel for many more years in transportation (see 8.1.2). If this is the case, one of the most important factors for Sweden's national energy security would be to secure the supply of oil and oil products.

Other ways to make energy supply in transportation more secure are introduction of alternatives to the traditional vehicles. For example, all new vehicles could have hybrid engines that allow using different types of fuels. Electricity and also biofuels are some existing alternatives that could increase their share of the energy supply, but then also possibilities to produce biofuels for transportation within the country needs to be better. If we are planning on continuing being completely dependent on the Brazilian ethanol production, we might not gain much from the security perspective. Expanding traffic on rail is also a good alternative to reduce use of insecure fuels (as well as reducing emissions). However this needs huge investments, and need to be a more reliable alternative for transportation also during the winter (which during the recent winter has not been the case). It would also take long time to move a significant part of the traffic from road to rail. The introduction of electric cars could go faster if more car producers were willing to invest in this technology.

9.4 Diversity

The fact that one type of energy supply is ranked as more secure than the others on the security index does not necessarily mean we should aim at just using that type of energy. Relying too much on one type of energy supply, or one single supplier, also has its obvious security risks. For example, even if Russia would be considered most secure in supplying the country with oil, importing oil exclusively from Russia would not be a secure strategy. Diversify and spreading the risk on different suppliers would be wiser just as in many other situations. By having diversity in the fuel mix and fuel supply you are better protected against price shocks or supply disruptions affecting one type of fuel. A tough question though can be how much diversity is wanted, which for example can depend on the balance between the extra cost and the degree of risk reduction that is achieved.

Looking at the total energy resources used in the country, the diversity among them seems to be fairly well regarding the different energy sources used (Sweden having an average ranking on diversity indexes compared to other countries, see chapter 2). Divided by each of the services however, the situation looks different. Not only the transport service where more than 90% of energy comes from oil, but also in the other services a greater diversity in energy use would be good for the energy security. The electricity production is an example of this, where the two main forms of productions are very dominant.

The hydro power is a relatively secure power source, but production volumes vary a lot from year to year, and also cannot be built out much more than is already done. It’s a power source showing seasonal variations as well, producing most of the electricity during spring and summer months. And since Norway’s power supply is almost entirely from hydro, it is already very dominant on the integrated Nordic market, making the price for electric power sensitive to the availability in the water reservoirs. The rest of Sweden’s electricity is mainly produced by the 10 nuclear reactors in the country. These reactors, however, need to be closed from time to time. And the effect of several reactors standing still at the same time has been seen during some cold weeks last winter, with repeated temporary power shortages and dramatic price changes on the market. A significant contribution from another alternative power source would reduce reliance on these, increase diversity in supply and help improve security. However, exploitation of alternative sources of electricity (wind, solar, biomass) is expected to increase a lot during the next decade, and especially for wind power the investments will be enormous to meet the targets.

The trend in heating is that district heating is becoming the primary energy source for a majority of all households (currently more than half of national heating requirement). This figure will vary a lot between different parts of the country however, where in some cities almost all household will be connected and some places where district heating system not even exists. Therefore this could more likely be a security issue on the local level than the national level (since the city’s district heating systems are working separately). Failure in the district heating system would be critical especially for the big cities with many consumers (for example Uppsala where 90% of households are connected to the district heating). Serious failures seem very rare in the systems however, and usually back up exist to handle temporary failures.

Electricity still is very important to get heat in our homes, and more than 20% still use it as main heating source. But also homes with district heating (and with geothermal heating as well)normally need supply of electricity to be heated, which than makes almost 80% of the household heating reliant on the supply of electricity (Energimyndigheten, 2007). This means most households need both functioning supply of district heating and electricity to be heated. Thus, heating sector cannot really be regarded as diversified in energy supply.

9.5 Other possible issues

Energy security in general seems to be associated by many with **nuclear energy** and the risks connected to nuclear power production (something I have noticed when discussing my thesis with others). Maybe not surprising since nuclear power is a type of energy that does carry many risk aspects important to consider. However, this has not been discussed very much in the thesis. The risks of accidents from use of nuclear power are very small, but with potentially enormous consequences. A risk that seems acceptable to many people but unacceptable to others, and opinions on this issue vary a lot.

Just recently Swedish government has suggested to cancel the decision taken many years ago that prohibits the building of new nuclear reactors. This would mean nuclear power will continue to be an important part of the electricity production for most of this century. The global uranium resources then become important to study further as well. Just like many other fossil resources these are concentrated mainly to certain regions of the world (Söderlund, 2009). And even assuming great availability of the resource, the accessibility, affordability and acceptability is uncertain for such long-term perspective.

Another thing that could be mentioned is the expansion of the **district heating** systems, which are growing bigger for every year. This has meant longer transports to meet the demand for energy input, and even increasing imports of waste and peat from other countries. Peat and waste imports are not renewable and can neither be considered secure. And establishing a demand for waste products is not really a sustainable way to secure our energy supply. Before increasing in the number of combustion plants, it should be assured that sufficient and secure supply input exist to keep the plant running (preferably from the region and not imported). But on the other hand, the amount of waste from society is constantly increasing according to many estimations (Hagberg, 2009), suggesting that it is going to be an acceptability issue rather than a problem of availability.

The planned increase in **power production** and more use of many various renewable sources will mean a need for more capacity and smarter grids. Better ways to store energy from renewables such as wind and solar could play an important role to secure the supply of electricity as well, allowing much more small scale production. Even though electric power has shown to be a relatively secure energy source in long-term perspective, the system in itself is vulnerable to disruptions (possibilities for blackouts etc). These risks could possibly be decreased with a more diversified small scale production and better storage possibilities.

10 Closure

The thesis has shown some quantitative measures that can be used to compare different jurisdictions, fuels or suppliers in terms of their energy security. Together with data on energy use and requirements these results can provide information important to evaluate if energy supply can be regarded as secure, and show ways to improve energy security by reducing or replacing insecure types of fuels with more secure ones. Since controlling energy resources usually leads to a more secure energy supply, a jurisdiction should seek to be independent from imported energy. Sweden is very far from this at the moment having to import around two thirds of the supply, which mainly depends on the big use of oil products and nuclear power. Breaking the dependence on fossil fuels is important for environmental reason, but maybe even more to secure sufficient supply of energy in the future. With the great indigenous renewable resources however, Sweden has good potential to produce more secure energy domestically. For the national demand in space/water heating Sweden already can, almost entirely, meet its demand with domestic production. Also much of the electricity can be produced from domestic and renewable primary resources. The main problem though, is the increasing energy demand in transportation sector, which today (to 95%) cannot utilize these renewable energy forms.

The 4 A's determine some important factors that needs to be considered when studying how secure an energy alternative is. A quantification of these is one way to facilitate a comparison between various sources or supplies, and constructing security indices. Especially this has proved to work well as a method for graphically illustrating energy security. There are many alternatives how to quantify security factors however, where this paper just presents one of many possible methods.

Despite national actions to increase energy efficiency and energy awareness the Swedish national energy demand is expected to stay high, and most likely increase, over the next years. But even though scenarios exist for 2020, 2030 or even 2050, predicting how we will produce energy and how much we will use, one must admit these to be very uncertain. New inventions might change these predictions a lot. Maybe energy sources today deemed to have small potential will make a relatively big contribution to energy supply in 10 or 20 years time. However, these will most certainly be renewable resources rather than fossil.

In the Swedish energy policy, some of the most important actions for making the energy supply more secure are being mentioned. Examples of this are the goals to make transports independent of fossil fuels and increasing the production of electricity from renewable sources. During the next years it will be find out if we actually can achieve these goals, or if they were more of optimistic wishful thinking.

11 References

Aleklett, Kjell; Höök, Mikael; Jakobsson, Kristofer; Lardelli, Michael; Snowden, Simon; Söderbergh, Bengt. (2009), *The peak of the oil age – analyzing the world oil production reference scenario in World Energy Outlook 2008.* Energy Policy 38 (2010), pp 1398-1414.

Aleklett, Kjell. (2009), *FN´s framtidsprognoser för klimatet är rena fantasier.* Dagens Nyheter 2009-12-07

Aleklett, Kjell. (2006), *Oil production limits mean opportunities, conservation.* Oil & Gas Journal (2006), vol 104, Issue 31.

Andrén, Lars. (2004), *Solvärmeboken.* Västerås 2004

APERC (2007), *A quest for energy security in the 21st century.* Asia Pacific Energy Research Center. Japan.

Bazilian, Morgan; Roques, Fabien. (2008), *Analytical methods for energy diversity & security.* Oxford

Björklöf, David; Karlsson, David. (2009), *Produktion av BTL-diesel och cellulosabaserad etanol i Sverige.* Uppsala University

BP (2009), *Statistical review of world energy 2009.* British Petroleum

Brazilian Sugarcane Industry Association (2009), *Brazilian ethanol production.*

Byman, Karin; Stenkvist, Maria; Grundfelt, Ellenor. (2008), *Naturgasen – en bro in i biogassamhället.* ÅF-Consult, Stockholm

Christos, V Roupas; Alexandros, Flamos; John Psarras. (2009), *Measurement of EU 27 oil vulnerability.* International journal of energy sector management, vol 3, no 2 (2009), pp 203-218.

Costantini, Valeria; Gracceva, Francesco; Markandya, Anil; Vicini, Giorgio. (2005), *Security of energy supply – Comparing scenarios from a European perspective.* Energy Policy 35 (2007), pp 210-216.

EFI (2006), *Forest products trade flow database.* European Forest Institute

Elforsk rapport 07:50. (2007), *El från nya anläggningar – jämförelse mellan olika tekniker för elgenerering med avseende på kostnader och utvecklingstendenser.* Elforsk AB, Stockholm.

Energimyndigheten 2009:06. (2009), *Energistatistik för småhus, flerbostadshus och lokaler 2007*. Statens energimyndighet, Eskilstuna.

Energimyndigheten 2009:10. (2009), *Energistatistik för småhus, flerbostadshus och lokaler 2008*. Statens energimyndighet, Eskilstuna.

Energimyndigheten 2009:14. (2009), *Långsiktsprognos 2008.* Statens energimyndghet, Eskilstuna

Energimyndigheten 2008:15. (2008), *Energiläget 2008*. Statens energimyndighet, Eskilstuna.

Energimyndigheten 2009:28. (2009), *Energiläget 2009*. Statens energimyndighet, Eskilstuna.

Energimyndigheten. (2008), *End-use metering campaign in 400 households in Sweden.* Enertech

Energimarknadsinspektionen (2009), *Uppvärmning i Sverige 2009.* Eskilstuna

Gnansounou, Edgard. (2008), *Assessing the energy vulnerability: Case of industrialised countries.* Ecole Polytechnique Féderale de Lausanne, Switzerland. Energy Policy 36 (2008), pp 3734-3744.

Hagberg, Mattias. (2009), *Skräp.* Atlas, Stockholm

Hammoudeh, Shawkat; Kyongwook, Choi. (2005)*Characteristics of permanent and transitory returns in oil-sensitive emerging stock markets: The case of GCC countries.* Journal of international financial markets, institutions and money, vol 17 (2007), pp 231-245.

Hughes, Larry; Shupe, Darren. (2010), *Applying the four 'A's of energy security as criteria in an energy security ranking method.* Routledge Energy Security Handbook.

Hughes, Larry; Shupe, Darren. (2010), *Creating energy security indexes with decision matrices and quantitative criteria.*

Hughes, Larry. (2009), *The 4 R's of energy security.* Energy Policy 37 (2009) pp 2459-2461.

Hughes, Larry. (2007), *Energy security in Nova Scotia.* Canadian centre for policy alternatives.

Höök, Mikael; Söderbergh, Bengt; Aleklett, Kjell. (2009), *Future Danish oil and Gas export.* Energy 34 (2009), pp 1826-1834. Global Energy Systems, Uppsala University

Höök, Mikael; Aleklett, Kjell. (2008) *A decline rate study of Norwegian oil production.* Energy Policy 36 (2008), pp 4262-4271. Global energy systems, Uppsala University.

International Energy Agency. (2001), *Toward a Sustainable Energy Future.* Paris

International Energy Agency (2009), *CO_2 emissions from fuel combustion.*

Jansen, Jaap C; Seebregts, Ad J. (2009), *Long-term energy services security: What is it and how can it be measured and valued?.* Energy research centre of the Netherlands, The Netherlands. Energy Policy 38 (2010), pp 1654-1664.

Jagemar, Lennart; Pettersson, Bertil. (2009), *Energieffektivisering – möjligheter och hinder.* Vägval energi, Kungliga Ingenjörsvetenskapliga Akademien.

Johansson, Kersti; Liljequist Karin. (2009), *Can agriculture provide us with both food and fuel? –A survey of present agricultural production.* Uppsala University

Jun, Eunju; Kim, Wonjoon; Chang, Soon Heung. (2008), *The analysis of security cost for different energy sources.* Applied Energy 86 (2009), pp 1894-1901.

Kruyt, Bert; van Vureen, D.P.; de Vries, H.J.M.; Gronenberg, H. (2009), *Indicators for energy security.* Energy Policy 37 (2009) pp 2166-2181.

KVA (2007), *Uttalande om bioenergi.* Energiutskottet och Miljökommittén vid Kungliga Vetenskapsakademien.

Löschel, Andreas; Moslener, Ulf; Rübbelke, Dirk T.G. (2009), *Indicators of energy security in industrialized countries.* Energy Policy

Münster, Marie; Lund, Henrik. (2008), *Use of waste for heat, electricity and transport – Challenges when performing energy system analysis.* Aalborg University, Denmark. Energy 34 (2009), 634-644.

Mäkivierikko, Aram. (2007), *Russian oil – a depletion rate model estimate of the future russian oil production and export.* Uppsala University

Regeringskansliet. (2009), *A sustainable energy and climate policy for the environment, competitiveness and long-term stability.*

Röller, Lars-Hendrik; Delgado, Juan; Friederiszick, Hans W. (2007), *Energy: Choices for Europe.* Bruegel Blueprint Series, Brussels.

SOU 2008:110, *Vägen till ett energieffektivare Sverige.* Statens offentliga utredningar, Stockholm

Statistiska Centralbyrån (MI 25 SM 0901). 2009. *Torv 2008 – Produktion, användning, miljöeffekter.*

Streimikiene, Dalia. (2006), *Monitoring of energy supply sustainability in the Baltic Sea region.* Kaunas faculty of Humanities, Lithuania. Energy Policy 35 (2007), pp 1658-1674.

Svensk Energi (2008), *Elåret 2008.* Stockholm

Svenska Petroleum Institutet. (2009), *SPI Branchfakta 2008.*

Söderbergh, Bengt. (2010), *Production from giant gas fields in Norway and Russia and subsequent implications for European energy security.* Global energy systems, Uppsala University.

Söderlund, Karl. (2009), *Fuel availability in nuclear power –An overview of the present demand and supply situation of nuclear fuels and possible future developments.* Uppsala University

Vattenfall. (2005), *Livscykelanalys – Vattenfalls el i Sverige.* Stockholm

Yergin, Daniel. (2006), *Ensuring Energy Security.* Foreign Affairs, vol 85, Iss 2, pg 69. Council of foreign relations, New York.

Webpages: (2010-04-16)

Air Transport Association,
http://www.airlines.org/Economics/DataAnalysis/Pages/AnnualCrudeOilandJetFuelPrices.aspx

Bioenergiportalen, http://www.bioenergiportalen.se/?p=1416&m=878

British Petroleum, http://www.bp.com/extendedsectiongenericarticle.do?categoryId=40&contentId=7061813

Dagens Nyheter, http://www.dn.se/2.738/2.739/dubblat-bensinpris-kravs-for-utslappsminskningar-1.688883

EIA (2010), Energy Information Administration – world crude oil prices
http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm

Energimyndigheten (2007), http://www.energimyndigheten.se/sv/Hushall/Din-uppvarmning/Fjarrvarme/

Energy Information Administration, http://www.eia.doe.gov/pub/international/iealf/table18.xls

European Commission, http://ec.europa.eu/energy/publications/statistics/statistics_en.

Global peace index 2009, http://www.visionofhumanity.org/gpi/results/rankings.php

Index Mundi, http://www.indexmundi.com/commodities/?commodity=coal-australian&months=60

Naturvårdsverket, http://www.naturvardsverket.se/sv/Klimat-i-forandring/Utslappsstatistik-och-klimatdata/Utslappsstatistik/

Nord Pool Gas As, http://www.nordpoolspot.com/Nord-Pool-Gas/Price/

Nord Pool Spot As, http://www.nordpoolspot.com/reports/systemprice/

OKQ8, http://www.okq8.se/privat/miljo/miljoochhallbarbilism/varadrivmedel/fordonsgas

Sveriges Riksbank - valutakurser, http://www.riksbank.se/templates/stat.aspx?id=16749

Vattenfall (2010), http://www.vattenfall.se/www/vf_se/vf_se/518304omxva/518334vxrxv/518814vxrxe/518844omxkx/519504frxgo/index.jsp#faq_13

World Coal Institute, http://www.worldcoal.org/coal/coal-mining/

World Nuclear Association, http://www.world-nuclear.org/info/inf23.html

Appendix

Appendix 1

Energy security indicators (APERC)
ESI_I (diversification of primary energy demand):

$$DoPED = \frac{D}{\ln T} \qquad D = -\sum_{i=1}^{T} (p_i \ln p_i)$$

For Sweden: "Coal" = p_1 = 27/612 = 0.044
"Oil" = p_2 = 194/612 = 0.317
"Gas" = p_3 = 10/612 = 0.016
"Hydro" = p_4 = 69/612 = 0.113
"NRE" = p_5 = 314/612 = 0.513

D = 1.16 => ESI_I = DoPED = 1.16/ln 5 = 0.72

ESI_{II} (net energy import dependency):

$$D = -\sum_{i=1}^{T} (c_i p_i \ln p_i) \Rightarrow DoPED_{import\_reflective} = \frac{D}{\ln T} \Rightarrow NEID = 1 - \frac{DoPED_{import\_reflective}}{DoPED}$$

$c_i = 1 - m_i$, m_i = the share of net imports in PES of source i.

=> $m_1 \sim 1 \Rightarrow c_1 = 0$
$m_2 \sim 1 \Rightarrow c_2 = 0$
$m_3 \sim 1 \Rightarrow c_3 = 0$
$m_4 \sim 0 \Rightarrow c_4 = 1$
$m_5 \sim 0.62 \Rightarrow c_5 = 0.38$ (uranium imports + ca 10TWh biomass imports)

=> D = - (0.113 ln 0.113 + 0.196 ln 0.513) = 0.376

=> $DoPED_{import\_reflective}$ = 0.376 / ln 5 = 0.234

=> ESI_{II} = NEID = 1 – (0.234/0.72) = 0.675

(If not counting energy from nuclear as imported; $m_5 = 0.03 \Rightarrow c_5 = 0.97$ => NEID = 0.50)

ESI$_{III}$ (non-carbon intensive fuel portfolio):

$$NCFP = \frac{(HydroPED) + (NuclearPED) + (NRE\_PED)}{Total\_PED}$$

$$\text{Sweden} \Rightarrow NCFP = \frac{68.3 + 61.3 + 121}{397} = 0.631$$

Diversity-based indicators from Jansen (2004):
8 catagories of PES: Coal, Oil, Gas, Modern Biofuels, Traditional Biofuels, Nuclear, Renewables n.e.s., Hydro power.

$$D = -\sum_{i=1}^{T} (c_i p_i \ln p_i)$$

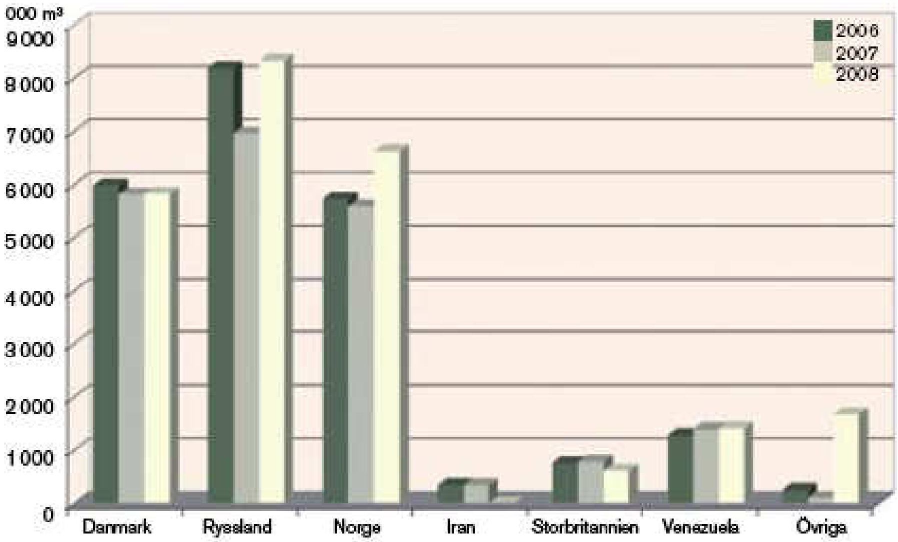
$p_1 = 0.044$
$p_2 = 0.317$
$p_3 = 0.016$
$p_4 = 0.007$
$p_5 = 0.194$
$p_6 = 0.301$
$p_7 = 0.023$
$p_8 = 0.113$

D = 1.615
Normalized = D/ln T = 1.615/ln 8 = 0.777

Appendix 2

Statistics on oil supply, balance and prices.

RÅOLJEIMPORT



Crude oil volumes imported to Sweden, by supplying country.

FÖRSÖRJNINGSBALANS ÅR 2008

Tillförsel			Avgång				
Produktgrupp	Import a)	Produktion	Raff. förbrukn.	Leveranser			Differens b)
				Inrikes	Utr. sjöfart	Export a)	
Råolja	24 455	-	23 992	-	-	0	463
Halvfabrikat	803	-	25	-	-	668	110
Motorbensin	2 190	6 083	-	4 930	-	3613	-270
Lätt-/gasbensin, övr.	506	370	458	8	-	403	7
Flygbränslen	1 120	309	-	1247	-	59	123
Dieselbränsle & Eo 1	2 157	9 817	20	5 771	121	6 167	-105
Övriga Eo	1 165	5 058	29	1 024	2 171	3 261	-262
Summa	32 396	21 637	24 524	12 980	2 292	14 171	66

Supply balance, including domestic refinery production import of refined products.

BENSINPRISER 95-OKTAN, ÅRSMEDELTAL I 2008 ÅRS PENNINGVÄRDE (KPI 1980=100)

Historic development of petrol prices, divided by taxes, product costs and gross margin. Other oil products would show similar upgoing trend.

Appendix 3

Calculation of index and indicators of 4A

Data used to calculate availability indicator:
Oil production, million tones (1998-2008), source: BP 2009

supplier	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**2008**
Denmark	11.6	14.6	17.7	17.0	18.1	17.9	19.1	18.4	16.7	15.2	**14.0**
Norway	149.6	149.7	160.2	162.0	157.3	153.0	149.9	138.2	128.7	118.8	**114.2**
Russian Federation	304.3	304.8	323.3	348.1	379.6	421.4	458.8	470.0	480.5	491.3	**488.5**
United Kingdom	132.6	137.4	126.2	116.7	115.9	106.1	95.4	84.7	76.6	76.8	**72.2**
Venezuela	179.6	160.9	167.3	161.6	148.8	131.4	150.0	151.0	144.2	133.9	**131.6**

For Swedish import volumes, see appendix 2.

Regression analysis, average value 2000-2008
Denmark: -0.9
Norway: -7.0
Russian Federation: 10.9
United Kingdom: -5.5
Venezuela: -3.9

Aggregated availability value: average linear regression*prod.share imported = (-0.9*0.351) + (-7.0*0.049)+(10.9*0.014)+(-5.5*0.007)+(-3.9*0.009) = -0.59 million tones = -6.87 TWh

Natural gas, production (mtoe), source: BP 2009

supplier	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**2008**
Denmark	6.8	7.0	7.3	7.5	7.5	7.2	8.5	9.4	9.4	8.3	**9.1**

Regression analysis, 2000-2008
0.2272 0.233 0.2179 0.2196 0.2562 0.3826 0.1485 -0.1069 -0.1456 0.7805

Average: 0.22
Swedish imports: 0.9 mtoe (=9,9%)
0.22 (mtoe) => 0.099*0.22=0.022 mtoe => 0.25 TWh

Coal, production (mtoe), source: BP2009

supplier	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**2008**
Australia	149.8	160.8	166.3	179.9	184.5	190.1	198.8	206.5	211.0	218.5	**219.9**
Russian Federation	103.9	112.1	116.0	122.6	117.3	127.1	131.7	139.2	145.1	148.2	**152.8**
United States	603.2	584.3	570.1	590.3	570.1	553.6	572.4	580.2	595.1	587.7	**596.9**

Regression analysis, average value 2000-2008
Australia: 4.97
Russian Federation: 4.78
United States: 4.89

Aggregated availability value: average linear regression*prod.share imported = (4.97*0.0028)+(4.78*0.0023)+(4.89*0.0005) = 0.027 mtoe => 0.32 TWh

Power sources, production (TWh), source: Energimyndigheten 2009

supplier	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Hydro power	73.8	70.9	77.8	78.4	65.8	53.0	60.1	72.1	61.1	65.6	68.3
Wind power	0.3	0.4	0.5	0.5	0.6	0.6	0.9	0.9	1.0	1.4	2.0
Nuclear power	70.5	70.2	54.8	69.2	65.6	65.5	75.0	69.5	65.0	63.8	61.3
Combined heat/power + Industrial back-pressure power	10.0	9.5	8.8	9.6	10.8	12.6	12.9	11.8	12.3	13.3	13.9

Regression analysis, average value 2000-2008
Hydro power: 1.02
Wind power: 0.32
Nuclear power: -1.56
CHP: 0.56

Aggregated availability value: (addition of the various power supplies) 1.02+0.32-1.56+0.56 = 0.34 TWh

Biomass supply in energy production (TWh)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Biomass	91	90	91	94	100	105	108	109	111	119	123

=>Average regression: 4.30

Ethanol supply (TWh)

2000	2001	2002	2003	2004	2005	2006	2007	2008
0.2	0.2	0.5	0.9	1.5	1.7	1.9	2.1	2.5

=>Average regression: 0.31

Biogas supply (TWh)

2000	2001	2002	2003	2004	2005	2006	2007	2008
0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3

=>Average regression: 0.05

District heating, production (TWh)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Fjärrvärme	52.3	48.4	45.8	50.9	51.8	52.3	51.6	50.1	52.2	51.6	55.0

=>Average regression: 1.25

Data used to calculate accessibility indicator:
(calculated as share of total energy requirement supplied by a specific energy resource)

Derived from Energimyndigheten, table for figure 7

Total slutlig användning uppdelat på energibärare / *Total final use per energy carrier*	
Oljeprodukter / *Oil products*	*125*
Naturgas, stadsgas / *Natural gas, gasworks gas*	7.6
Kol, koks / *Coal, coke*	*16*
Biobränsle, torv, avfall m.m. / *Biofuels, peat, waste etc*	70
El / *Electricity*	*129*
Fjärrvärme / *District Heating*	48
Totalt / *Total*	**397**

Where energy supply to district heating is:

Energy source	TWh
Oil products	1.5
Natural gas	2
Coal	2.6
Biomass (incl waste,peat)	39.4
Heat pumps	5.5

Energy requirement in transportation:
(from Energimyndigheten, table for figure 18)

Fuel	TWh	Share of supply
Petrol	42.6	0.331
Diesel/gas oil	42.0	0.326
Electricity	3.0	0.023
Bunkers oils	24.2	0.188
Medium/heavy fuel oils	0.4	0.003
Aviation fuels etc	11.6	0.090
Natural gas, including LPG	0.4	0.003
Renewable motor fuels	4.4	0.034
Total	128.7	

Bunker oils containing mainly medium/heavy oils (23 TWh) but also gas oil (1.2 TWh).

Energy requirement in heating:
(data from Energimyndigheten, ES 2009:10, Energy statistics for dwellings and non-residential premises 2008)

Fuel	TWh	Share of supply
Fuel oil	3.3	0.044
District heating	42.5	0.565
Electricity	16.6	0.221
Biofuels	12.1	0.161
Gas	0.7	0.009
Total	75.2	

Electricity production from different sources:
(from Energimyndigheten, table for figure 22 and 27)

Power source	**2008**	Share of supply
Hydro power and wind power [1]	68.3	0.468
Wind power (from 1997)	2.0	0.014
Nuclear power	61.3	0.420
Industrial back-pressure power	6.2	0.042
Combined heat and power	7.7	0.053
Cold condensing power	0.4	0.003
Gas turbines	0.0	
Total net production	145.9	
Import minus export	-2.0	

Data used for calculating affordability indicator:

Crude oil, average import price 2008: 0.40 SEK/kWh
Coal: 0.161 SEK/kWh
Forest fuels: 0.167 SEK/kWh
(Energimyndigheten)

Average price for electric power: Residential use = 0.855 SEK/kWh
Industrial use = 0.661 SEK/kWh
Industrial use 55.5 TWh ~ 39% => weighted price = 0.779 SEK/kWh

Average price for natural gas: Residential use = 0.449 SEK/kWh
Industrial use = 0.38 SEK/kWh
Industrial use 5.4 TWh ~ 52% => weighted price = 0.413 SEK/kWh

Commercial prices in transportation:

Fuel	SEK/kWh (average 2008)	References
Bensin	0.556	Energimyndigheten, table 42
Diesel	0.636	Energimyndigheten, table 42
Heavy oil	0.374	Energimyndigheten, table 42
Aviation	0.556	www.airlines.org –Annual crude oil and jet fuel prices, converted from $/bbl
El	0.779	Energimyndigheten, table 42
Ethanol*	1.100	Statoil, average price excl VAT 2008
Biogas	0.93	Statoil, average price excl VAT 2008
Natural Gas	0.413	Energimyndigheten, table 42

*Ethanol price from E85, calculated on mix of 85% ethanol and 15% petrol.
(Energimyndigheten table 42: Table of actual commercial energy prices in Sweden 2008)

In generating the affordability indicator for transports, engine efficiencies was also estimated for the different fuels, with these values: Electric engine (95%), petrol and gas (25%), diesel and medium/heavy oil (35%), ethanol (30%).
Furthermore, the reciprocal was used for the final values to have high values representing a more secure alternative.

Fuels for space and water heating:

Fuels	SEK/kWh	References
Fuel oil	0.592	Energimyndigheten, table 42
District heating	0.447	Energimyndigheten, table 42 & 30, (0.648 SEK incl taxes)
Electricity	0.855	Energimyndigheten, table 42: Electric heating
Biofuels*	0.273	Energimarknadsinspektionen & Energimyndigheten
Gas	0.449	Energimyndigheten, table 42: Natural gas, residential

*Calculated value is an average from pellets price and forest fuel prices

Estimated efficiencies: Electricity and district heating (100%), gas furnace (90%), oil and biomass furnace (80%)

Electric power, production costs:

Fuels	SEK/kWh	References
Hydro	0.25	Elforsk
Nuclear	0.271	Elforsk
Wind	0.473	Elforsk - for land based wind power, higher costs for sea based
CHP	0.67	Elforsk – for use of forest fuels, use of waste mean lower costs

Crude oil spot prices ($/barrel) divided by supplier, average prices 2008:

Europe Brent	97.53
Norway, Ekofisk Blend 42	100,02
Russia, Urals 32	95.08
United Kingdom, Brent Blend 38	98.98
Venezuela, Tia Juana Light 31	95.69
Angola, Cabinda 32	94.88
Libya, ES Sider 37	97.09
Nigeria, Bonny Light 37	101.78

http://tonto.eia.doe.gov/dnav/pet/pet_pri_wco_k_w.htm

Data used for calculating acceptability indicators:
(taxes charged for use of different energy alternatives, excl VAT)

Coal: 0.395 SEK/kWh

Natural gas taxes: Industrial use = 0.041 SEK
Residential = 0.218 SEK
⇨ Average ~ 52%*0.041+48%*0.218= 0.126

Electricity taxes: Industrial use = 0.005 SEK
Residential = 0.270 SEK (0.178)
⇨ Average ~ 39%*0.005+61%*0.27 = 0.167

Transport

Petrol	0.585	Energimyndigheten, tabell 3
Diesel	0.413	Energimyndigheten, tabell 3
Heavy oil	0.355	Energimyndigheten, tabell 3
Aviation	0.475*	Hjelmco Oil (for Jet A1, mars 2008)
El	0.167	Energimyndigheten, tabell 3
Etanol	0	
Biogas	0	
Natural Gas	0.116	Energimyndigheten, tabell 3

*Aviation fuels in general not taxed, only for private domestic flights which is the number used here.

Heating services:

Fuel oil	0.366
District heating	0.071*
Electricity	0.27
Biofuels	0
Gas	0.218

*Value calculated from the input of fossil fuels in district heating systems, which were (2008):
Oil: 1.5 TWh ~ 3%
Natural gas: 2.0 TWh ~ 4%
Coal: 2.6 TWh ~ 5%
Peat: 2.8 TWh ~ 5% (0.018 SEK/kWh)
Waste: 10.5 TWh ~ 19% (0.162 SEK/kWh)

⇨ 0.03*0.366+0.04*0.218+0.05*0.395+0.05*0.018+0.19*0.162 = 0.071

Emissions from production of electric power (environmental acceptability)

Production plant	g CO_2 emissions / kWh
Hydro power	5.2
Nuclear power	2.8
Wind power	10.3
Combined heat/power	15.8

Data from *Life cycle assessment – Vattenfall's electricity in Sweden*.

Indicator for political acceptability
Global Peace Index (can be found: http://www.visionofhumanity.org/gpi/results/rankings/2009/). An index measuring the relative position of nation's and region's peacefulness, mainly including factors such as levels of violence and crime, political instability, external relations, military expenditures and wars.
144 countries were studied and included in the latest index. Some countries interesting to Sweden and their ranking:

Rank	Country	Score
2	Denmark	1.217
2	Norway	1.217
19	Australia	1.476
35	United Kingdom	1.647
46	Libya	1.710
54	Latvia	1.773

65	Namibia	1.841
83	United States	2.015
85	Brazil	2.022
98	Belarus	2.103
100	Angola	2.105
120	Venezuela	2.381
129	Nigeria	2.602
136	Russia	2.750