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Investigating the development of forest-based bioenergy

Transferring knowledge from Sweden to Poland

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Be to my virtues very kind. And to my faults, be a little blind.

Abstract

Bound by the European Union policy, Poland needs to increase the share of renewable energy by 7,5% by 2010 and 15% by 2020. Biomass was once viewed as the largest potential for expansion of renewable energy in Poland. However, in the light of this thesis work, it appears that recent legislation and the standpoint of the State Forest Company will result in the barely emerging market for biomass from forests being phased out.

Supportive policies for production of renewable electricity in Poland are complicated systems of tradable permits. The policy provides strong incentives for co-firing with biomass which resulted in huge demand by almost all energy companies in Poland. This practice of co-firing is an intermediate solution towards dedicated biomass installations. With many problems in the supply chain it is hard to visualize the transition to the dedicated biomass combustion.

The supply chain of forest biomass in Poland is very weak. For that purpose, a comparison with Sweden is conducted in this thesis in order to identify crucial steps and to overcome critical barriers.

The results of the analysis show that the key policy instrument in Sweden is the carbon tax. Taxation of fossil fuels is an effective way to stimulate use of less carbon intensive fuels such as biomass. Expansion of the district heating sector was most affected by the carbon tax and consequently contributed the most to the expansion of the use of biomass.

These lessons cannot be easily translated to Poland. The protection of the plywood industry and coal mining industry has resulted in the legal obligation to decrease forest fuels in all installations larger than 5 MW and ultimately cancel them by the year 2017. Poland will have to look for renewable targets in alternative sources, such as waste or energy crops for example.

Executive Summary

Background information

Poland is the largest country in Central Europe and part of the Baltic Basin. As a part of the European Union it shares the common goal of the EU to increase the share of supply of energy from renewable sources. The Polish Government has set a target that by the year 2010, the share of renewable energy will be 7.5% and 14% by 2020. At this point, Poland is highly dependent on imported energy, up to 14.7%. High imports of crude oil and gas from Russia make the Polish economy vulnerable. The production of heat and electricity in Poland is derived mainly from indigenous sources of coal. Poland has a significant area covered with forest, which is increasing due to the national Forest Augmentation Program.

The introduction of a tradable certificate system has created a strong incentive for co-combustion of biomass with coal. For every MW of produced renewable electricity, energy companies are getting substantial premiums. Almost every energy company in Poland is co-firing which has created huge demand for biomass. Huge demand is a problem for the weak supply chains in Poland and the opinion of the experts is that co-firing needs to stop. Examination of the supply chain and the forestry industry in Poland should reveal the potentials for improvement.

For the purpose of exchange of information and business cooperation, Poland and Sweden have established several networks, one of them being the Swedish-Polish Sustainable Energy Platform. Sweden is observed as one of the champions of the utilisation of logging residues. The scope of the Technology Innovation System for this thesis is the supply chain of the residues. Logging residues are studied because they are considered as a primary step in utilisation of bioenergy. Logging residues have distinctive environmental, social and economical benefits. They are an easily accessible, ready made by-product of the integrated forestry operation.

With regards to the observed Technology Innovation System in Poland, Sweden was taken as a role model country. Sweden has been utilising forest biomass for over three decades. Utilisation has been followed by extensive research in related areas. Sweden, as the largest of all Nordic countries, shares some similarities with Poland but also significant differences. Despite a smaller population, Sweden has bigger energy demand than Poland as a result of higher energy intensity. The supply of energy is more diversified and a significant share of renewable energy comes from forest biomass.

Research question and objectives:

How can Poland learn from the development of forest-based bioenergy in Sweden?

1. To describe and analyse the actors, networks and institutions for forest-based bioenergy in Sweden and Poland.

2. To identify and discuss the key lessons from Sweden in regards to the drivers and constraints for the development of forest-based bioenergy.

3. To outline key recommendations for the development of forest-based bioenergy in Poland.

4. To identify the role of the forestry sector in the observed bioenergy market situation in Sweden and Poland.

Methodology

In this thesis, an archival review was supplemented by approximately 20 stakeholder interviews in Sweden and Poland. Special attention was given to the triangulation of data. When examining the literature, the intention was to find potentially opposing sources, such as forestry journals, bioenergy journals and ecology and environmental journals. The literature also consisted of governmental, industrial and institutional reports and articles in online periodicals.

In both countries two approaches have been applied: bottom-up and top down. In the bottom-up approach, the forestry industry was delineated with special attention to the felling operations, use of mechanisation and the supply chain of the logging residues. In the top-down approach to the observed Technological Innovation Systems, relevant markets and policies were assessed. More attention was given to Sweden in order to identify crucial factors that helped the development of the bioenergy market. For that reason other aspects in Sweden, such as grants, subsidies and research and development were also studied.

Main findings

Bioenergy in Sweden accounts for the highest share of renewable energy. This is a result of multiple factors that have promoted the use of forest biofuels over many decades. The bioenergy from forest biofuels in Sweden can be summarised as follows:

- The majority of forest biofuels are used for the production of heat. Production of electricity and liquid biofuels is still not considered to be cost-effective for the production on the large scale.

- Most of the biofuels are used internally by Swedish industry where the forestry industry dominates. Industry is followed by the district heating sector that is widespread in Sweden.

- Utilisation of forest biofuels is promoted by the carbon tax. The carbon tax was part of the tax reforms in the 1990s. Although the use of fossil fuels was already significantly decreased in the industrial sector due to the high energy taxes, the carbon tax was a major policy tool that promoted biofuels in the district heating sector.

- The carbon tax is levied on all fossil fuels. The carbon tax is much higher for district heating systems than for industry. There are exceptions in taxation of industry. The high carbon tax on fossil fuels and no carbon tax levied on biofuels made the transition to the forest biomass logical from an economic standpoint.

- The current support system for the biofuels in Sweden, the green certificate system provides a very high premium for the production of renewable energy. The demand for biomass is high but the premium is high enough that energy companies are able to compete with other industries for raw materials e.g. the plywood industry.

- Forestry industries are generating substantial income from the production and sales of wood chips. The production volumes of wood chips and pellets are increasing every year along with the import of pellets.

- Integration of forestry operations makes logging residues an easily accessible by-product. Depletion of nutrients is successfully recovered through careful ash recycling.

- There are potentially negative long term effects of the extraction of the residues but that will be observed in the distant future.

- Further increases in production will likely seek to exploit other parts of the tree, such as stumps or pulp wood.

In Poland the bioenergy market is much less supported. The utilisation of forest biofuels will be prohibited by the year 2017 when all forest biofuels will be replaced by agricultural biofuels. The support is streamlined towards energy crops, but other authors argue that the support by the Polish Government is not sufficient. The Technological Innovation System in Poland is characterised by:

- Scattered actors that are hardly integrated into the networks. There are very few networks in Poland that are lobbying for the extraction of forest biofuels.

- The supply chain is very weak, in many cases non-existing. The State Forest Company holds the monopoly on the raw resource and has a lack of business initiative. The Company is inconsistent as some regional Directorates are engaged in the sales of logging residues while others are not. The company is generally against the extraction of the residues, citing environmental harm due to the removal of residues.

- Availability of the residues is limited by the mechanisation used, felling practices and species composition. The amounts produced in Poland are approximately 0,2 million m^3 while the technical potential is estimated to be 0,5 million m^3. Stump extraction does not have public support. The area on which clear felling practices are performed is gradually being decreased in Poland. Clear felling practices are the most suitable practices for the extraction of logging residues.

Conclusion

The success of forest bioenergy in Sweden is a result of good supportive policies, continual investment into the research and development, liberalized markets and the independent district heating sector. Integrated forestry, huge forest reserves, strong industrial clusters and networks and initiatives, created good business opportunities in Sweden that closely correlate with the renewable energy targets.

Strong and strict legislation are the strongest factors that are hindering the development of forest bioenergy in Poland. The Technological Innovation System is currently in the development stage but with current laws it will likely cease to exist. The alternative production of energy crops at this point will hardly meet the future demands of the bioenergy market. Insufficient subsidies have resulted in very little established plantations. The recent EU legislation could limit and even decrease the land availability for energy crops in the future. If

Poland is to pursue the scenario with agricultural energy crops, then new analysis should be conducted of the available land suitable for production of energy crops.

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Abbreviations

TIS-Technology Innovation System

RD&D-Research, Development and Demonstration

CRL-Compact Residual Logs

WTU-Whole Tree Utilisation

1 Introduction

The sustainable development of each country is interlinked with the sustainable supply of energy. In this thesis, two countries were analysed with Sweden as a 'role model' and Poland as a 'student country'. The focus of the analysed bioenergy market was solely on the forest fuels. Transformation of Poland into a more sustainable economy is certainly a challenge that cannot be achieved in a short time. It is important to notice the number of opportunities.

In order to better understand the focal problem of the thesis, short background information is provided on both countries in the subsequent sub-chapter. The scope of the work, along with limitations, methodology used for this research is described in the following sub-chapters.

1.1 Background

Poland as a part of the European Union (EU) shares the common goal of the EU to increase its energy share from renewable energy sources.. The Government of Poland has set a target, with the intention that by the year 2010 the share of renewables will be 7.5% (European Commission Energy, 2007) and 14% by 2020 (Ignaciuk, 2005). According to a report from European Commission, Poland is highly dependent on imported energy, up to 14,7% (European Commission Energy, 2007). Highest imports of crude oil and gas from Russia (European Commission Energy, 2007) make Polish economy vulnerable. With regards to the recent oil crisis, Poland wants to secure future energy supplies in order to enhance economical growth.

In 2004, the share of renewables in Poland in primary energy supply was less than 5% (European Commission Energy, 2007), and 2% belonged to the generation of electricity out of which biofuels (in this case biogas, solid biofuels and biowaste) constituted roughly 17% (European Commission Energy, 2007). Notably there is rather confusing data, the report provided by International Energy Agency in 2002 states a higher share of bioenergy in the renewables sector, up to 98% (Rogulska, Pisarek, & Wiśniewski, 2002). The biggest share of renewable energy goes to hydropower, both small and large scale projects. The European Commission considers that the development of the renewable energy sector is too slow in Poland. These figures are especially concerning if we look at the situation ten years ago in Poland. Figures presented by Leszczynski, Brzychczyk & Sekula (1997) clearly demonstrate that Poland has not done much in the period of 1994-2004 since the figure shows that the share of renewables was around 4% in 1994.

On the other hand, the Swedish government set the ambitious goal of reducing CO_2 emissions. Although it is legally bound not to exceed emission level from 1990 by 4% in the period of 2008-2012, the government actually decided to reduce emissions by 4% in the same period, having emission level at 96% of the baseline year 1990 (Swedish Energy Agency [SEA], 2008). Also, in 2006 emissions per capita were 7,2 tons of CO_2. One of the goals is to reduce this number down to 4,5 tons of CO_2 per capita by year 2050 (SEA, 2008).

Sweden is the champion of the utilisation of forest biomass with a successful 3 decades of practice (Nilsson, Johansson, Åstrand, Ericsson, Svenningsson, & Börjesson, 2004). Poland on the other hand, has an emerging bioenergy market. Poland has a forest cover of 8.8 million ha which constitutes 28,1% of the country. With roughly 38% of the population living in rural areas combined with an unemployment rate in some rural areas reaching up to 50% (Rogulska, Pisarek, & Wiśniewski, 2002), Poland is facing numerous challenges but with good opportunity to end up in a win-win situation.

For this purpose, the two countries established a collaboration with the intention of dissemination of knowledge and speeding up started processes in Poland. The Swedish-Polish Sustainable Energy Platform was established after the conference on bioenergy between two countries held in Warsaw in 2007 (Energy Platform, 2009). However, there are other already established collaborations between two the countries, such as the Bioenergy Network of Excellence.

These countries share some similarities but also differ in many aspects. For example, according to Rykowski (1997), the paper consumption in Poland was 44 kg per capita per year, while in Sweden, the number is much higher. In 2000 it was 280 kg (World Resources Institute, 2003). The differences in countries are much more obvious in GDP per capita and the overall economic indicators. Both countries have large potential for renewable energy from the forest biomass. Also, both countries have similar vegetation cover with dominant Norwegian spruce and Scots pine. These factors could positively contribute to the established collaboration and make the matchmaking in further steps easier. Notably, there are differences in forestry industries in two countries, Polish forestry is roughly one third the size of Swedish forestry industry comparing the number of employees. As noted in the Poland's national energy policy (Ministry of Economy [MoE]., n.d.), large domestic supplies of coal and national reserves will play important role, at least till 2030.

1.2 Purpose

With regards to the presented situation in Sweden and Poland, the main research question is:

How can Poland learn from the development of forest-based bioenergy in Sweden?

The main research question opens a series of objectives:

1. To describe and analyse the actors, networks and institutions for forest-based bioenergy in Sweden and Poland.

2. To identify and discuss the key lessons from Sweden in regards to the drivers and constraints for the development of forest-based bioenergy.

3. To outline key recommendations for the development of forest-based bioenergy in Poland.

4. To identify the role of the forestry sector in the observed bioenergy market situation in Sweden and Poland.

1.3 Scope and limitations

The term bioenergy in this thesis will used as the term for heat and electricity produced from solid forest biofuels. Liquid fuels will be excluded. Although liquid biofuels present more efficient energy carrier than solid biofuels, they are a product of advanced steps in the bioenergy industry. This paper will try to delineate primary steps in the development of bioenergy market. For the same purpose, this paper will exclude any description of production or supply chain of transport biofuels. The latest trends will be, however, presented at the end of the chapter about Sweden. The bioenergy market is dynamic and liquid biofuels and biorefineries are the trends for the future development in Sweden.

Although energy from biomass can be obtained through several sources such as forest residues, waste wood (demolition wood) and wood produced in forest plantations, for practical reasons this paper will focus on supply chain of logging residues for energy production. There are several reasons for this. First of all, utilisation of logging residues would be the first logical step, because the raw material is already produced and it is already ready for utilisation. Second, supply chain of logging residues is well organised in Sweden and research on this will probably identify key elements that could be transferred to Poland. Third, production of willows as raw material is to this date, not really a successful story in Sweden (Nilsson et al., 2004). And the fourth and the last factor, is limited time to conduct thorough analysis in both countries in all aspects of the bioenergy market.

Logging residues are raw material which is part of the supply chain and later on processed, or comminuted to wood chips. They include slash from final fellings, tree tops and branches, leaves and needles, small trees from thinning operations, unmerchanteable wood and stumps. They are also referred to as primary forest fuels (Junginger, Faaij, Björheden, & Turkenburg, 2005). Wood chips however can come from other sources as well, mostly from sawmills. Supply chain of those wood chips will not be elaborated in this work since the main accent is on the forestry operations.

The intention of this work is to have two different positions at the observed system, or rather two different approaches. The premise is that the production of energy from primary forest fuels can be divided into a bottom-up approach, and a top-down approach. The bottom-up approach will be the observation and analysis of the forestry sector in more detail, since the majority of the observed supply chain lies in this industry. The top-down approach observes the broader picture of the external influences on the supply chain, mainly markets, policies and different actors, networks and institutions. For that reason aggregation level of the research will be broad.

1.4 Research methods and data collection

1.4.1 Archival review

Methodology for this thesis had two independent stages. The first stage was an archival review from various sources. The intention was to use articles from potentially 'opposing' sides such as journals about bioenergy, and forestry journals for which I believed would be more conservative about utilisation of forest resources. In addition, I have read articles from business organisations such as the Swedish Bioenergy Association and reports from national agencies such as the Swedish Energy Agency and Swedish Forest Agency. The method of collection included using the search engines ELIN (Electronic Library Information

Navigator) of the Lund University and Google with key words: forest biomass, bioenergy, logging residues, supply chain, bioenergy market. Additional collection of material was conducted by following the references of the documents and articles.

For the literature on Poland, it should be noted that there is substantially less material published, especially in English language. There have been some very useful and concise reports, but unfortunately some of them can be considered outdated. For that reason, the gaps in knowledge were supplemented through interviews of various stakeholders in both countries, especially Polish contacts.

1.4.2 Interviews

The second stage of the research was conducted through **interviews** of various stakeholders in both Sweden and Poland. The interviews provided up-to date developments in both countries as well as the answers to the research questions. The profile of the interviews is deliberately chosen in such way to provide solid ground for qualitative triangulation of data. For that purpose, a number of interviews were carried out among key representatives from:

- Forestry industry
- Bioenergy industry
- Industry associates and lobby groups
- Academics
- Representatives of energy agencies
- Plant operators (as well as the other members in the production chain)

Approximately 20 interviews were conducted in relatively tight timeframe. The list could have been longer but this has proven to be sufficient number, since most of the answers started to be repeated. Time limitation was serious constraint to the research. It was virtually impossible to arrange some interviews and perhaps some of the stakeholders were left out. That is the limitation of this thesis. Some of the stakeholders, refused to give the interview although they were contacted on several occasions. One of the most important stakeholder, The State Forest Company in Poland could not find suitable person to talk to me, or time, or the good will.

1.5 Research justification

Bioenergy in Sweden has been a widely discussed and researched topic for a long period of time. Since the early development of the market for biomass, a lot of articles and reports have been published with thorough analysis. The published material covers broad area from the utilisation and production of solid and liquid biofuels, to optimisation in the production processes and most other analyses. There is a substantial literature on the policies and markets in Sweden. A lot of material is also available about Swedish forestry as well.

Furthermore, despite the collaboration between Sweden and Poland, and the published material compares the two countries, there is very little analysis and comparison of the forestry sector between the two countries, especially the supply chain of logging residues. It is firmly argued that the logging residues are the first step in utilisation of the forest biomass, yet this is happening to small degree in Poland. According to the earlier studies, Poland has big potential in the forests so it is interesting to study why the forest biomass is underutilised. Sweden has been using forest fuels for over 30 years at this point which makes it especially interesting to compare the two countries and try to identify the differences, challenges and opportunities. For that purpose, analysis carried out in this thesis will delineate and identify the interaction between various actors, policies and especially forestry sector in both countries.

1.6 Analytical Framework

The structure of analysis for this thesis will follow the framework for technology innovation systems (TIS) as presented in article by Bergek, Jacobsson, Carlsson, Lindmark, & Rickne (2008). The analysis of the system comprises of six steps, of which some have sub-steps. The system analysis presented in the article is, however, too complex and some parts are not applicable to the studied system. Therefore some parts of the analytical framework proposed by the authors will be omitted. Notably, the authors also share the idea that the framework can be scaled to proportions for the studied system. According to the authors, the proposed framework is still in the development stage since further research is needed for some steps, such as the evaluation of the functionality of certain structure elements (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008).

The beginning of the analysis starts with identification of the focus of the TIS. As mentioned in the scope sub-chapter, the focus of the study will be forest residues supply chain. The level of aggregation is characteristic of the focus which is basically setting boundaries of the system, or how much will be included. The scope can be broad, or more focused, depending on the actors involved and influence. It is believed that the market for forest residues was primarily developed by internal policies in Sweden, but in the future it will be influenced by the external actors such as the international trade or EU policies. Although Sweden is mature and Poland is young and still an emerging market, similar rules in the future will be applied for both countries. Having this in mind, the aggregation level will be broad for this study.

The second step delineates the actors, networks and institutions in the system, defining the structure of the system. In case of Sweden it is expected to be clear but in Poland perhaps the structure is not so clear. More importantly, maybe some important parts in the structure are missing and that should be identified. As briefly introduced in the background section the most prominent actors would be forestry and bioenergy industry, for networks different associations and collaborations, and institutions would be scientific institutions, government or energy agencies.

In the third step we move from structural elements of the system to the functions they hold. The attempt to describe how each function fits in the system will be made. One of the key elements is the development and diffusion of knowledge and how it is fostered. There are different types of knowledge that are relevant for this study: scientific, technological, production, market and logistical (Bergek et al., 2008). Some mechanisms have combined effect on diffusion of knowledge, depending on the different incentives, different actors and the way they engage in the TIS. A very critical part in this section will be the market for the studied system-forest residues.

The fourth step is normative evaluation where we try to understand and asses how good is each actor functioning within the system. For practical reasons it will be merged with the third step. Evaluation will rely heavily on the responds from the interviews as it is obvious that within the given time frame it is virtually impossible to develop personal opinions. Since it is normative evaluation, the authors of the article argue that it is difficult to assess the 'goodness' or 'badness' of the components and their functions especially because different systems could be in different stages of development (Bergek et al., 2008). That is precisely the case with Sweden and Poland.

For that reason, the authors differentiate two phases of development. *Formative* phase of the development is the initial stage characterised by the assembly of the constituent elements into the place, very little of diffusion of knowledge, low level of economic activities, unarticulated demand, little self-reinforcing mechanisms and to large extent uncertainties regarding technology, markets and applications (Bergek et al., 2008).

The formative phase is followed by a *growth* stage when the TIS develops to more self-sustaining way. The focus becomes expansion of the markets, resource mobilisation and large-scale diffusion of technology. The shift from formative to growth phase depends on the interactions between actors within networks, 'entrepreneurial' experimentation and legitimation of the new, introduced system (Bergek et al., 2008). The change has temporal dimension as every development takes time.

The phase analysis can provide solid background to compare studied systems. The authors suggest comparison between systems as a measure to evaluate functionality but combination of the two methods seems most logical. Comparison between systems will essentially be the most important part of the study. It will provide strategic insight for policy makers for the future development. The comparison between observed can produce so called 'process goals' (Bergek et al., 2008), which are closer to the instruments that can render them more functional.

The fifth step is identification of barriers that are hindering the development of the TIS. Barriers can vary on different levels. The poor organisation of actors or networks can cause poor development of the bioenergy market. Conflicts between institutions due to the lack of information or other reasons can cause 'weak legitimation' of the emerging TIS (Bergek et al., 2008). It is helpful to map the obstacles and barriers and connect them to the corresponding functional units as sometimes it might turn that one mechanism blocks several functions.

The sixth step is a set of recommendations for future policies. The goal of this step is to strengthen the development of the TIS in accordance with the information gained in the previous steps. One of the critical factors for the success of the knowledge and technology transfer would be the establishment of regular assessment of progress in RD&D. Regular assessment should provide updated recommendations.

2 Overview of logging residues

2.1 Definitions

Forest biomass is the mass produced by the trees and it includes stem, stumps, roots, leaves or needles, branches and tree tops. Stem is usually used in timber industry. Upper parts of the stem with smaller diameter are used in pulp industry, and unmerchanteable stem tops are used for production of wood chips.

Logging residues are the leftovers in the forest after the felling operation or thinning operation. They are also referred to as primary forest fuel, which is used without any intermittent operation (Junginger et al., 2005). Logging residues include: branches, tops, small trees, unmerchantable wood (European Biomass Industry Association [EUBIA], 2007) and lately stumps.

Supply chain is organised system of people, services and products, where products and services are delivered from producers to consumers.

Regeneration felling is felling operation performed at the end of the stand's rotation period. The length of rotation period is different for different species. The end of rotation is characterised by the decreased increment in trees. There are several methods of *regeneration felling* of which the most distinctive ones are: clearcutting on large areas, shelterwood method or complex felling. Hybrid methods exist in large numbers which are adapted to the species that exist in smaller populations, or to certain habitats (e.g. mountain regions with steep slopes).

Thinning is selective cutting and removal of undesirable stems which fosters the growth of the remaining trees. *Thinning* opens space and creates better growing conditions for the favoured trees. There is ongoing dispute between different forest regimes; one is maximisation of production of forest biomass and the other is maximisation of the carbon stock in the forest. In the first case, thinning operation has significant importance (Eriksson, 2006).

2.2 Logging residues and sustainability

Logging residues or the primary forest fuel are considered to be a fuel of zero net carbon emissions, if we omit the emissions coming from the production of wood chips and transportation. After certain age, forest stands are uptaking CO_2 and storing it into the carbohydrates (Figure 2-1). Extraction of the logging residues has advantage only if it is part of integrated forestry since it is easily accessible, readily made by-product of the felling operation.

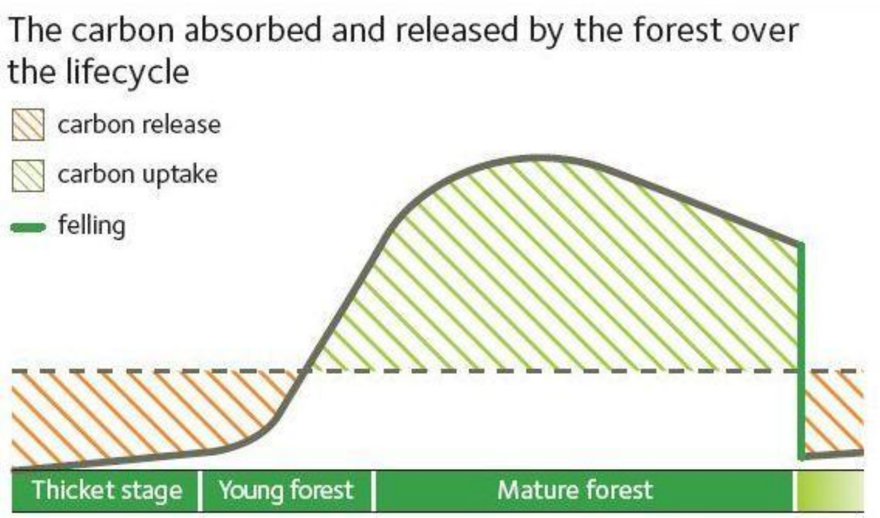

Figure 2-1 Carbon uptake in the forests. Green shaded area shows that more carbon is sequestrated than released.

Source: Swedish Forest Industries [SFI], 2009.

The availability of the residues is a function of the density of the forest stand, felling method, mechanisation used, soil fertility and tree species (including genetic factors). The ratio of the tree crown and stem is changing throughout lifecycle of the tree. In young stands tree crowns are proportionally larger than in older stands, because lower branches die due to the lack of light (Hakkila & Parikka, 2002). That is one of the reasons why shade-tolerant Norway spruce has considerably larger mass of the tree crown compared to the light demanding species such as Scots pine (Hakkila & Parikka, 2002) and why the most of the extraction of the logging residues occurs in spruce stands.

Combustion of logging residues has several advantages over other conventional fuels. Only natural gas has lower ratio of carbon and hydrogen than all fossil fuels, including the wood biomass. If the biomass produced comes from sustainable forestry regime, it can be considered almost as carbon neutral fuel because carbon circulates in a closed loop. There are however peak emissions coming from the extraction phase which are not presented in the Figure 2-1. The input-output ratio of energy from wood chips is in range of 3-5% compared to 5-10% for coal and 10% for oil (Hakkila & Parikka, 2002). Low energy density per area of logging residues makes extraction feasible only in integrated forestry operations.

Emissions of other elements such as sulphur, nitrogen and trace elements are generally lower than emissions from combustion of fossil fuels. Nitrogen can, however, form nitrous oxide N_2O, which is very dangerous greenhouse gas that also depletes ozone layer. One of the advantages of wood biomass is that it can be combusted at lower temperatures where emissions of nitrogen oxides are kept at the low level (Hakkila & Parikka, 2002). Sulphur concentration in the wood biomass is significantly lower than in the fossil fuels. Some alkaline elements from the wood have the ability to capture some of the sulphur in the ash when co-fired with coal thus reducing overall negative impact (Eriksson, Hall, & Helynen, 2002).

Extraction of logging residues has certain impact to the environment. Removal of nutrients is an issue that has been compensated so far by the ash recycling. There are differences in different parts of Sweden. In southern part due to the aerial pollution of nitrogen, removal of residues is considered as beneficial to the environment. In northern parts, the situation is the opposite and stands are reacting positively to the nitrogen fertilisation with increased increment. Experts believe that nutrient removal is possible threat to the sustainability of the forests but the changes will be observable in remote future since changes are slow in forest ecosystems. Also if necessary the problem will be easily solved with additional fertilisation. Additional impacts are disturbances to the soil-increased trafficking with heavy mechanisation causes compaction of the soil and metallization of the mercury in the soil (R. Björheden, personal communication, April 20, 2010).

Some authors argue that intensive trafficking can be reduced by use of so-called mid-fields, especially in the thinning operations. The aspects of the use of the mid-fields are, reduced network of skid roads in the forest stands which creates more natural stand. Mid-field consists of the trees that are beyond the reach of the harvester boom-those trees are later cut manually. At this point such practice could be too expensive in the countries with expensive manual labour, but when all positive externalities are included then it becomes feasible (Mederski, 2006).

Bioenergy industry and market have several benefits when observed from the perspective of three pillars of sustainability. Environmental and economic benefits seem to be obvious, unlike social benefits which among others include alleviation of poverty, mitigation of demographic migrations from rural areas to urban areas, especially in the transitioning and developing countries (Voytenko, Israilava, & Peck, 2009).

Wood chips can also be produced from the dedicated energy crops, predominantly short rotation Salix plantations, managed as coppice stands. Dedicated energy crops are different system and supply chain than the logging residues. Although this thesis will not investigate production of energy crops in Sweden and Poland, it should be stressed out that Salix plantation is the envisioned alternative to forest fuels in Poland.

Beside the above mentioned reasons for utilisation of biomass, perhaps it should be noted the other environmental benefits from forest and in the case of Salix plantations, agricultural biomass. In the town of Enkoping, the Salix plantations have been used as a filter and removal mechanism of the excess nitrogen in the municipal waste water. Instead of expensive treatment of nitrogen removal, pretreated waste water is being used for irrigation purposes. Such nitrogen rich water is excellent fertiliser and at the same time, young trees are purifying water.

Kåberger (n.d.) reports that Salix plantations are suitable and very effective way of remediation of contaminated sites. Some clones of Salix have the ability to uptake excess cadmium, which has contaminated a lot of agricultural land due to the too high concentrations in fertilisers. Also, some clones are able to uptake caesium, a radioactive element. Burning of such wood material and preserving the ash could help to clean up the contaminated sites.

3 Sweden

3.1 Energy sector in Sweden

Sweden is one of the countries with the lowest emissions of CO_2 and yet the highest energy intensity per capita. Production of electricity is dominated by nuclear and hydropower. Sweden is country in a cold climate with large heat demand since heating season is from 8-10 months (Nilsson et al., 2004). Gross supply of energy in Sweden is presented in the Figure 3-1 in the period from 2003 to 2008.

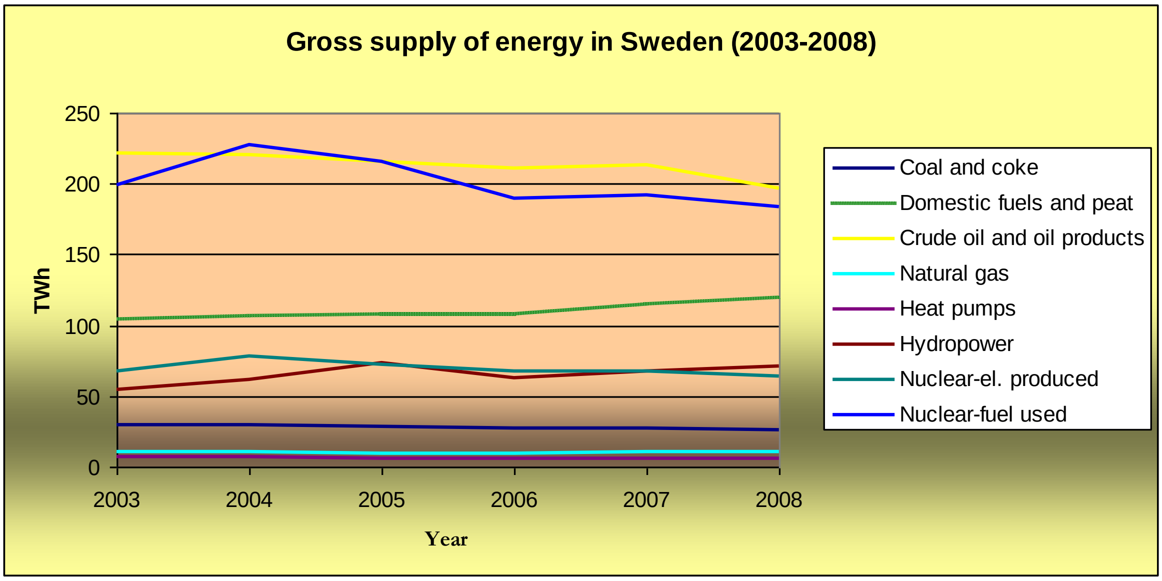

Figure 3-1 Gross supply of energy in Sweden from 2003-2008 from different energy carriers

Source: (Statistics Sweden, 2010)

The proportion of renewables is 44% in 2008 and it has been steadily increasing since 90s. Sweden's target is to increase the share of renewables up to 49%. The majority of renewable energy is the electricity produced in hydropower plants, followed by the large supply of heat in district heating sector from biomass. Third, industry is a large producer and consumer of the wood fuels and black liquor that is also combusted for energy purposes (SEA, 2010).

We can observe the changes in gross supply. Use of coal and coke is still present and despite the variations, the trend is declining. Biofuels are aggregated with the peat and waste, although peat is not listed among the renewable sources of energy according to the Renewables Directive (SEA, 2010). The share of solid biofuels from this source is steady and it is expected to increase (H. Nordstrom, personal communication, March 19, 2010). Total supply of energy in 2008 is presented in Figure 3-2. Electricity produced from biofuels amounts to 9,5 TWh which constitutes around 15% of the electricity produced from nuclear energy. Despite the share of around 20% in the total energy supply, biofuels will hardly compete with nuclear energy in the future in production of electricity.

It is difficult to evaluate the share of logging residues in the energy mix. For that reason, data from the older works is presented to illustrate the situation ten years ago (see Table 3-1).

There is no doubt that values presented for biofuels are much higher in 2010 then they were in 2000 (Johansson, Börjesson, Ericsson, Nilsson, & Svenningsson, 2002). About 10 TWh of energy is produced today from waste (K. Andersson, personal communication, March 19, 2010), of which roughly 20% is electricity.

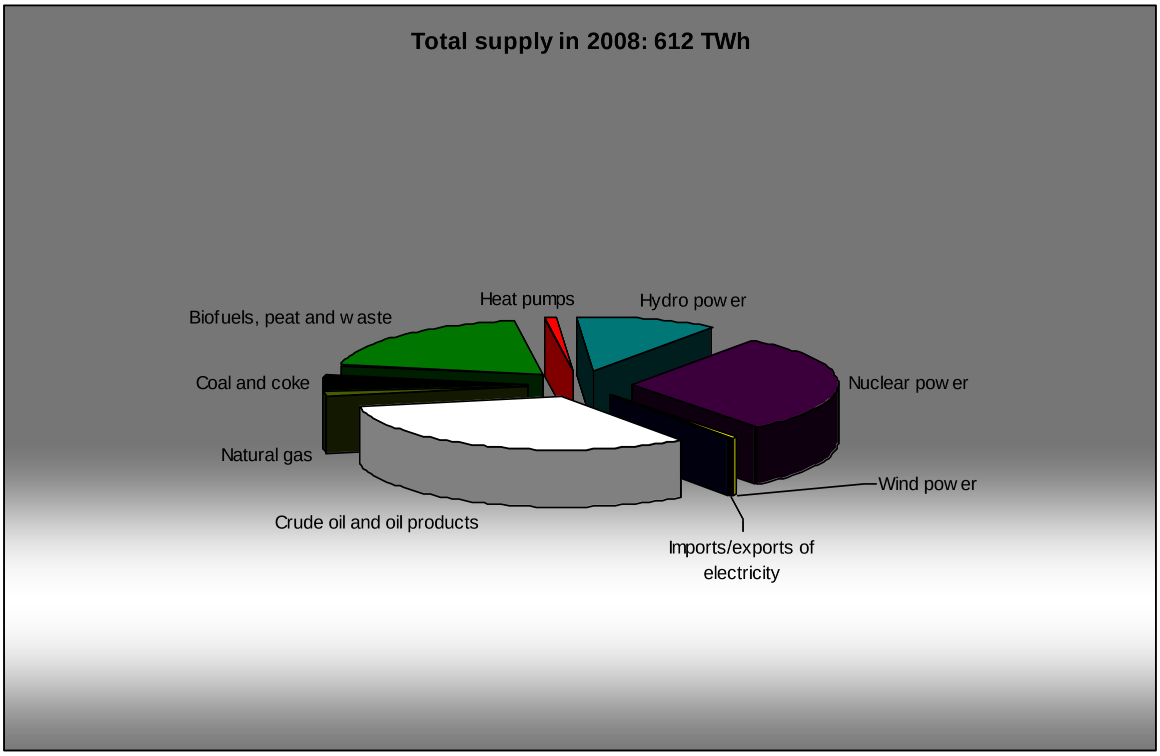

Figure 3-2 Proportions of fuels in energy mix in total supply in Sweden in 2008

Source: (SEA, 2010b)

In 2002 the net emission per capita in Sweden was 6 ton/capita/year, while electricity intensity was pretty high with total consumption of 17 MWh/capita (Johansson et al., 2002). High electricity intensity is a result of the energy-intensive industry such as steel industry and the widespread electrical heating (Johansson, 2000). District heating in 2002 provided 45% of the heat for the residential sector (Johansson et al., 2002). However, low carbon emissions from high energy consumption are only possible with production of electricity from low carbon sources. Thanks to the developed biomass market Sweden is one of the prominent world examples in production of clean energy.

Most of the energy from forest biomass is utilized as heat in forestry industry followed by district heating systems (Ericsson & Nilsson, 2004). Biomass is also used in small percentage in small house heating systems but this market sector is increasing. Although the majority of produced energy is coming from industrial waste in the form of black liquor in pulp mills, the great share also comes from the logging residues (Table 3-1) (Johansson et al., 2002).

Approximately 10 TWh of heat and electricity is produced from the municipal waste (K. Andersson, personal communication, March 19, 2010) and 83 TWh from peat (SEA, 2010b).

In the energy balance of Sweden, sources of biomass are not differentiated and aggregated results also contain the imports, not only domestic production (Junginger, Faaij, Björheden, & Turkenburg, 2005). The same authors report other uncertainties as well. For example, it is unclear what the fraction of marketed wood chips is, and how much was used internally. After the 80s the recycled wood became increasingly important, as sawmills also started to produce wood chips from their waste wood, such as shavings.

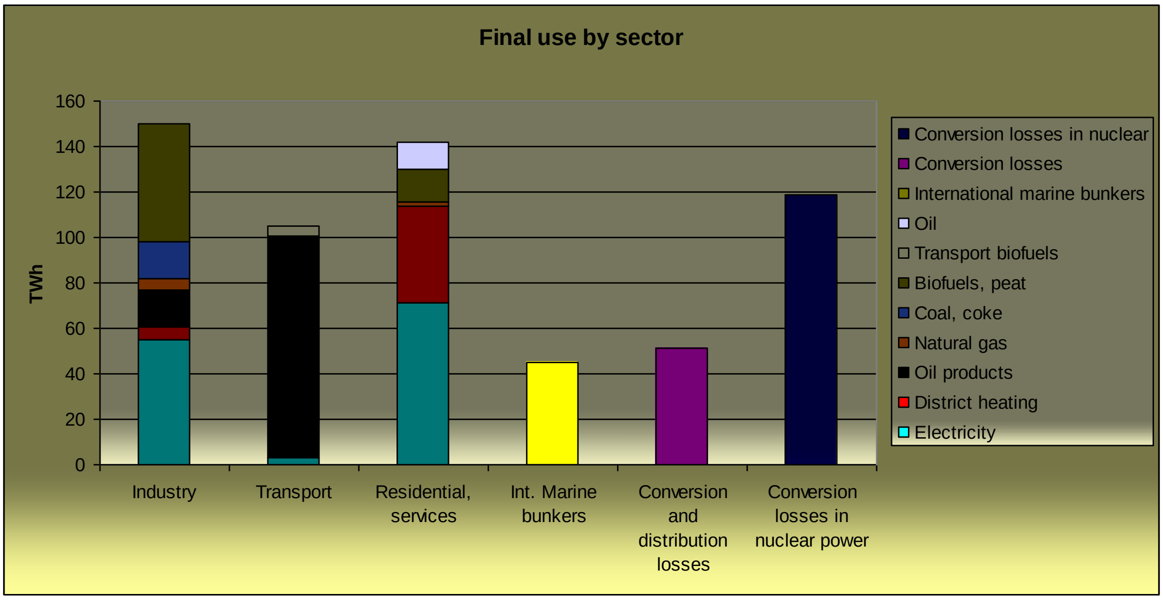

Figure 3-3 Total final use per sector in 2009

Adapted from (SEA, 2010b).

Future development will probably move to production of liquid fuels for transport supplemented with production of various chemicals in biorefineries. Although the authors of the report from 2002 claim that replacement of fossil fuels with biomass in heating sector was logical and cost-effective, the situation with production of liquid fuels or utilisation of biomass for electricity was not fully (Johansson et al., 2002). In other words, energy obtained from logging residues comes from mature technology. In 2007 transport renewable fuels supply for road transport was only 4% of the total energy use (SEA, 2008), while in the following year the share increased to 4,9% (SEA, 2010). The expansion of renewable transport fuels will probably not happen in the near future.

The properties of end use of energy have also changed with time. Since 1970 until now, the industry has changed from energy intensive products to the less intensive, followed by increased output value of the products (SEA, 2008). Households and service sector used up 35% of the final energy supply in 2007 (SEA, 2008), while industry used up 39% in the same year. Since 1970 till today, the demand for energy has increased by 5,3%, from 375 TWh to 395 TWh. The rest of the total consumption are losses in the conversions, grid, and non-energy purposes (Figure 3-3). In the same period, production of energy has increased 34%.

This is the result of the major shift from oil to other sources for production of electricity, in both industrial and residence sector (SEA, 2010).

3.2 Markets

There is a lack of clear data on the updated logging residues potentials. According to the evaluation by Nilsson et al. (2004) in 2001 wood fuels provided roughly 53 TWh of energy in Sweden. Swedish Bioenergy Association's (SVEBIO) projection is that roughly 50 TWh are supplied to Swedish energy mix, and that this proportion can at least be doubled without harming the environment or biodiversity. Total projected potential from wood fuels is 135 TWh and it is based on a study by the Swedish University of Agricultural Sciences (SLU) (Swedish Bioenergy Association [SVEBIO], 2004). These potentials however include bark, shavings, sawdust, wood powder and consequently produced pellets and briquettes. The supply of wood chips from logging residues is smaller than the industrial wood waste (Table 3-1). According to the SFA statistics, in 2008 Swedish forestry produced 11,2 million m^3 of wood chips. The Agency reports for the same year 5,6 million m3 of sawdust, powder and *biofuels* (Swedish Forest Agency [SFA], 2009a). It seems that there are some overlaps in definitions in reporting.

Table 3-1 Estimated biomass supply in Sweden in 2000

Source	**Biomass supply TWh**
Logging residues	7
Fuel wood	10.5
Industrial residues	65
Imported biomass	6
Agriculture	<0.5
Total	89

Adapted from (Johansson et al., 2002)

There is a certain level of disparity in the statistics and estimates of the primary forest fuels, which is due to different aggregation of data and the definitions, which is visible if we compare the data for 2000 with the report by Swedish Forest Agency (2009a) (Figure 3-4). Wood chips are also produced in sawmills, so we can have only rough picture about the production of the primary forest fuels. The increasing trend of sales can be observed in the Figure 3-4 for all fuel types from the forest biomass.

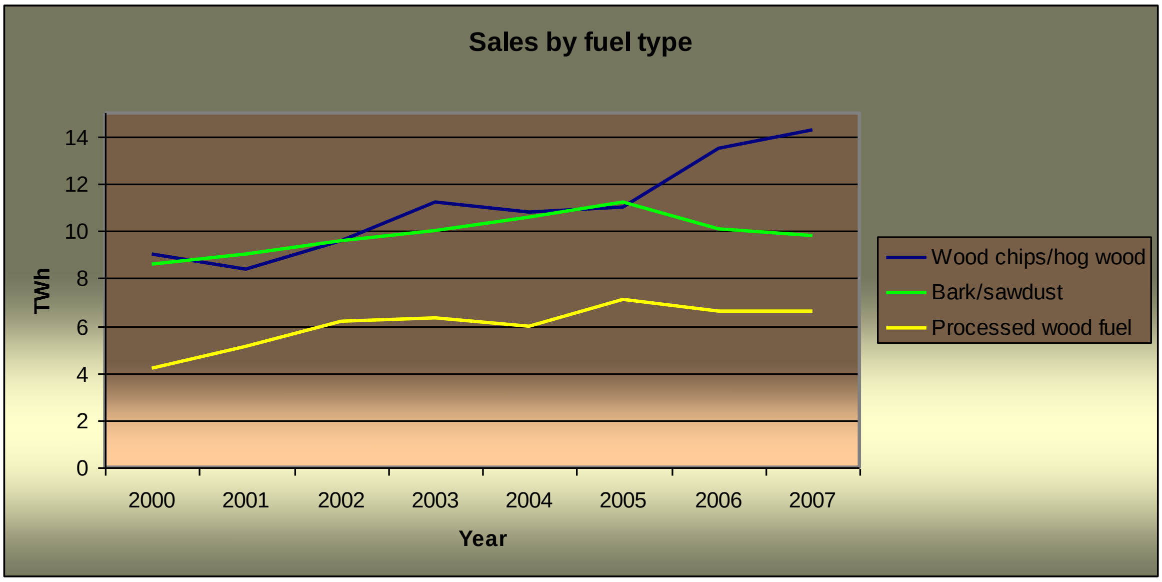

Figure 3-4 Sales by fuel type in period 2000-2007

Adapted from: (SFA, 2009a)

There is ongoing discussion how much can be extracted from the forest without harming the environment and destroying the habitat. Up to this date it is still considered that Sweden is not utilising its full potential of the logging residues. Relatively recently, Sweden has begun with the extraction of stumps as well for energy purposes. This practice began earlier and it was initiated by the pulp industry. However the practice showed that it is very difficult to remove impurities, stones and mud from the stumps which renders stumps unsuitable for pulp industry but they are suitable for the production of energy. The extraction is highly debated and we could conclude that it still in experimental phase. Only small fraction of area is dedicated to extraction of stumps, around 20 000 ha (M. Parikka, personal communication, March 19, 2010)

Sweden is also importing large quantities of forest biomass. In 2000 the direct imports of forest biofuels amounted to 5 TWh which corresponded to 26% of fuel consumed by the district heating sector in Sweden. The price of wood chips and pellets in Baltic States such as Latvia, is far below the Swedish average (Ericsson & Nilsson, 2004). The demand for pellets is continuously increasing which results in high imports as well (Figure 3-5).

Today the cost of price of logging residues in the last three years has risen to 18 euro/MWh or even 20 euro/MWh (J. Saltin, personal communication, April 17, 2010), (SEA, 2010b), while the cost of production in the past years was stabilised at around 12-14 euro/MWh. The costs have been slightly fluctuating mainly due to the fluctuations of the fuel prices for mechanisation that is used. The increase in price is less of a result of increase in diesel prices and much more of the increase in the demand.

Experts believe that various national support systems for the energy from the biomass could, from time to time, destroy market prices in the future. If the high demand for the fuel causes increase of price to 30 euro/MWh, then companies will not be competitive, especially with regards to the fact that the price of 1 MWh from the residues was 10 euro for years. The situation is much easier for the co-firing boilers, but much more difficult for the dedicated biomass boilers (H. Nordström, personal communication, March 18, 2010).

Although pellets do not fit under the definition of the primary forest fuels, pellet industry also plays important role in Sweden. Generally pellets are more expensive than wood chips, the quality of the fuel is higher due to the less moisture content. Pellets are more utilized in small scale installations. The production of the pellets however is happening outside of the forest, in sawmills and pulp factories. Pellet industry is growing but imports have always been larger than exports, especially in the last decade (Figure 3-5).

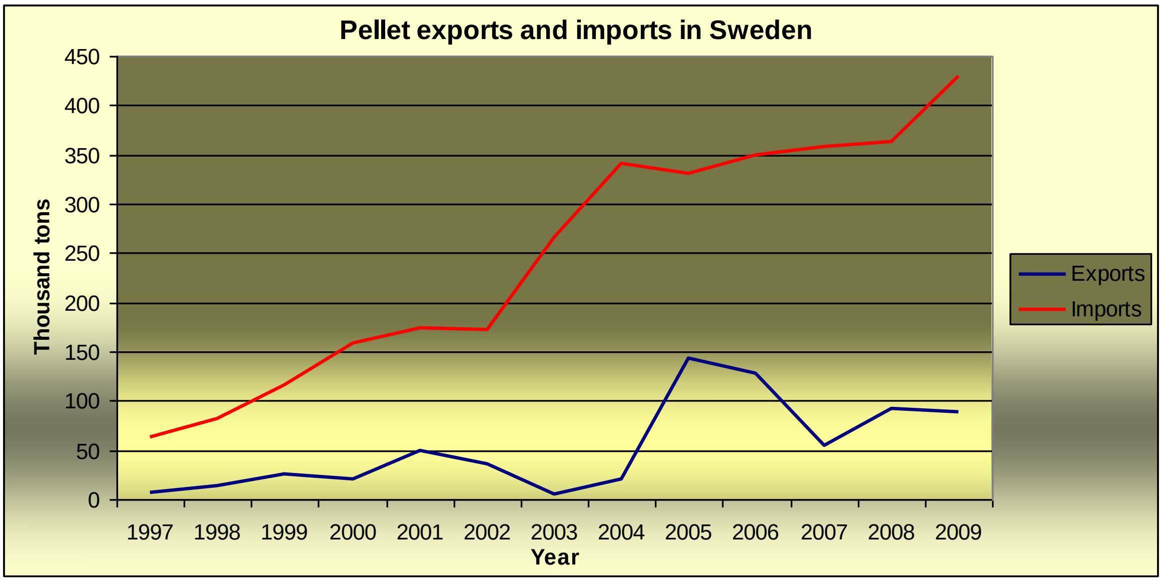

Figure 3-5 Pellet exports and imports in Sweden in period 1997-2009

Source: (Swedish Association of Pellet Producers (SAPP), 2010)

Consumption of pellets is steadily growing in Sweden (Figure 3-6). This is also being a result of increased number of small installations in households. Initially the market for pellets was driven by large scale installations, but in the past years small scale installations are developing faster. Total deliverables from the pellet industry in Sweden was 1,7 million tons in 2007 (Höglund, 2008).

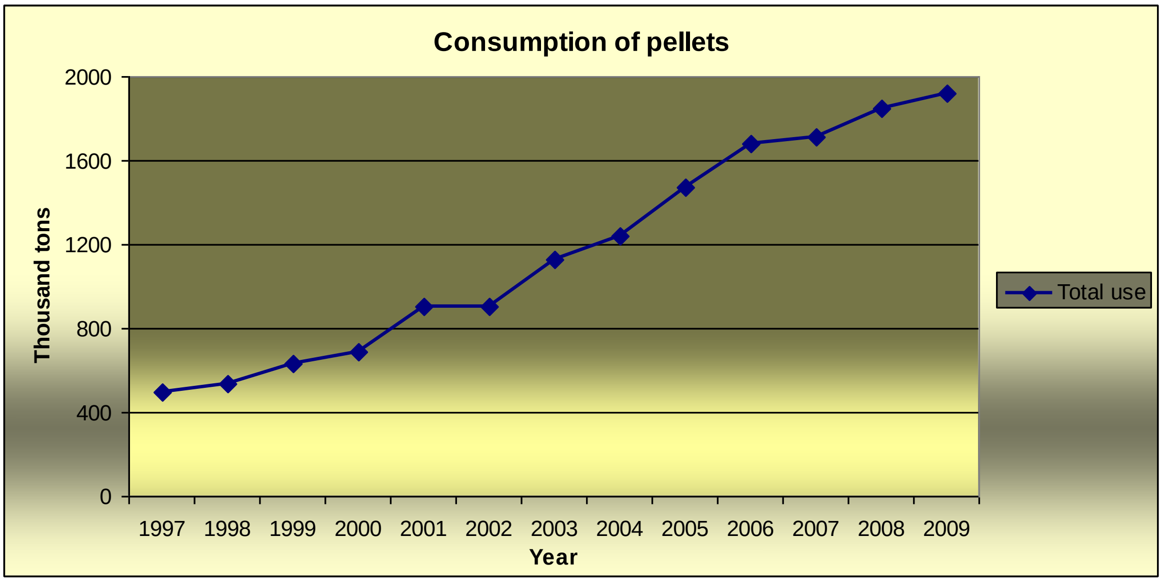

Figure 3-6 Increase in use of pellets in Sweden from 1997-2009

Source: (SAPP, 2010)

The pellet industry reports each year volumes delivered last year and forecasts for the next three years. The statistics are collected from member companies and PiR (Swedish Association of Pellet Producers) adjusted against non-members delivered volumes.

Secondary forest residues or processed wood waste, such as shavings and sawdust gained more importance in the 90s, which has slowed down the growth of production of logging residues. However, a steady increase in demand has been observed since 2000, which has positively affected the production of logging residues (Junginger et al., 2005). The price of wood chips has followed the price of oil. In the 80s when the price of oil decreased, so did the production of wood chips. However, after the 1990, the production have been increasing by 10-15% (Junginger, Faaij, Björheden, & Turkenburg, 2005).

3.3 Policies

There are several milestones in policy of Sweden that enabled the development of the bioenergy market. However, the crucial and most important step is considered tax reform at the beginning of 1990s and the introduction of carbon tax in 1991 (Johansson et al., 2002). In 1970, Sweden was heavily dependent on imported oil, up to 70% and majority was from the Middle East (K. Andersson, personal communication, March 19, 2010). Two oil crisis at 1973 and in 1979 caused increase in prices of oil. At that point the Swedish Government had realized how vulnerable Swedish economy is and after the oil crisis decided to become resilient to the fluctuations of oil prices. For that reason, the research programs were established and new energy policies were issued. The leading motif was domestic supply and utilisation of fuels that will not be susceptible to the drastic changes in trade. Energy from the biomass, waste, peat, coal and nuclear emerged as the most promising alternatives to oil. In 1991 the climate change became issue to deal with and the Government internalised the problem with introduction of the carbon tax.

3.3.1 Taxation in Sweden

Taxes in Sweden can be divided to: carbon tax, environmental taxes that include sulphur and NOx tax, energy tax, tax on nuclear power, tax on hydro power, petrol tax, special tax to combat acidification and environmental tax on domestic air transport (Johansson et al., 2002). Taxes that target energy production and consumption are energy tax, carbon tax, sulphur tax, nitrogen oxide tax, nuclear capacity tax, electricity consumption tax and value added tax which amounts to 25% to all energy consumed. In plethora of policies and instruments that played the important role in Sweden, there is consensus that the most important step was the introduction of the carbon tax in 1991. Currently there is a whole list of policies, but the focus of the thesis will be only on environmental taxation, energy tax, carbon tax and the Green Certificate system.

Energy and carbon tax

Carbon tax was a part of major tax reform in Sweden. Prior to its introduction, there have been already high taxes imposed on fossil fuels. The decline of use of fossil fuel in industry, for example use of oil in paper mills, thus was not a result of carbon tax (L. E. Axelsson, personal communication, March 18, 2010). Carbon tax Introduction of carbon tax was followed by 50% reduction in energy tax (Johansson et al., 2002). Energy tax varied with time, in 1993 it dropped down to 25% while in 1997 it increased to 50% (Johansson, 2000).

The revenues from environmental taxes continued steady growth but remained the percentage of the GDP and range from 2,5 to 2,7 in period 1990-1999 (Johansson et al., 2002). In 2002 the carbon tax was 0.63 SEK/kg CO2, or 63 euro per ton of CO2. Today the carbon tax amounts roughly 100 euro per ton while when introduced, it was 250 SEK per ton of CO_2. This means that it has increased 4 times in period of 20 years. There has been period when it was stable for 6 years at the level of 360-370 SEK per ton of CO_2.

There are exceptions however, in taxing the emissions of carbon dioxide. For instance, electricity producers are exempt from paying tax and heavy industry such as iron and steel are paying reduced tax. Exemption of taxation of electricity is maybe one of the reasons why production of electricity from biomass is still not competitive with production of electricity from fossil fuels (Johansson et al., 2002). Production of transport fuels from biomass as well as production of electricity is still not cost-effective. Some experts believe that the situation will change especially in the sector of biorefineries and transport fuels, but not likely in close future.

No tax is levied on producers of electricity except when CHP plants use fraction of fossil fuels for production of heat (it is usually small fraction to supplement demand) (L. E. Axelsson, personal communication, March 18, 2010) they pay full carbon tax but 50% energy tax (Johansson et al., 2002). The Government decided to reduce taxes on fossil fuels in CHP plants (Johansson et al., 2002). Although production of electricity is not taxed, all non-industrial consumers are levied for electricity-consumption tax (Johansson, 2000).

The purpose of energy tax in 1970 was to decrease use of fossil fuels, especially oil. Today its aim is to stimulate energy efficiency, decrease electrical heating and use of oil for production of heat. It is levied on most of the fuels (SEA, 2010).

Carbon tax influenced on behaviour of companies but had little overall influence on industry. The reason is that tax was much higher for district heating than for industry, fossil fuels already phased out to major extent before introduction of carbon tax, total taxation on fossil fuels was reduced after the tax reform, and energy costs represented only small fraction of total costs for companies (Johansson, 2000). It is logical to assume that development of district heating sector as a result of carbon tax, subsequently stimulated the development of bioenergy market. Carbon tax did influence great reduction in CO2 emissions (Johansson, 2000).

Nitrogen and sulphur tax

Sulphur tax was, like carbon tax, introduced in 1991. It is levied on coal and peat and heavy fuel oil. The rate for coal and peat is 30 SEK per kg emitted and 27 SEK for each tenth of a percent of sulphur by weight per cubic metre of oil (SEA, 2010).

Nitrogen tax was introduced in 1992. Peculiarity about the nitrogen tax is that it is levied on energy producers that produce more than 25 GWh/year (which include boilers, turbines and stationary plants). Nitrogen tax intends to be fiscally neutral, meaning that it is reimbursed to energy producers in proportion to the energy they produce, and reversely proportional to their emissions. Ultimately, only highest emitters are net payers of this tax (SEA, 2010).

Energy producing plants contribute by small share in total NOx Swedish emissions, therefore nitrogen tax had little effect on total NOx emissions in Sweden. Nevertheless, emissions of NOx were reduced by 60% of which nitrogen charge contributed by 80% in period of 1990-1995. In comparison to nitrogen tax, sulphur tax has reduced emissions by 30% in period 1989-1995 (Johansson et al., 2002).

In Figure 3-7 taxes per fuel type are summarised. The values of taxes for fuel types are expressed per ton (LPG, domestic waste, coal and peat (45% of moisture content)), m^3 (heating oil, heavy fuel oil, crude tall oil) and 1000 m^3 (natural gas). For domestic waste tax is levied for ton of fossil carbon, which is estimated to be 12,6% of total weight (SEA, 2010). Sulphur content in peat is estimated to be 0,3%. Combustion of one ton of coal causes emissions of roughly three tons of CO2 (Hong & Slatick, 1994), which means that carbon tax today is around 1000 SEK or around 100 euro/ton.

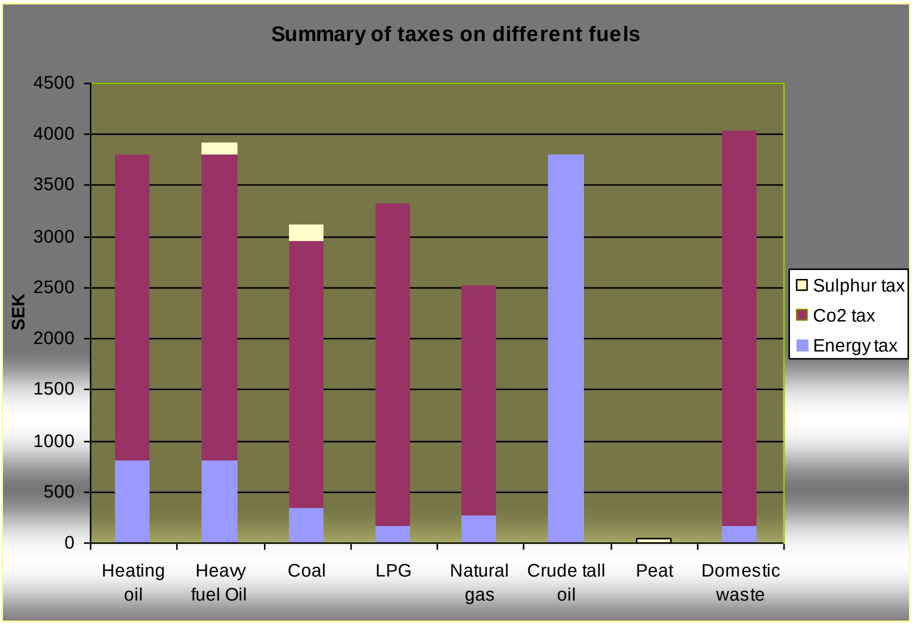

Figure 3-7 Taxation on fuels for heat and electricity on January 2009

Adapted from (SEA, 2010)

3.3.2 Green Certificate System

Until 2003, subsidies and grants were the main support system for investments in Sweden. In 2003 the Government introduced green-certificate system. In that system, end users are obliged to purchase certificate. Each certificate corresponds to 1 MWh of produced electricity from renewable energy and every year the quota is increasing. The quotas are delivered by the Swedish Energy Agency and Svenska Kraftnät[1]. The objective of the system is to increase production of electricity from renewable sources up to 25 TWh by year 2020. The system covers solar, wind, small hydro power (up to 500 kW installed capacity), geothermal and wave energy as well as biofuels. Combustion of peat can obtain certificates only when burned in CHP plants, not for production of heat (J. Saltin, personal communication, April 17, 2010; (SEA, 2010a)).

In 2008 there were 2254 certified plants, of which around 90% were wind and hydro. Biofuels constituted 156 plants (SEA, 2010a) .Experts have split opinion and views on the system. The result of the system is shown in the Figure 3-8.

[1] Company that runs and administers national electrical grid

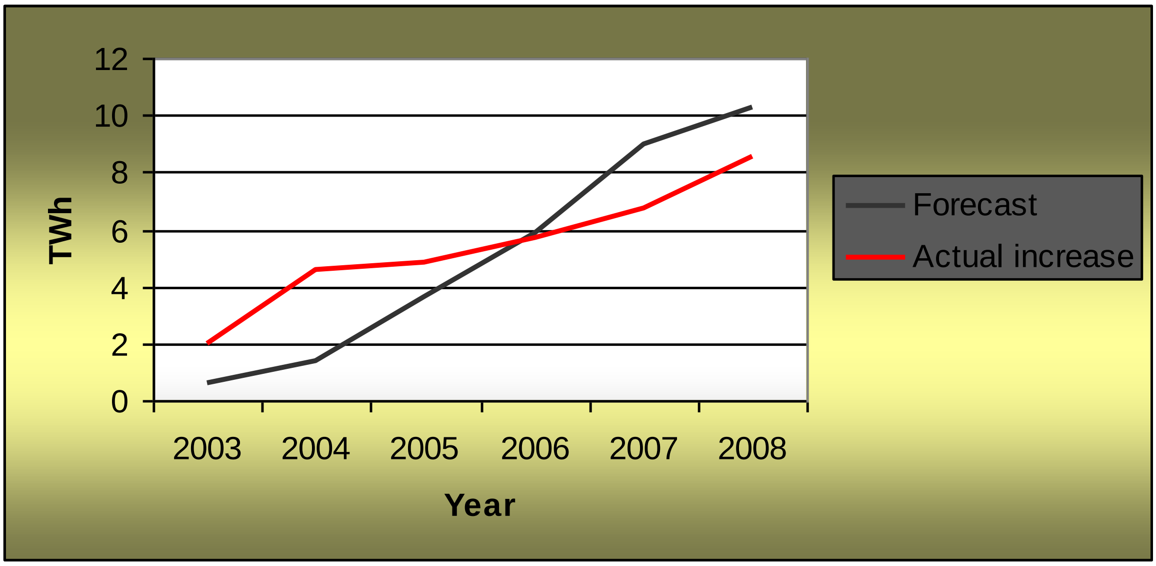

Figure 3-8 Forecast and the actual result of increase in renewable electricity from the Green Certificate system

Source:(SEA, 2010a)

In 2006 we can observe that actual increase in renewable electricity is for the first time less than anticipated. SEA is forecasting steady increase and by year 2030, there should be around 18 TWh of renewable electricity.

In the document named The Swedish Forest Industries Federation's EU manifesto, it is stated that EU policies should not prioritize renewable energy over primary wood products.

In other words, wood comes first and bioenergy comes second. Ironically enough, the premium from tradable certificates in the past years is high enough that some companies are beginning to purchase roundwood for the purpose of production of energy. In the end, the certificate system could perhaps create unhealthy competition between the two industries.

Some believe that for instance, feed-in tariff would be much better system with guaranteed prices. Nordstrom (2010) mentioned example of Italy which also has certificate system. The price of certificates has dropped dramatically which has decreased the willingness of investors to engage in the renewable energy industry. Long term decrease of price could become serious problem, even reason to cancel some projects.

3.3.3 Grants and subsidies

Swedish government was decisive to increase share of electricity from the renewable energy. The result of reluctance to impose carbon tax on electricity production and the drop of prices of electricity in 1990s was little incentive to expand renewable energy sector. For that purpose, government introduced grants for bioenergy sector and wind power to stimulate expansion of this sector. These grants were significant, yet the highest influence had the district heating sector, at that time mostly owned by municipalities (Johansson, 2000).

In 1991 investment grant amounted to 4000 SEK/kW for production of electricity from biomass. As a result, 16 new co-generation biomass plants were built of which 12 belonged to district heating sector and remaining 4 to the industry sector (Johansson et al., 2002). In general, all boilers and CHP plants had subsidy up to 25% in the investment costs both in the 80s and 90s (Hillring, 1998). Despite the investment grants, low prices of electricity on the market still rendered biomass co-generation plants non-competitive economically. Commitment to renewable energy was much easier since Swedish district heating system holds the monopoly on the district heat market. District heating sector of Sweden had expectations of increase of price of electricity in the future, which could be mitigated through the transfer of the costs to end-users of district heating through increase of price of heating (Johansson et al., 2002).

In addition to above mentioned incentives there has been a whole range of grants and subsidies. Also, there has been a number of grants for Local Investment Programs (LIP) in period 1998-2002. Grants from this fund covered different areas and for renewable energy 370 million SEK has been allocated (Swedish Environmental Protection Agency [SEPA], 2009). These grants have been distributed among 161 municipalities and municipalities, among other investments, could either build new capacities or to convert the existing ones to biomass-based energy. Most of the money was used for the district heating systems (B. Johansson, Börjesson, Ericsson, Nilsson, & Svenningsson, 2002). In 2002 local investment programs were replaced by climate investment program (KLIMP) (S. E. P. Agency, 2009a). The new program ran from 2002-2008, and its main aim was to improve energy efficiency and reduce greenhouse gas emissions (SEPA, 2009a). The funds were distributed among 67 municipalities, climate 126 projects and 23 special projects (SEPA, 2009a). Total sum of the money available was 1,8 billion SEK, of which 500 million SEK was transferred from the LIP (Johansson et al., 2002).

3.4 Rise and fall of nuclear energy in Sweden

The development of the biomass market in Sweden coincided with rise and fall of nuclear energy. After the Three Mile Island incident in 1979 (United States Nuclear Regulatory Commission, 2009), the resistance in Sweden started to grow which ultimately ended in referendum in 1980 (Johansson et al., 2002; Kåberger, 2007). That is when the decision to phase out nuclear reactors was brought by Swedish Parliament. Ironically, after referendum the share of energy supply from nuclear power has increased. Although the Swedish government decided to phase al nuclear reactors in Sweden by 2010, only 2 of them have been shut down at this point, Barsebäck I and Barsebäck II (T. B. Johansson, personal communication, March 4, 2010; Kåberger, 2007) The decommission of the two reactors was political decision that would increase the price of electricity and increase the cost-effectiveness of the remaining reactors, since their operations failed to payback the investment (Kåberger, 2007).

The future of nuclear energy in Sweden remains to be seen. At this point production of electricity from biomass cannot compete with nuclear energy and today it constitutes less than 15% of electricity production. Most of the electricity from biomass comes in CHP plants and industrial back-pressure power plants (SEA, 2010). Electrical heating is also still widespread in Sweden and around 20 TWh is consumed in the households for this purpose (SEA, 2010). Although the dedication to decommission of all nuclear reactors was 'irrevocable', there have been many swindles in the energy policy. Reactors are likely to stay in Sweden for a long time.

Sweden will very soon become net exporter of electricity and one of the reasons for such situation are nuclear reactors (SEA, 2010c). By the year 2030, it is predicted it will export 25 TWh of electricity. That will be the result of moderate increase in electricity demand followed by rather large expansion of supply (SEA, 2010c). The energy efficiency is constantly increasing thus reducing the need for energy. International trade in the future will decide the fate of the nuclear energy in Sweden, but green certificates system will continue to foster the development of the CHP plants based on the biomass. The solid foundation for the bioenergy market has been set.

3.5 Research and development

Sweden has been supporting RD&D of energy sources for long time. The oil crisis in 1973 triggered mobilisation of the government and funds for the research of alternative energy sources. In 1975, the Government launched Energy Research Program.

In the 70s, biomass has not been seen as promising source of energy. Most of this opinion was generated from forestry industry which feared the potential scarcity of raw materials and competition in new industry. Increase of prices of oil, especially after 1979 has changed this situation (Johansson et al., 2002). and investments in biomass energy grew to record level, reaching almost 330 million SEK in 1981 (Johansson et al., 2002). With time, interest in coal and peat has decreased due to the growing awareness associated with environmental problems with these sources. After the decision of phasing out nuclear reactors, production of electricity became important issue. In the early 90s, the focus of investments moved to gasification of biomass and cogeneration plants.

Since 1975 Government invested annually almost 1 billion SEK in RD&D in Sweden. Roughly 11% of those spendings were invested in bioenergy RD&D. This figure has been changing with time, mostly favouring biomass. Substantial investments were made by the two largest energy companies: Vattenfall and Sydkraft as well as the forestry industry. Government investments in biomass varied with time, after peak period in the 80s, they levelled out with 90s in the year 2000, amounting to roughly 60 million SEK. In the last decade of the 20^{th} century, priority of RD&D became transport fuels, small scale combustion, production of ethanol from forest resources and cogeneration. Funding for ash recycling, harvest of logging residues and environmental aspects of utilisation of logging residues decreased significantly, which was a result of saturation in knowledge in these areas. Up to this date, significant amounts of money were invested in the RD&D of cultivation of energy crops, primarily Salix monocultures. Due to the market conditions and insufficient incentives, this sector of bioenergy market has not developed fully.

In comparison with countries from the rest of the EU, Sweden has spent more money in the RD&D of the bioenergy. If the ratios of investments and forest and agricultural land were used for comparison (Johansson et al., 2002), then the averages would be the same. The situation has changed in time and it became more complicated with the prolonged operations of nuclear reactors. In the 1990s, there was a belief that electricity production from nuclear power will be successfully replaced by alternative sources. In contrast, the price of electricity has dropped down which has reduced incentives for further RD&D in bioenergy at the same level as in years before. Sweden has still managed to gather large data base of knowledge about extraction of logging residues and production of energy crops in period of more than 30 years, while production of electricity from gasification of forest biomass and transport fuels is still underdeveloped and a lot of RD&D is ahead. In the same period, bioenergy has successfully penetrated the market and occupied its own niche (Johansson et al., 2002).. The barriers in higher utilisation of biomass in mature technologies are not knowledge gaps, they are rather external and more of a logistic nature.

4 Forestry in Sweden

Forestry industry in Sweden has played important role in the development of the bioenergy market. Ownership of the forest land is such that most of the land is owned by private individuals and companies, while smallest share belongs to state-owned limited companies (Figure 4-1).

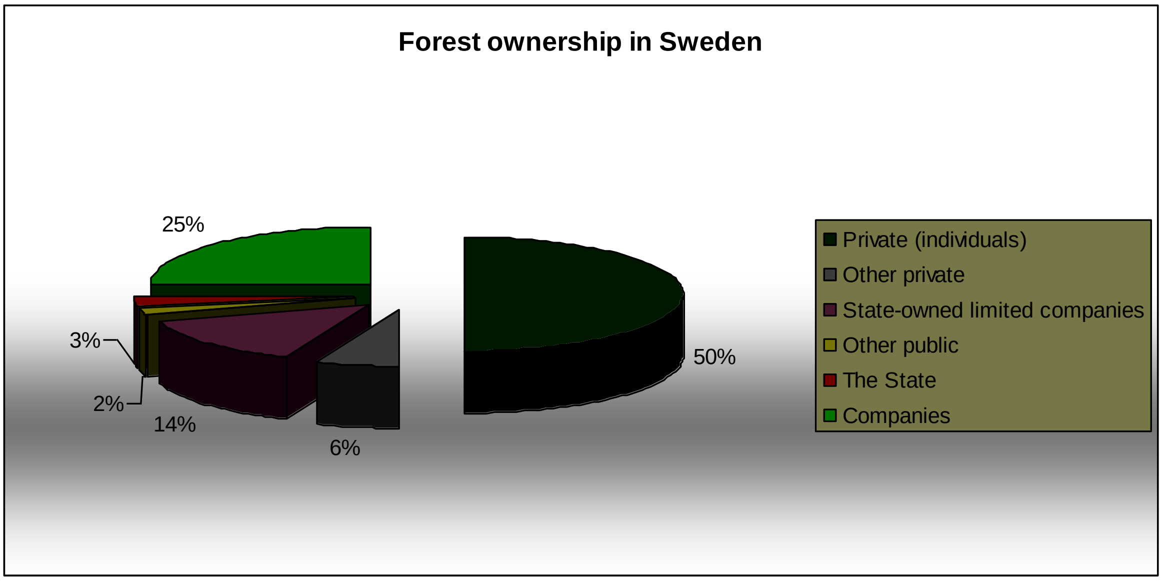

Figure 4-1 Ownership of the forest land in Sweden

Source: (The Swedish Fores Industries, 2009)

Forests in Sweden are one of the most important and abundant resource. Since 1903, after the issuing the Forestry Act, deforestation has been prohibited, but mostly driven by economic factors. Forestry Act was the document that made reforestation after felling compulsory (Swedish Forest Agency [SFA], 2009a) thus protecting Swedish forests from permanent destruction. Forests cover approximately 60% of the land (SFA, 2010). The forestry industry in Sweden employs around 100 000 people and it contributes by 12% in the income generated through export (SFA, 2010). The productivity in the forest operations has increased a lot. For example, in 1950 productivity was 1,2m^3/man-day and in 1992 it increased up to 14 m^3/man-day (Carlsson & Rönnqvist, 1998). The annual cut is below the annual increment. However, since the beginning of forest management in Sweden, the share of large trees with large diameter has decreased significantly (by 80%) as well as the areal extent of the forest stands older than 150 years (BorealForest, n.d.).

The dominant type of forest vegetation in Sweden is Norway spruce stands (45%) and Scots pine stands (39%). Birch contributes significantly by 10% and the remaining species by 6% (SFA, 2009b). Conifers however, dominate in the total stand volume and combined contribute by 85%. Birch is the most dominating deciduous species, but the volumes of oak and beech have doubled in the past 60 years (SFA, 2009a).

Parallel to the increase of net production of forestry industry in Sweden, standing volumes have increased as well as a result of improved silvicultural practices. Today the annual increment in forests of Sweden amounts to 100 million m^3 (Agency, 2010). In 2008, Swedish forestry produced 45,2 million m^3 sawlogs, 44,2 million m^3 of pulpwood, 11,2 million m^3 of chips, and 5,6 million m^3 of sawdust, bark and biofuel (SFA, 2009). Total standing volume is estimated to be around 3 billion cubic meters (SFA, 2009d)

In 2008 almost 780 000 ha were logged, out of which final felling constituted 140 000ha, thinning operations 308 000 ha and the rest was clearing operations (SFA, 2009a). Not all of that area was subject of biofuel extraction since certain share of the forest is in sensitive areas. Actually, only 85 000 [2] ha in 2008 was notified for the extraction of the residues. Mean size of regeneration felling area was 4,3[3] ha (SFA, 2009).

It is essential that forestry is adaptive in Sweden, since there are large differences in the north and south of the country. For instance, growing period in the north is only 120 days per year, while in the southern part it is double (Agency, 2010). Also the rotation periods for some species such as Norway spruce have been shortened as a result of the market demand for different dimensions of the trees (R. Björheden, personal communication, April 20, 2010).

One could argue that bioenergy industry and the bioenergy market saved some of the forest industries in Sweden. In forestry, only half of the harvested biomass is used for the primary purposes. The rest is rendered as a waste. When the waste became economically feasible, it added value to the timber product. In fact, sales of the pellets and chips from sawmills in some years were higher than the profits from the timber products. The same case was with the pulp industry; internal utilisation of black liquor and bark for energy purposes has greatly reduced the costs. Some paper mills today are converted to modern biorefineries. The original fear of competition between forestry industry and bioenergy industry thus has proven to be wrong. The only industry that faced direct competition for raw material was chipboard or plywood industry. This branch however has mostly shifted to production of wood pellets (Kåberger, n.d.)

4.1 Supply chain of logging residues

There are three main types of logging residues: 1. slash from regeneration felling, or the final felling, 2. small trees from thinning and cleaning operation and 3. unmerchanteable wood. After felling operation, slash is collected in heaps which are later collected by forwarders. Very often slash is left in forests for couple of months (this depends on the season and the demand for wood chips). During that time moisture content is greatly decreased which increases the quality of the fuel. Also during that time needles fall off onto the ground. This is beneficial for two reasons: 1. needles are not good material for combustion and 2. most of the nutrients is returned to the stand since the highest concentrations are in needles. Stumps are also being used for the production of energy, but at this point extraction of stumps is limited to roughly 20 000 ha in Sweden and is still considered to be in experimental phase. Forest fuel supply chain consists of four main operations:

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[2] Notification means issuing a permit for the extraction of the biomass. There are different types of permits for regeneration felling, thinning operation or extraction of logging residues. Permits are also different for different size of felling sites. Rules for notification procedure can be found in Swedish Statistical Yearbook of Forestry.

[3] The size of the felling area greatly affects the supply chain, which will be discussed later in the thesis.

- Harvesting
- Forwarding
- Comminution or chipping
- Transportation

There are four different main types of supply chain in Sweden (Junginger et al., 2005):

1. *Terrain-chipping* method-residues are chipped by a mobile chipper in the field, then later transported to the roadside in small containers and transferred to truck.

2. *Roadside chipping* method-residues are forwarded to the roadside and directly chipped to the large container of a truck (it can be up to 100 m^3 volume).

3. *Terminal chipping* method-this method was popular in Sweden, but has not been used lately. Residues are transported to the terminal by trucks, where they are chipped and then later on distributed by trucks or train. Chipping at the terminals the most cost-effective method of all, but terminals negatively affect transportation cost because of increased handling with material (Eriksson Ljusk & Bjorheden, 1989; J. Johansson, Liss, Gullberg, & Bjorheden, 2006). Another version of this method is transportation directly to the power plant if the distance is small, where residues are chipped and put to use. In the 80s, tree section method was practiced, when trees were delimbed at the plant (Bjorheden, 2006).

4. *Bundling method-* logging residues are compacted into bundles by a specialised machine called bundler. The bundles have a shape and dimensions of a roundwood which are loaded onto a truck. Residues are chipped either at the terminal or at the power plant. Ironically, this technology has been developed in Sweden but is not being practiced. The machine is still considered to be too costly and at this point there are 2 or 3 bundlers at operation in Sweden (R. Björheden, personal communication, April 20, 2010). Ironically enough, bundling technology was invented in Sweden, but previous heavy investments in the system rendered resulted in well established infrastructure where bundlers are hardly competitive (J. Johansson, Liss, Gullberg, & Bjorheden, 2006).

The Whole Tree Utilisation

In 1974 the Whole Tree Utilisation program was initiated, driven mainly by the pulp wood industry which has foreseen the shortage of the raw material. Previously unused parts of the tree became exploitable and used for energy purposes (Bjorheden, 2006). As a result, 17% of the raw material became more available for the ply wood industry and significant amount for the production of energy. Plywood industry has also initiated research on the extraction of the stumps. The reality was such that extracted stumps had, although large supply of biomass, too much of impurities such as soil or stones. Stump extraction is becoming more important in Sweden. According to Parrika (2010), Swedish Forest Agency claims that around 20 000 ha in Sweden is suitable for extraction of stumps so the practice could be considered still in the experimental phase. Sustainability issues of stump extraction are not clear since it is great disturbance to the soil profile. There is one benefit from stump extraction. In Sweden there are many stands infected by fungi disease that cause root rot (*Heterobasidion*, *Armillaria*, and *Phellinus* sp.), Extraction of stumps in infected areas has proven to significantly reduce the infections in the next generation, increases stand productivity and seedling survival and stand establishment is increased (Vasaitis, Stenlid, Thomsen, Barklund, & Dahlberg, 2008).

For the whole tree harvesting, tree section method has had great importance where trees were harvested as a whole and delimbed at the energy plants. For that purpose harvesters with head that can handle multiple trees were developed. These harvesters are very important in clearing and thinning operations.

Whole tree utilisation has certain effects on the future generations of trees. Although there is very little evidence to support the theory of reduced height, some experiments demonstrate that chest diameter in the second rotation plants can be reduced (Walmsley, Jones, Reynolds, Price, & Healey, 2009) Other studies show that there is no effect on the growth of trees (Saarsalmi, Tamminen, & Kukkola). Oddly enough, sites that have been harvested by WTU practices seem to increase the survival and establishment of new young generation of trees (Walmsley et al., 2009).

4.2 Optimisation in the supply chain of logging residues

The costs in the production system of the forest solid fuels are still high enough to be non-competitive with the fossil fuels. That is why optimisation in each individual step needs to take place in order to reduce the overall cost. In Sweden the costs of production of wood chips were reduced four times since the practice of extraction of logging residues began (R. Björheden, personal communication, April 20, 2010). The price of wood chips has increased though, that it cannot be used anymore as a proxy for costs. The main problems with logging residues are: 1. high transport costs, 2. dirt content and 3. problems with storage of the material and storage area (Johansson et al., 2006). There are, however, other challenges imposed on the supply chain. Proper timing and synchronisation of all operations is very difficult, but necessary (Figure 4-2). For instance, adequate timing of chipping needs to be aligned with available storage area. The choices of contracting sawmill or harvesting certain area, using terminal or transporting directly to the heating plant-these are examples of choices that make planning difficult. With time the quality of wood fuels is decreasing and that should be taken into the consideration (Gunnarsson & Lundgren Jan, 2004).

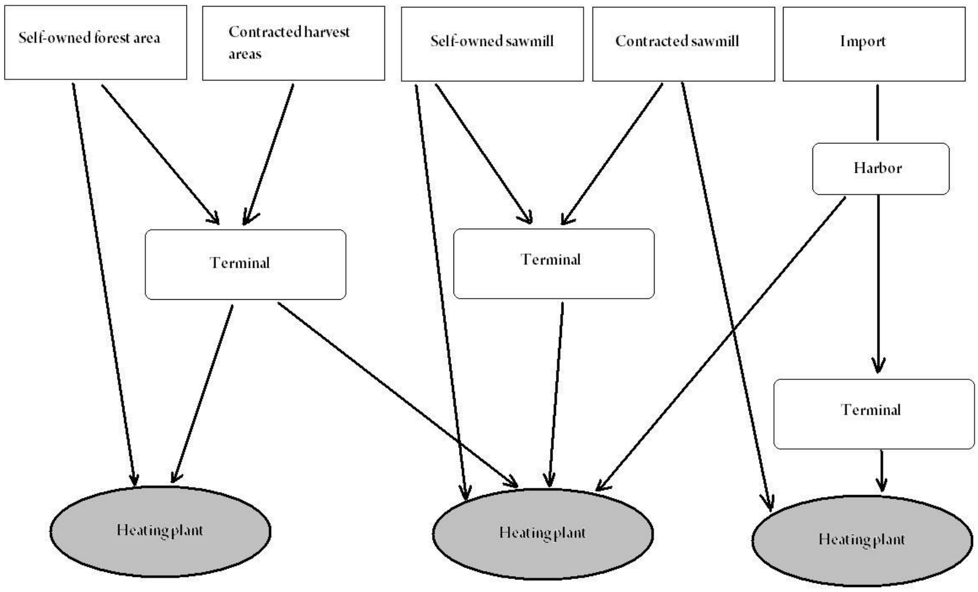

Figure 4-2 Possible wood chip flows in Sweden

Adapted from: (Gunnarsson & Lundgren Jan, 2004)

In essence, optimisation of the supply chain and the production costs means optimisation of transportation (Eriksson Ljusk & Bjorheden, 1989). According to Björheden (2010), the people need to learn the system, and use it for long time in order to maximize the output. Sweden has been successfully producing forest fuels for several decades, and it is one of the most advanced countries in this field. Reduction of the costs has occurred through iterative process of several types of learning, of which probably the most important was learning-by doing. Björheden (2000) was investigating the productivity or performance of a system after the introduction of the tree section method. He came to a conclusion that productivity is a function of a payload. The practice was introduced for the first time to the forest contractor. Productivity is considered to be a result of four main factors:

1. technology used
2. skill level of the machine operator (experience)
3. work object properties (e.g. size, weight) and
4. conditions of work (legislation, weather conditions etc.)

Technology that was used in the research was taken as a constant although the improvements and changes in technology are affecting the result. The overall results of the research are demonstrating strong correlation between weather conditions and productivity of the system. Since payload is affected by the weight of the load, it is indirectly affected by the weather conditions. Wet conditions of snow and rain are causing greater density of wooden material and thus bigger weight for the same volume opposed to the dry conditions. Despite the fact that most of the research is centred on truck operators, there are clear indices that the conclusions could be applied to other machinery. One of the key findings is that experience greatly affects productivity, for both truck and harvester operators. Formal training is helpful, but the greatest influence in the optimisation is learning-by-doing.

Improvements in the supply chain through the RD&D have also played important role, as well as the technological improvements. For instance, first chippers had capacity of 10-15 000 lose cubic meters of chips, while modern machines have capacity of 100 000 loose cubic meters per year (A. Bruks, personal communication, March 30, 2010).

Junginger et al. (2005) reported several optimisation steps that reduced the costs in the supply chain of wood chips produced from logging residues. The steps refer to the road side chipping method, since it is the most practiced in Sweden.

For *felling* operation, it is important to collect slash and put it into heaps. In the past, after clearcutting, slash used to lie scattered on the site, which made collection more costly. Also, harvester operators now have learned not to drive the machinery over it, a practice that was causing more contamination with soil and rocks. At this point, the costs of felling are allocated to the timber and pulpwood, since revenues from the slash are marginal, but in the future, this is expected to change. From the technological perspective, there have also been some improvements. One important innovation is harvester with accumulative felling head, an innovation that is very useful for precommercial thinnings, cleanings of the road sides and powerline corridors.

Forwarding costs have been reduced in the first place due to the increased experience of the operators and improved performance through learning-by-doing. With time, the practice of collecting 'cream off the top' was accepted which meant spending less time to collect all the slash possible at the felling site. In period of 1983-2003 forwarding costs have dropped down by 58% and in the given period, it is the biggest saving of all (Junginger, Faaij, Björheden, & Turkenburg, 2005).

Chipping cost reduction, as already mentioned, is a result of increased capacity of chippers since 1980. The technical availability has increased from 50% to 90% since 1980 (Junginger et al., 2005).

Transportation costs are relatively unchanged for a long period of time. This is due to a fact that truck transportation is dominant with large containers. All of timber in Sweden is transported at one point by trucks (75% of all deliveries) (Carlsson & Rönnqvist, 1998), and later, if needed by other means such as train or ship. In 1998, around 8 million m3 of wood chips was imported from Baltic States and Russia (Carlsson & Rönnqvist, 1998). For roundwood transport in 1998, the average transport distance by truck was 80 km and 229 km by train (Carlsson & Rönnqvist, 1998). Trucks used in Sweden and the rest of Scandinavia are unique in Europe. The dimensions of the containers can be more than 100 m3 and the length of composition is around 24 m (P. Staland, personal communication, March 18, 2010).

There is still room for improvement. Swedish forestry was and still is heavily reliant on the export so the rationalisation in the supply chain, predominantly transportation, was needed. With time, however, it became more customer-oriented which meant delivery of raw material at the right quantity at the right time. This concept is optimising the productivity of the customer, but puts pressure on the logistics of the Swedish forestry but in return might add extra value to the final product. The storage areas are decreased and the need for transport increase is needed. This is valid for timber operations, but there are parallels with transportation of the solid fuels.

The biggest concern for haulers is to have enough of material to transport year-round. The major problem in the wood flow are so called single-trips where trucks go loaded in one direction, and come back empty. As a result, efficiency is only 50%. This can be avoided by careful planning of the routes but still the planning is a function of geographical boundaries. For instance, in southern Sweden sawmills are relatively evenly distributed, while in the north of Sweden, most of them are located on the east coast. Naturally it is easier to manoeuvre in south of Sweden since haulers can more easily adapt their routes. Optimisation in this case consists of providing of real-time information to the haulers with details of alternative routes during the forest operations (Carlsson & Rönnqvist, 1998). The advantage of the system with big truck containers is that haulers can transport different goods when the forest operations stop.

Stumpage fee, or the price that companies are paying for the logging residues to the forest owners have varied in the period of 1983-2003 (Junginger, Faaij, Björheden, & Turkenburg, 2005), but in general it has increased. This is probably due to high demand for the raw material. Today the stumpage fee amounts from 0-30 SEK, depending on the distance of the forest to the power plant. If the demand is low, the owners do not get paid for the residues. Notably, in most of the cases, the owners are trying to get rid of the residues even for zero profit, because it is easier to prepare the soil for the next planting (R. Björheden, personal communication, April 20, 2010).

Recent survey has showed that forest owners in Sweden are heavily in favour of extraction of logging residues (74% were positive, 15% said maybe and 11% were against) (Norin, 2009). The conclusion of the survey is that the willingness of the owners will not be limiting factor for the future expansion of the extracting operations. The main reasons of the supporters of the extraction were additional income (28%) and facilitation of the forest health care (28%). Other reasons were: tidiness of a forest (15%) and the fact that wood chips are reducing the use of fossil fuels (14%). What is also very important from the survey is the way of information dissemination about extraction of residues. One third of respondents obtained necessary information from the forestry magazines (34%), one third from timber and the remaining from the regular forest meetings (Norin, 2009).

Further reduction of costs could be possible with increased use of *bundlers* (Figure 4-3). Bundlers are machines that are compacting loose residues into the so called Compact Residue Logs (CRL). The production of CRLs is as follows: loose residues go through the machine and then later are tied up to logs that are 70-75 cm thick and then cut to the length of 3 m by a chainsaw (Kärhä & Vartiamäki, 2006).

In the research by Kärhä & Vartiamäki (2006) the average reported volume was 0,47 m^3. The authors argue that the aim should be the volume of 0,60-0,65 m^3 for green and 0,55-0,60 m^3 for brown biomass. The density of bundles is higher than lose residues which directly affects transportation cost per ton. Naturally the effectiveness of the bundlers is site specific and depends on the removal of the residues. In the article by Kärhä & Vartiamäki (2006) the average reported ratio of removal was 29% on the research sites, meaning that for removal of 1 solid m^3 of residues, 3,5m^3 of roundwood needs to be harvested. Combination of bundlers with terminals can exploit the fact that non-chipped material can be stored for longer period of time, unlike chipped material that needs to be transported immediately (Gunnarsson & Lundgren Jan, 2004).

Figure 4-3 Slash bundler

Source: (Michigan Society of American Foresters [MSAF], 2010)

Despite the fact that utilisation of bundlers reduces chipping costs significantly (Gunnarsson & Lundgren Jan, 2004; Johansson et al., 2006), experts still agree that at this point they are far too expensive machinery to use. Also transportation of bundles on the long distances is cheaper than the transportation of loose residues. Bundlers are very successfully used in Finland and are expected to be even more cost-effective in the future. The difference between two countries is that Finland has built large CHP plants such as Alhomens Kraft plant of 550 MWth/240 MWe. These huge plants require a lot of biomass, which could affect transportation distances which indirectly makes use of compacted bundles more feasible (Junginger et al., 2005).

The experience from other countries, namely Finland, shows that prerequisite for cost reduction for bundlers is experienced personnel, larger sized bundles, operation in two work shifts, increased bundling productivity and increased recovery of material. All these prerequisites are supporting the fact that bundlers are very expensive machines to use. However, if prerequisites are met, Karha & Vartiamaki (2006) are anticipating bundlers to become the most cost-effective method in the future for distances longer than 60 kilometers.

Another option for future cost reductions could be higher utilisation of other parts of wood, namely pulp wood for production of wood chips. This will be function of market prices of residues. Some experts believe that at this point bioenergy industry is not outcompeting pulp industry (K. Andersson, personal communication, March 19, 2010) and that there is strong synergy between pulp industry and bioenergy industry. Increased use of logging residues and trees from the thinning operations is adding extra value to the forest. It is also stimulating faster growth of the trees which results in bigger production of pulp wood as well. Integration of the forest industries in Sweden enabled increase of value of the by-products of other industries, such as pulp industry. Forest companies in Sweden are transformed to integrated energy and forest companies.

The experience of the other actors is showing the opposite picture. For instance, energy companies such as VEAB AB are already willing to pay much more money for the wood chips. According to Saltin (2010), in the past couple of years, it was possible to buy pulp chips for production of energy. That is a result of the Green Certificate system since the premium is so high that purchase of more expensive raw material is becoming feasible. That is the shortcoming of the system, and in the future it might cause the unhealthy competition between industries. Also if the prices of certificates continue to grow, the companies will start buying sawlogs for production of energy (J. Saltin, personal communication, March 19, 2010). It is probably better to produce paper or furniture, which later on can be used for production of energy at the end of life-cycle.

Integration of operations is reducing costs as well. For instance, in Finland there are new approaches and technologies developed, such as combination of one machine that functions as slash scarifier-forwarder, thus harvesting logging residues and preparing the site for the new planting (Laitila, Asikainen, & Hotari, 2005).

4.3 Forests and concerns

Sustainable forestry will be the management model for the 21st century. There are numerous challenges since sustainable practices are aiming at conservation of biodiversity, sustainable yield, water quality, carbon sequestration, flood control, production of biomass for energy at the same time (Burger, 2009). In intensively managed forests fungi, insects and cryptogams are threatened because of the reduced quantities of dead wood. These groups of organisms are crucial for the processes of nutrient cycling (Spence, 2001). For the purpose of preservation of biodiversity, there is consensus that in every biogeographical region around 9-16% of land should be excluded from management practices (Spence, 2001). Forest management practices should whenever possible follow natural disturbances.

The pressure on forests is increasing and there are world wide attempts to cope with this problem. In some countries the practices are to convert natural forests to plantations and dedicate it to intensive timber production. This is believed to decrease the pressure on native forests. This in return is causing the change in soil, climax soils are replaced by new type, mostly with early-succession type (Burger, 2009) which is ultimately, the deterioration of the soil. The progress of silvicultural methods and soil science is reported to successfully deal with the nutrient recovery problems (Siry, Cubbage, & Ahmed, 2005).

In Sweden, most of the forests are managed in a way that clearcutting is followed by planting of seedlings. Such forest resembles a monoculture. After 10 years from planting, only 60% of the trees are planted trees and the rest originates from adjacent stands which creates boreal forest type (R. Björheden, personal communication, April 20, 2010). Intensive management of the forests in the long term decreases levels of nutrients, but also negatively affects the biodiversity when compared to the natural forests.

In a survey conducted by Swedish Forest Industry Association it is visible that public is deeply concerned about the forest in such way that forest is considered as the national treasure. In general forestry sector enjoys good reputation which was built over a longer period of time. Yet, public debates that potentially question sustainability of the forests practices quickly change the public opinion (Hörnsten, Johansson, & Lindstedt, 2007).

There is plethora of management regimes of the forests that are tackling the issue of biodiversity preservation. It could be argued that long rotations with maximisation of the volume at the end of the rotation are perhaps straightforward method in right direction. In stands where production of the wood is primary function of the forest, there is an approach practiced in Sweden called retention-wood method,. This method means that after clearcutting a small retention of dead trees, snags and coarse wood is left on the site. Some authors argue that 5-10 snags per hectare are enough to preserve biodiversity, but some authors are strongly challenging the idea saying that there is no proof for that (Simberloff, 2001). Still, the same author sees fragmentation of the forest stands as bigger problem which can be overcome through establishment of corridors which allow migrations of the populations, individual organisms and exchange of genetic material (Simberloff, 2001).

Some author argue that long tradition in monoculture type of even aged coniferous stands is not profitable in the long term (Mederski, Jakubowski, & Karaszewski, 2009). This is due to the number of problems that correspond with natural vitality of the monoculture. Even aged coniferous stands are more prone to calamities from pest outbreaks or natural disturbances such as windthrows. With time, even the natural yield can decrease (Mederski et al., 2009). This is also one dimension that might change in the future as the established spruce or pine monoculture replaced once existing native forest. The implications of this change will become visible after several generations because all changes in forest systems are very slow.

For the purpose of conservation efforts of the forests, Swedish Forestry Agency has issued guidelines for safe extraction of fuels from the forest called *Recommendations for the extraction of forest fuel and compensation fertilising* (2002). It is detailed framework with detailed guidelines how to treat ash, logging residues and how to ensure proper nutrient recovery. For instance, removal of slash is increasing the pressure from the vehicles onto the soil because slash from the felling operation has protective properties. There is a whole set of recommendations depending on the site specifics. The document is also addressing the issue of biodiversity stating that extraction of fuels from rare species should not be practiced. Also a proportion of the residues should be left in the forest and on the sites with poor soil conditions-it should be avoided (Swedish National Board of Forestry, 2002).

4.4 Ash recycling and nutrient recovery

Today there is no evident case that forest stands have decreased productivity due to the extraction of the residues. Some experts do believe that is presents potential issue, but the effect will be observable after many years or perhaps after several rotations. If it happens, then artificial fertilisation will probably be the solution to the problem. Ash recycling is good practice that returns the valuable nutrients to the forest. It contains all relevant elements except the nitrogen. In some parts of Sweden, extraction of residues is actually beneficial to the stands. Southern Sweden has high concentrations of air pollution which eventually ends up saturated in the residues (Börjesson, 2000). Estimates say that in north of Sweden around

100 kg per hectare of nitrogen should be recovered in order to prevent potential short term decrease in increment (Börjesson, 2000). Whenever possible, ash should be stabilised into a slowly dissolving form that will degrade in several years. Also, ash should be recovered into the growing forest, instead of clearfelling area in order to prevent the shock to the environment.

The traditional view of the soil food web is that it is donor-controlled. This means that the donors or-availability of food (in this case dead wood and other biomass in the forest) will linearly affect the abundance or species richness in the soil. From that perspective the Whole Tree utilisation concept must affect the soil fauna, and indirectly the fertility of the soil. However, some authors strongly disagree with that concept claiming that it should be scrutinised and tested. In the experiments of two stands, one of Norway spruce, and the other one of Scots pine, change did occur, but was more quantitative rather than qualitative. This means that the number of species or groups of organisms did not change, only number of individuals (Bengtsson, Lundkvist, Saetre, Sohlenius, & Solbreck, 1998).

4.5 International trade and governance of the biofuels market

Biomass trade is expected to increase worldwide. According to their study, the range of costs for production of wood chips in Europe amounts from 2,2-4 euro/GJ. On a European level, de Wit & Faaij (2010) are anticipating increase of use of stemwood for energy purposes. Since the demand is expected to increase, there will have to be other ways to cover the gaps in supply. What is interesting is that if the stem wood is used for the production of wood chips, the costs are increasing very little and yet the supply grows from 1 EJ/year to 5 EJ/year.

Verdonk, Dieperink, & Faaij (2007) argue for necessity of establishment of international governing body for the international trade in biofuels. In Europe it is considered that energy crops have higher potential than the forest fuels. Growth of energy crops for liquid biofuels (e.g. soybean for biodiesel) has already proven to be problematic. European Union was accused for non-transparency, hiding and removal of some important parts of the documents that are demonstrating the negative environmental effects in the supply chain of production of biodiesel (Reuters, 2010). Around 30% of the demand for the biodiesel is covered from the imports from the developing world, namely Brazil. Land use change and conversion of the forest to the agricultural land ultimately result in far higher CO_2 emissions than the savings from the burning of biofuels. Production of palm oil in developing countries has also resulted in increased pressure on the environment, destruction of biodiversity and pressure on local communities (Verdonk, Dieperink, & Faaij, 2007).

In Europe, subsidies of energy crops have caused distortion on the food market and increase in prices. Probably for that purpose, a new Renewable Energy Directive was issued from the European Parliament (2009/28/EC) that will possibly complicate things on the bioenergy market in the future. Probably one of the reasons why the Directive has been issued is the conversion of the land and land use change. European Union does not want that energy crops are grown instead of food which caused the increase in prices of food. Article 17 of the Directive greatly limits the availability of the land suitable for growth of energy crops. For that reason, the expansion of the agricultural energy crops might be delayed and limited.

In case of forest fuels Verdonk, Dieperink, & Faaij (2007) are arguing that perhaps certification schemes could possibly be a warrant of sustainable practices of the extraction of forest fuels. Verdonk, Dieperink, & Faaij argue that hybrid model of the Forest Stewardship Council (FSC) certificate would be perhaps the most comprehensive certification scheme for forest biofuels. FSC has relatively low market share and the biggest promotion and support of FSC certification comes from big retailers (e.g. IKEA) which are promoting green supply chain management. The success of the certification however still depends on the conscious customer.

Negative aspects of uncertified biofuels should be left for the governments to handle. Governments should support certification schemes, primarily through binding agreements between government and industries, setting restrictions to imports of non-certified biofuels and through legislation that internalises 'environmental costs and benefits in the market prices of energy' (Verdonk, Dieperink, & Faaij, 2007). Combination of standards such as FSC and Fair-Trade could breed international hybrid standards (proposed name BLO-Bio-energy Labelling Organisation and IAB-International Agreement on Bio-energy) with life cycle approach that would ensure sustainability of the produced biofuels.

4.6 Future trends in Swedish forestry

High share of Norway spruce in Swedish forests has some serious drawbacks. One of the most distinctive is susceptibility to pest outbreaks and different diseases. Pest outbreaks are normal occurrence worldwide. Some outbreaks follow large natural disturbances such as forest fires, dry season, or anything that would decrease natural resilience of the forest. Norway spruce is species with shallow root system and as such is susceptible to damage from windthrow. Windthrow is simply broken or unrooted tree because of the strong wind. In 2005 a storm called Gudrun has uprooted approximately 75 million m^3 of trees, mostly Norway spruce in southern Sweden. Another storm called Per uprooted approximately 12 million m^3 in similar area. The windthrows were followed by the explosion of population of spruce bark beetle. Estimates were that bark beetle could kill another 1-3 million m^3 in 2008 (Lindelöw & Schröder, 2008).

In Sweden there are ideas put into the practice that the share of broadleave species needs to be increased. The mixed stands are more stable than one-species stands due to heterogeneity of the habitat and diversity of species, including natural predators and parasites of pests. In Swedish forest stands there are several dominant problems: spruce bark beetles, root rot, pine nematodes that are introduced species, pine weevil and pine rust. Also large populations of moose and deer has caused replacement of native pine with spruce, especially in the south oh Sweden (Nohrstedt, 2010). For that and other reasons, increase of broadleaves would mitigate problem. In a study by Holgen & Bostedt (2004) the results show that despite the lower profitability of the beech compared to spruce, forest owners are becoming increasingly in favour of the broadleaves option. Non-timber values, such as birdwatching, recreation and the whole set of ecosystem services are becoming more important. After the establishment of mixed or broadleaved stand, there is consensus that such stand should be regenerated naturally, probably applying shelterwood method. Such practice would affect the supply chain of timber and residues. However, forested areas in Sweden are so abundant which scales down this change to a small level. Also, increase of share of broadleaves is not happening overnight; rather it is slow and gradual process. Perhaps in a distant future it will have significant impact, but at this point it is negligible (R. Björheden, personal communication, April 20, 2010).

5 Poland

Poland is the biggest country in Central Europe with an area of 312,679 km² and population of over 38 million people (Wikipedia, 2010b). The main industries are coal mining, iron and steel, food processing, ship building, production of chemicals, glass, textiles and beverages. In 2004, the annual growth of GDP was 5,4% of which industry accounted for 31,3% (Cogen Europe, 2007). Poland has set targets for renewable energy, in 2010 7,5% and in 2020 15%. In 2007 majority of the renewable energy came from co-firing biomass with coal (91,3%). In 2020 the share of renewable energy is projected to increase, but the relative use of solid biomass will drop to 60,6% (Rogulska, 2010). In 2004, the share of renewables in Poland in primary energy supply was less than 5% and that was the year when Poland joined European Union. The data presented by Leszczynski, Brzychczyk, & Sekula (1997) show that the share of renewable energy in 1994 was 4%. This clearly demonstrates that renewable energy was hardly a priority in Poland since in a 10-year period the share of RES increased only by 1%.

5.1 Energy sector in Poland

Poland is the biggest producer of coal and from the point of the domestic supply of raw material, Poland is one of the most independent states in Europe for production of electricity (Chalvatzis & Hooper, 2009). In 2000 Poland produced 99,6% of electricity from indigenous sources, while in 2005 the figure was 102, 2% making Poland a net exporter of electricity. Oil and natural gas on the contrary are imported. In 2000 and 2005 oil imports amounted up to 97%, and natural gas 67% and 69% for the observed years. Oil and gas are minor sources for generation of electricity in Poland since coal is the main source (Chalvatzis & Hooper, 2009) (Figure 5-1)

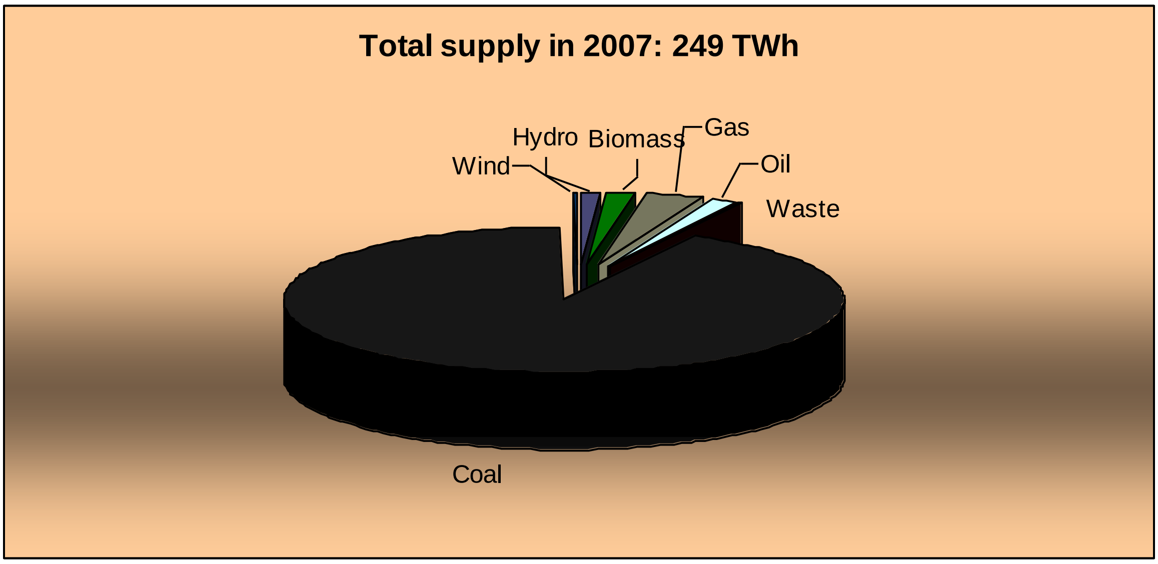

Figure 5-1 Total supply of energy in Poland in 2007

Adapted from: (International Energy Agency [IEA], 2010e)

High imports of oil and gas is problem of transport sector. In the past four decades, energy use has changed in Poland (Figure 5-2). The overall energy consumption has increased, but the shares of energy carriers have changed as well. Coal consumption has reduced twice, while oil and gas has increased roughly two times. The final use however, is dominated by transport sector, commercial and residential sector, while industry uses barely one third of the total supply (IEA, 2010g).

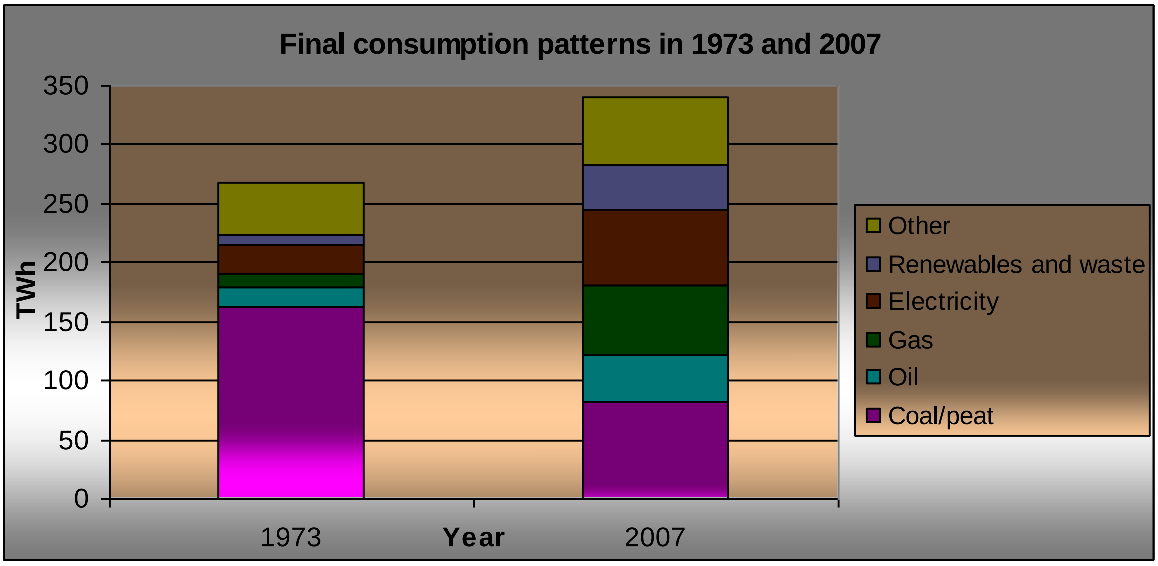

Figure 5-2 Comparison of final consumption between 1973 and 2007

Adapted from: (IEA, 2010d)

There is a number of problems associated with current energy sector in Poland. For instance, condensation plants have low efficiency (35%), and then the whole range of environmental problems related to emissions of CO_2 and various pollutants such as flying ash (J. Neterowitz, personal communication, April 7, 2010). The number of CHPs is increasing in Poland, but some of the boilers are old and need to be replaced. In 2003, one fifth of the generated electricity in Poland came from well developed CHP network. Estimates are that at least 70% of space-heat is the cities is coming from individual district heating networks (Cogen Europe, 2007). Polish CHP Association estimates that 40% of electricity needs in Poland could be covered by CHP plants. Small and medium CHP plants are underdeveloped, accounting for roughly 8 MWe of installed capacity, compared to 2,600 MWe of installed capacity of the industrial CHP plants (Cogen Europe, 2007).

With economy being so dependent on the coal, there are also environmental problems with the extraction of raw material. The biggest problems are degradation of landscapes, waste from mining operations, saline waters from drainage of mines and the whole range of pollutants emitted during the extraction that affects forest and agricultural land (MoE, 2009a).

Total fuel consumption in 2008 amounted to 1442547 TJ or 400707 GWh by thermal plants. When we look at the electricity supply mix in Poland (Table 5-1) and the figure of total net generation, it is easy to assess the overall efficiency. When all conversions losses are taken into account, the overall electricity generation efficiency in Poland is around 33%, which is very close to the opinions of the experts. In individual cases it is possible that the efficiency is even lower.

Table 5-1 Total gross and net electricity generation in Poland

Poland energy mix in 2008 (gross)	GWh	Poland energy mix in 2008 (net)	GWh
Conventional thermal	147324	Conventional thermal	133036
Hydro and wind	7174	Hydro and wind	6905
Geothermal	0	Geothermal	0
Nuclear	0	Nuclear	0
Total gross production	154498	Total net production	139941

Source: (EUROSTAT, 2009)

After accession to the European Union, Poland was granted three transitional periods to adjust emissions from the power sector to EU limits (Environmental Protection Bank, 2009). Energy sector in Poland is dominated by the coal-based power generation (Figure 5-3). In 2009, almost 95% of electricity in Poland was generated from coal combustion, and small fractions from hydro power and wind energy (EUROSTAT, 2010). In 2008 gross inland consumption of hard coal was more than 87 million tons (EUROSTAT, 2009). Majority of the consumed hard coal comes from domestic production, and 10 million tons comes from the imports, mainly from CIS countries (EUROSTAT, 2009). Poland is also producing large amounts of lignite, almost 60 million tons in year 2008 (EUROSTAT, 2009). What constitutes a concern is a large imports of oil, almost 22 million tons, of which most is imported from Russia (EUROSTAT, 2009). Poland is also importing large quantities of natural gas, in 2008 imports amounted for 9 156 ktoe (or 38 PJ) (EUROSTAT, 2009).

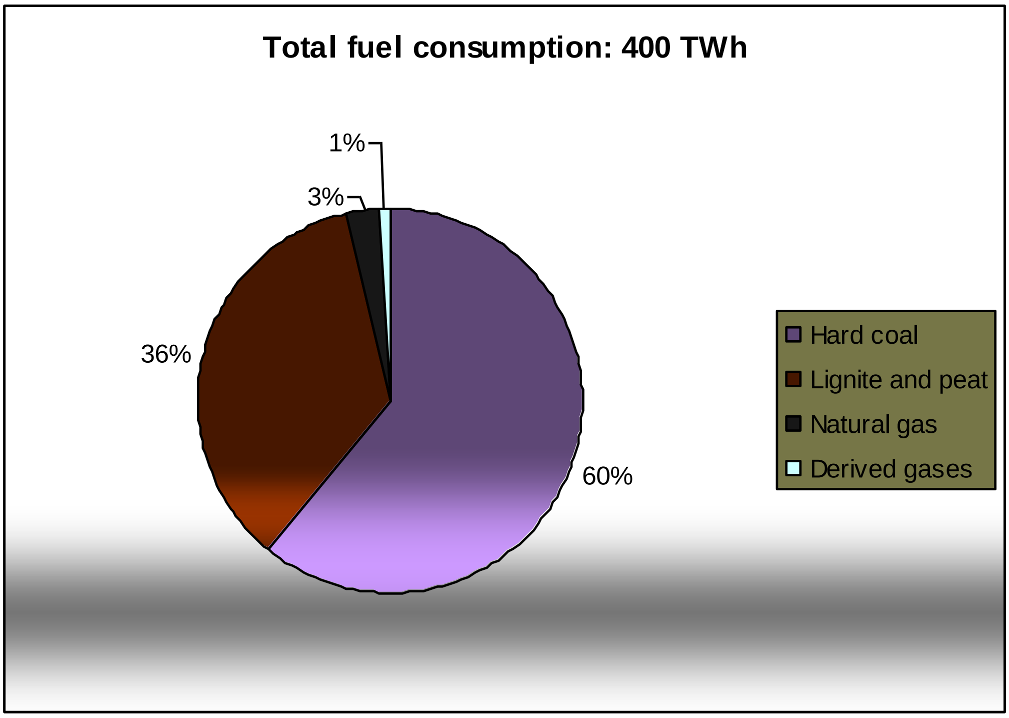

Figure 5-3 Fuel consumption in Poland by thermal plants in 2008

Source: (EUROSTAT, 2009)

After accession to the European Union, Poland adopted the obligation to increase the share of renewable electricity up to the 7,5% in 2010. Depending on the definitions, the highest share of renewable energy in Poland comes fom either hydropower[4] or biomass. According to the European Commission, large scale hydro power plants amounted to the largest share in 2004 (European Commission, 2007). According to the Council of Ministries and the document called Development strategy of renewable energy sector (2000) the biggest share in 1999 was in biomass and the biggest potential for future development.

The biggest potential lies in small and medium scale installations dedicated to biomass. However, co-firing is the cheapest option and thus mostly practiced (Berggren, Ljunggren, & Johnsson, 2008). In several articles it is reported that the market for forest biomass is non existing and that it lacks fundamental driving force in terms of securing energy supply, expansion of production of heat and electricity or the environmental protection (Nilsson, Pisarek, Buriak, Oniszk-Poplawska, & et al., 2006).

The CHP Directive from the European Parliament (2004/8/EC) states that more than 10% of the energy savings can be achieved through highly efficient cogeneration and that one of the critical aspects of it is maintenance of the functioning conditions of the CHP plants. This document is one of the most important steering documents of the EU that aims to promote expansion of CHP energy generation, in order to battle the climate change and to meet Kyoto protocol targets. As such, it has influence to Polish energy policy, since one of the

[4] In some reports large hydro power installations are also calculated in the renewable energy mix

general objectives is '*To increase transparency for the consumer's choice between electricity from cogeneration and electricity produced on the basis of other techniques*' and therefore '*it is necessary to ensure that, on the basis of harmonised efficiency reference values, the origin of high-efficiency cogeneration can be guaranteed*' (2004/8/EC). This document will shape some of the Polish energy policies, as it will be presented later in the paper.

Currently, there is ongoing debate on the national level to build 2 nuclear power plants. Not surprisingly, there is some opposition to the idea in the media and in the public, but it is likely that the projects will go through the negotiation phase and those plants will be built.

Relatively recently, Poland has also introduced the certificate system of tradable permits. Introduction as such, intended to stimulate the production of 'green electricity'. However, according to the all respondents in the interviews conducted in Poland, it created a mess to some extent. After the introduction of the system, the practice of co-firing of coal with biomass began, which has created huge demand on the forest biomass in particular (A. Rajewski, personal communication, April 13, 2010). According to Rajewski (2010), there has been clear consensus among the energy experts in Poland that the practice of co-firing as such needs to end. The main reason was mindless consumption of the biomass, a huge demand from the energy companies and lots of problems in the supply chain. It is firmly believed from all interviewees that co-firing is a cheap way to obtain certificate, but with short term benefits (Ericsson, 2007).

The price of electricity produced in Poland is 180 PLN/MWh (roughly 500 SEK) if it is base load. If the electricity produced comes from the co-firing, then it has premium of 200-240 PLN/MWh times the percentage of the biomass added. We can assume that on average, 10% of the biomass is added to coal, so the premium in that case is 20 PLN/MWh. Summarised, the price of base load MWh, generated with co-firing is 200 PLN or 554 SEK (provided that exchange rate is 1 PLN= 2,77 SEK). The price of premium of 20 PLN or 55 SEK might seem small from the Swedish perspective, but in the Polish reality it is clearly strong incentive to burn biomass with coal. Furthermore, the price of the premium will probably increase in the future.

When comparing the prices between two countries, it can be observed that the price of kWh in Poland is lower than in Sweden for around 30% (Europe's Energy Portal, 2010). It is expected however, that the prices of electricity in Poland will increase significantly in the future, roughly by 60% in 2030 compared to 2010 levels (MoE, 2009b). The increase is anticipated due to the higher prices of allowances and increased prices of energy carriers. Prices for heat will follow the same pattern.

5.2 Markets

The production of wood chips in Poland was around 227 000 m^3 in 2005 (Holding, 2005). In one report by the State Forest Company, the amount was 0,2 million m^3 (Pigan, 2008). The biggest market is internal market, although some of the biomass is exported to the countries like Germany. The demand in Poland is high, but that is a result of the premium from the certificates. Today there is only one large dedicated forest biomass power plant in Poland of 252 MW installed capacity (Energy Regulatory Office, 2010) and several smaller installations. Majority of the biomass is co-combusted with coal.

The use of wood for energy is widespread in Poland, however, only in other forms, such as split firewood. There are some statistical assessment difficulties of the total supply of logging residues, because they are grouped in the 'small wood' category in the statistics of the State Forest Company. This will probably change in the future (M. Rutkowska-Filipczak, personal communication, April 6, 2010).

Currently around 2,2 million m^3 of firewood is being used, and there are estimates that it could be increased for further 0,2 million m^3. The amount of logging residues could be doubled and the amount of chips from the extraction of stumps could be 1,3 million m^3 (Pigan, 2008).

Poland is today producing around 410 000 tons of pellets out of which 230 000 tons is used internally. At the beginning of the production of pellets in Poland, producers were exporting majority of their products to the international partners. The situation is changing slowly and more is being used internally. Production is increasing followed by the decreased exports (M. Bastian, personal communication, April 12, 2010).

5.3 Policies

There is a number of policies in Poland currently that are being used to mitigate climate change, but three of them are considered to be principal support for RES. They are:

1. Tradable Certificates of Origin (2005, amendment on the Energy Law);
2. Obligation for Power Purchase from RES (introduced in and came as amendment to the Energy Law in 2000);
3. Excise tax exemption (Chalvatzis & Hooper, 2009) and
4. Green, Yellow and Red certificate system.

Polish Government is generally trying to promote two types of power generation-high efficiency co-generation and renewable sources of energy. One of the incentives to the producers of renewable energy is 50% reduced cost for connection to the national grid. In addition to the national programs, the list of policies is summarised in the Table 5-2. Overview of the national policies dealing with the energy production that is based on biomass will be presented in more details below.

Regulation by the Ministry of Economy from 2008, named: *On the specific scope of responsibilities of obtaining and presenting to remit a certificate of origin, payment of substitute fee, purchase of electricity and heat generated from the renewable sources and the obligation to confirm the data on the amount of electricity generated from the renewable sources* (MoE, 2008) is one of the most powerful and influential legislative acts on Polish bioenergy market. The Regulation basically states that all forest fuels should be replaced with agricultural fuels by year 2017 for all installations with bigger capacity than 5 MW. There are targets set for each year that are gradually decreasing the share of forest fuels. If this Regulation remains to be part of the Energy Policy, then the market for the forest fuels will cease to exist. The aim of the Regulation is to stimulate development of rural areas, agricultural biomass and to eliminate competition between plywood industry and energy producers (M. Rudawski, personal communication, April 8, 2010).

Some authors argue that in short term Poland is going to reach very difficult its target of 7,5 % electricity from renewables by the 2010, or 15% by the 2020 (Ignaciuk, 2005). Also the same author claims that the target could be achieved in combination with government subsidy of 20-22% on bioelectricity. The same goal could be achieved with 4% less subsidy than the proposed one if the government would decide to utilize residues (in this case forest and agricultural residues-straw) (Ignaciuk, 2005). The Regulation is setting limit to pretty much all use of the forest biomass by the energy companies.

Energy Law Act

Starting in 1997, the Energy Law Act has been amended 2 times, in 2005 and 2007. The Law is the fundamental legislation for generation of energy for third parties access, independent power producers and renewable energy sources. Originally, the Law set requirements for purchase and production of green electricity. However, original targets have increased with amendments, up to 10,4% in 2010-2014, compared to originally 9% target. The Law provides reduction in grid fee for small scale renewable energy facilities, or cogeneration plants. The threshold is 5 MW of installed capacity, or at least 70% conversion efficiency for cogeneration plants (IEA, 2010f). In the amendments in 2005 and 2007, the Law introduced obligation to purchase energy from renewable sources and that is considered as one of the 3 principal supports in Poland for renewable energy (Chalvatzis & Hooper, 2009).

Programme for renewable energy and high efficiency cogeneration projects:

The program was enforced in 2009 and it is scheduled to end in 2012. Total funding for the programme are 1,5 billion euro. The program will partially support biomass projects, precisely 40% of the funds will be invested in thermal power plants (capacity below 40 MW thermal energy) and CHPs (below 3 MW electric power). The program offers loans ranging from 4-50 million euros with fixed interest rate of 6%. Under certain conditions, upon completion of a project, grace period of 18 months can be granted. Also, in special conditions, parts of the loans can be transformed to grant (IEA, 2010j).

Long-term Programme for Promotion of Biofuels or Other Renewable Fuels:

This program is targeting rural development, environmental protection, improvement in energy supply and increase share of biofuels to 7,1% by year 2013. The moving force behind this program is reduction of oil dependence.

Strategical measures are: reduction of corporate income tax, investment support (including EU funds) and support for establishment and growth of energy crops, reduction in ecological fees for vehicles powered by biofuels, creation of ecological zones dedicated only to '*ecological pubic transport*' and excise tax exemptions. The program started in 2008, and will expire in 2014 (IEA, 2010i).

Act on electricity production from cogeneration and the Green, Yellow and Red Certificate system

Unlike the previous two programs, this one is regulatory instrument rather than financial. The introduction of the CHP Directive from the European Parliament (2004/8/EC) in 2004 has caused amendments in the Polish Energy Law. In order to promote and to ensure that electricity is produced in high-efficient cogeneration plants, Ministry of Economy has issued various acts to ensure the origin of produced electricity. The jurisprudence of the Directive is combined with the certificate system in Poland. Electricity generators are obliged to obtain certificates by producing electricity in high-efficiency cogeneration plants. Certificates are tradable on the stock exchange. The definition of high-efficiency is according to the CHP Directive: the annual total efficiency needs to be over 75% and Primary Energy Savings (PES) factor over 10% (A. Rajewski, personal communication, April 13, 2010).

There are several types of certificates in Poland. The Energy Regulatory Office issues certificates to the power generators, provided that they produce promoted type of energy.

1. *Green* certificate is issued to the producer of energy from renewable sources. This category also encompasses co-firing with coal.

2. *Yellow* certificate is issued to the high-efficient co-generation based on gaseous fuel, or where electrical output is below 1 MW (in this case regardless of fuel).

3. *Red* certificate is issued to the other types of high efficiency co-generation not based on gaseous fuel and of higher electrical output than 1 MW.

Every year, power distributors need to present the report and the shares of each certificates according to the quota set by The Energy Regulatory Office. Failure to obtain certificates imposes penalty on the electricity producers through so called substitution fee (Cogen Europe, 2007; IEA, 2010a). Substitution fee is the difference between average electricity price on the market and the production cost in highly efficient cogeneration plants. Substitute fee is direct function of The Energy Regulatory Office, since the Office is in charge of setting the price of the payment. This program will end in 2013 (A. Rajewski, personal communication, April 13, 2010).

The trade happens when power generators sell certificates to the distributors. Due to the price of substitution fee, the price of certificates is pretty much fixed, since distributors will not pay for the certificates above the penalty, and vice versa, distributors will not the certificates below the price of the penalty. Notably, certificates are traded independently of the trade of electricity, meaning that electricity can be sold to one, and certificates to other distributor. The prices of certificates are as follows: PLN 250/MWh for Green, PLN 120/MWh for Yellow, and PLN 20/MWh for Red (A. Rajewski, personal communication, April 13, 2010).

Certificates can be combined but only in combination Green+Yellow (biomass) and Green+Red (biogas plants and small scale installations). According to Rajewski (2010), there is ongoing dispute between producers and the Energy Regulatory Office because in the past two years, the Office refuses to issue two different types of certificate for one produced MWh, stating that the intention behind the system was to diversify energy supply in Poland. The Energy Law however, does not prohibit combination of certificates and apparently this dispute will be settled by another amendment to the existing Law. It is unclear what will happen once the system expires in 2013.

This policy is also combined with the Obligation for Power Purchase from Renewable Sources policy. As described before, all distributors that are connected to the national grid are obliged to purchase energy from RES as well as the certificates. The price is determined by the Energy Regulatory Office. The quota must be met, and it increases each year, determined by the targets set by the Directive from 2008 from the Ministry of Economy. Final target of the Directive is 12,9 % in the year 2017.

Biofuels targets 2008-14

In 2007 Polish Government presented targets for liquid biofuels in the transport fuel portfolio. The targets are steadily increasing every year, starting from 2,30% in 2007 to 7,55% in 2014 (IEA, 2010c).

Renewable Energy Tax Excise

If the share of biocomponents in the raw material mix used to generate electricity is at least 2%, then the electricity produced is exempt from the Polish excise tax (IEA, 2010k).

Poland is also a part of Emissions Trading System. In the assessment of the policies by the Ministry of Economy from 2005 onwards, Ministry is openly unsatisfied by the allowance of the CO_2 emissions in the period 2008-2012. The EU actually allowed Poland to increase emissions by 2,66% while anticipated growth of the economy was 5,1%. Polish Government has seen this as major problem since Polish economy is highly dependent on the coal, and the change in 5 year period is considered as big challenge. After the official appeal, Poland was allowed to increase the emissions (MoE, 2009a).

5.3.1 National investment support in Poland

In addition to the national programs there is a governmental body named National Fund for Environmental Protection and Water Management. The Fund's role is distribution of money for investments in environmental protection programs. In addition to that, Fund is also responsible for distribution and management of international investments. For example, 2,85 billion euro from the Convergence fund within the framework of Instrument for Structural Policies for Pre-Accession (ISPA) has been provided as financial support from the European Commission in the period 2000-2006. In the period 2007 and 2013, the Fund will be responsible for absorption and distribution of 5 billion euro of foreign investments for additional projects, of which some will include 'environmentally friendly power generation' (National Fund for Environmental Protection and Water Management Management, 2009).

Loans from the National Fund for Environmental Protection and Water Management

This Fund in 2009 celebrated 20 years of existence. In 20 years of existence, the Fund allocated 21.4 billion PLN, but mostly for water management projects (National Fund for Environmental Protection and Water Management Management, n.d.).

The responsible agencies are two Ministries, Ministry of Environment and Ministry of Economy. The fund is providing loans with small interests to the projects that are involved with the environmental protection. Certain fundings are available for construction, instalment and modernisation of biomass plants, and co-firing plants. However, there is a large list of projects that can compete for the funding, including wind power generation, improvement of processing of energy production. Also, biogas projects are included, heat pumps, energy efficiency in buildings and so on (IEA, 2010h).

The list of the projects available from this fund seems rather large. Some of the respondents believe that the amounts of allocated money for the production of energy are not sufficient, especially for the promotion of usage of biomass in power generation. For instance, the Fund is supportive mechanism for small and medium size installations, while large companies do not have access to the Fund. In a complex energy generation system in Poland, it is little likely that small and medium enterprise will change the energy portfolio to large extent (M. Pisarek, personal communication, April 9, 2010).

Ecofund Foundation

Ecofund is a fund established by the Ministry if Treasury in 1992. Since the establishment, the Fund's work has been guided with 5 priorities divided in 5 sectors. One of the sectors is Sector 3: Climate protection, under which funds for the 'Use of biomass for energy generation purposes in the household and welfare sector and at industrial plants' are allocated (EcoFund, 2008).

Environmental Protection Bank

Bank is offering target oriented credits and preferential credits. It is owned mainly by the National Fund for Environmental Protection and Water Management (77%), The State Forests National Forest Holding (7%) and the other shareholders (16%). In 2008 the total value of disbursed loans for environmental protection amounted for 742,4 billion PLN. One of the main activities of the bank is coordination of the funds available from the EU (Environmental Protection Bank, 2009). In the period of 1996-2008, the funds from this bank resulted in production and power savings of 519 700 MWh from renewable sources of energy (Environmental Protection Bank, 2009).

5.3.2 International investment support in Poland

Foundation of Assistance Programmes for Agriculture

The main aim of this program is rural development, offering financial assistance. It was established in 1992. Most of the funds are drawn from the Ministry of Agriculture and donations, but there was a number of international sources at its establishment, such as: World Bank, USA Government or British Agriculture Development Fund (Foundation of Assistance Programmes for Agriculture [FAPA], 2006). The Foundation is supporting 'agriculture, agricultural markets and sectors of agricultural economy' which means that energy crops for instance, could be supported as well.

Intelligent Europe Network

This programme is support for the EU 27 countries, including Croatia, Norway, Liechtenstein and Iceland. The support however, is not for investments but rather for information dissemination projects. Typical budget for the project is between 0,5-2,5 million euro provided that there are at least three partners in the project, but typically more. Partners in this case are countries and institutions that can help with know-how approach in building capacities. Currently there are six ongoing projects in Poland related to biomass (European Comission, 2010).

Table 5-2 Overview of policy instruments in Poland

Policy name	Type	Target	Status
Programme for renewable energy and high efficiency cogeneration projects	Incentives/Subsidies	Energy Production	In force since 2009
Long-term Programme for Promotion of Biofuels or Other Renewable Fuels	Financial Policy-Processes Public Investment	Energy-Production Framework-Policy Multi-sectoral Policy	In force since 2008
Act on electricity production from cogeneration	Regulatory Instruments	Energy Production	In force since 2007
Biofuels targets 2008-14	Policy-Processes	Energy-Production Transport	In force since 2007
Energy Efficiency Action Plan	Policy Processes	Multi-sectoral Policy	In force since 2007
Excise tax rebates for biofuels	Financial	Energy-Production Transport	In force since 2007
Red Certificate System	Tradable Permits	Energy-Production	In force since 2007
Renewable Energy Tax Excise	Financial		In force since 2002
Loans from the National Fund for Environmental Protection and Water Management	Incentives/Subsidies	Appliances Buildings Energy Production Industry Transport	In force since 2001
Energy Law Act	Regulatory Instruments	Energy-Production Framework-Policy Multi-sectoral Policy	In force since 1997, amended in 2005 and 2007
Obligation for Power Purchase from Renewable Sources	Regulatory Instruments	Energy-Production	In force since 2005; 2008
Quota Obligation and Certificate of Origin Trading System	Regulatory Instruments Tradable Permits		

Adapted from (IEA, 2010b)

6 Forestry in Poland

Forests in Poland comprise of 28% of the state territory with total area of 9 million hectares. Majority of the forest cover is dominated by the coniferous stands, of which Scots pine is the most abundant (69%), followed by the Norway spruce (5.5%). Poland has significant share of broadleave forests of which oak forest comprise 7,3%, beech 5%, birch 5,9% and alder 4,4%. The remaining species are grouped together. The shares of volumes of each species follow similar pattern. Distribution of the timber by age class follows the Gauss curve, meaning that most of the timber is aged between 40-100 years. Annual cut is below the annual increment, since annual cut in 2005 amounted for 6,9 m^3/ha, while the increment amounted to 8,1 m^3/ha (The National Forest Holding, 2005). Poland is harvesting approximately 60% of the annual increment, which means that standing volume is increasing every year (The State Forest Information Center, 2006).

Poland has established 19 Promotional Forest Complexes which serve for scientific purposes but mostly, for communication with the public. The intention is to promote multifunctional forests and 'pro-ecological' and sustainable forest management, especially among Polish youth (Holding, 2005). Promotional forests supplement national parks for tourists. The overall area of the promotional forests is almost 1 million hectares.

In 1995 National Program for the Augmentation of Forest Cover was initiated. The aim of the program is to increase the area covered by forest up to 30% by 2020 and 33% by 2050 (Center, 2006). The afforested area is mainly private land, former agricultural land but also areas where forest stands have been removed. The Program also aims to optimise the spatial distribution of afforested land since forested areas can vary from 11% to 48% in different regions (Pisarek, Oniszk-Poplawska, & Tymendorf, 2005). In some areas, such as Carpathians and national parks, Norway spruce is being taken out and replaced with once native vegetation (Koziol, n.d.).

6.1 Structure and organization

The state owned company is in charge of the most of the forested area in Poland (Figure 6-1). The company has strong pyramidal structure and hierarchy comprising of one General Directorate, 17 regional Directorates and 428 Districts. Number of employed people is around 26 000 (The National Forest Holding, 2005) but that is changing with time. In 2001 the Company employed 6 000 more people (Pisarek, Oniszk-Poplawska, & Tymendorf, 2005). State Forests are managing 7,6 million hectares of land of which 95% is forest.

In private owned forests a much smaller intensity of timber products is observed. When compared to the state owned forests, the intensity is 3-4 times smaller, and in 2006 it was always below 1 m^3/ha (The State Forests Information Center, 2006). In the report by Central Statistical Office it can be observed that there is a large number of private individuals that own the forest. When the number of hectares is divided by the number of persons, the average area owned by private individual is in range of 1-1,5 ha (Central Statistical Office, 2009).

Unlike is Sweden where forestry is 'profit-oriented', Polish forestry tradition is much closer to the German tradition, which is 'volume-oriented' (Brukas & Weber, 2009). One of the major differences between forestry sectors is that, in Poland clear fellings are seldom practiced. The long term aim of Polish forestry is sustainable management of the forest in such manner that it resembles natural forest as much as possible. This means that such management system will support uneven-aged structure with mix of species. The most obvious motivation for such system lies in stability of such stands. Mixed uneven-aged stands are naturally more resilient to pest outbreaks, they support larger number of species and are more resilient to abiotic disasters such as windthrows (M. Rutkowska-Filipczak, personal communication, April 6, 2010).

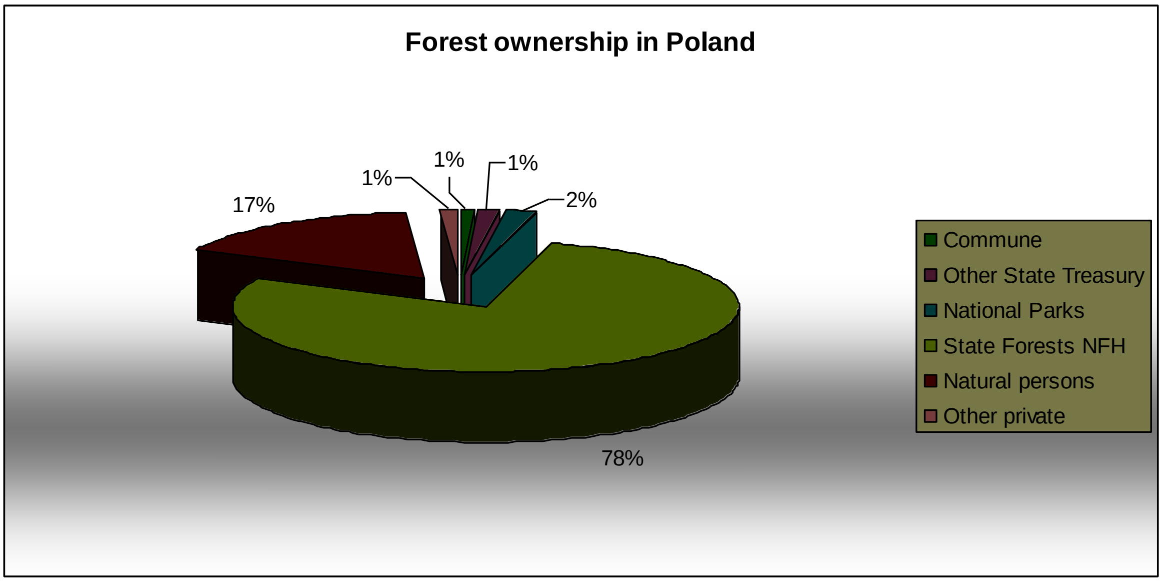

Figure 6-1 Structure of forest ownership in Poland

Source: (The State Forests Information Center, 2006)

Recreational values of such forests should not be underrated and the supportive values for hunting tourism. According to the respondents in Poland, Polish people are very fond of hunting. Some recent studies demonstrate that Polish citizens are strongly supportive for natural ecological processes and are willing to pay for the passive protection of biodiversity-rich areas, such as Białowieża forest. In general, they are concerned about the environmental protection methods (Czajkowski, Buszko-Briggs, & Hanley, 2009). This suggests that change of forest management regimes, such as intensified clearfelling, would be scrutinised and possibly hard to accept.

Despite the tourism activity, majority of the income comes from the timber sales. In 2005, total income for the Company was 4,6943 billion zloty, or 1,16 billion euro[5] (Holding, 2005).

In 1991 the Forest Act changed the forestry policy significantly. Before 1991 the main purpose of the forests was the production of timber. After the issuing of the Act, a new sustainable management was implemented. Each forest district became financially independent which allowed certain privatisation of some operations and reduction of employment (Lawrence, 2009). This was criticised in a single assessment of forest policies in

[5] With exchange rate 1 zloty=0,246931254 euro

Poland carried out by Siry & Newman (2001). In some cases the reduction of employment is considered to be counterproductive. The reduction of employees was mostly among workers, while the number of administrative personnel has slightly increased. More than half of the forest districts have technical efficiency less than 50%. This simply means that forest districts fail to produce as much timber output as input usage allows. In other words the same output could be produced with twice less input (Siry & Newman, 2001).

6.2 Felling practices

Polish forestry practices are characterised by several options. Majority of the timber volume is harvested through sanitation cutting (thinning and cleaning operations), around 43%. It is followed by 20% of the timber from clear fellings, and complex felling 18%. The rest of the volume comes from various incidental cuttings (The National Forest Holding, 2005). In 2005, the clear cuts were performed on area of 25 000 ha in the State Forests (The National Forest Holding, 2006). The share of clearfelling is declining every year and this is a result of more 'pro-ecological' approach and management. The size of clearcut area in Poland ranges from 1-4 ha, but typically no more than 2 ha.

In addition to the clearfelling practices, there is a whole range of complex felling and shelterwood practices. Typical complex regeneration in Poland is regeneration in lanes and nests (Figure 6-2), as well as the various shelter-wood methods. Regeneration in nests means that in one area, distant one to another, several 'nests' of circular shape of forest are being cut. The space in between circles is intact. After couple of years when young trees start to grow in cut circles, the remaining area is being cut. It can be done in several stages, effectively creating uneven-aged stands as presented in Figure 6-2. The maximum sum of areas of all circles is 2 ha.

Figure 6-2 Schematic complex nest felling in Poland

Adapted from: (Orzechowski, n.d.)

Another method is cutting in lanes. In one year, one lane of forest is removed, the second year adjacent lane and so on. Both methods are creating uneven stand. Careful design of these methods shows that use of heavy mechanisation, although possible is not preferred. One of the reasons is that harvesters and forwarders could damage the remaining vegetation and compact the soil. Other reason is that using such mechanisation is not economically feasible. Reported harvested volumes with single machine range in between 15 000 and 35 000 m^3. In comparison, in Finland the same machine harvest 50 000 m^3 in one year (Pisarek, Laitila, Ala-Fossi, & Tymendorf, 29–30 June 2006).

The nest regeneration and regeneration in lanes, although complex felling operations are varieties of clear fellings. The contrast to clear felling would be shelter-wood method, where forested area is continuosly covered by the canopy of the trees. The regeneration is done under the tree crowns, in several years. When the last of the old growth stand is removed, the soil is already covered with the carpet of young trees. This method is practiced in broadleaved forests, and it can be considered as sensitive operation since workers and mechanisation need to manoeuvre among the living trees and be careful not to damage the existing stand.

Although there are roughly 13 harvesters in Poland, the dominant method of wood extraction is combination of manual cutting with chain-saw and forwarding with adapted agricultural tractor. Due to high share of manual labour, costs of harvest and extraction of wood are dominant (54%) in the cost structure in the State Forests company operations (Holding, 2005). One of the advantages in using harvester is that it increases the usable share of residues by 15 % when compared to manual cutting (Pisarek, Oniszk-Poplawska, & Tymendorf, 2005).

Such small tractors are equiped with cranes and loading area. Without harvesters, the price of production of logging residues is becoming increasingly high. Harvester can easily create heaps of logging residues that are later on collected with forwarders (Figure 6-3), but in this case residues need to be piled up manually. Before 1990, the practice of clear cuts in pine stands on areas of 6 ha was common practice (P. Mederski, Jakubowski, & Karaszewski, 2009). After 1990 it has started to change, presumably due to the Forest Act. and today the average size of clear cut area is 2 ha. Naturally, expensive machines such as harvesters and forwarders require large felling areas in order to be cost-effective.

Figure 6-3 Forwarder collecting slash in Poland

Photo by Mikolaj Rudawski

6.3 Supply chain of logging residues

One of the multiple facets of the supply chain of logging residues in Poland is that in many cases it is non-existing. As presented in the previous chapter, majority of the forests in Poland is state owned and managed by The State Forest Company. The company is divided into 17 Regional Directorates. In some Directorates extraction of logging residues is taking place, but in majority it is not. This is explained in different ways. The major standpoint of the forestry industry in Poland is that, extraction of residues is harmful to the environment, since valuable nutrients are taken away. This is, albeit, considered as the 'common wisdom' among the forester professionals without much of a scientific validation.

The State Forest Company is reluctant to engage in extraction of the residues. In some parts of Poland with poor living standards, residues are given away to local people for free. This at least sheds some doubts about the prevalent argument about removal of the nutrients from the forest stands. The production of wood chips is still happening, however, in State Forest Company, and in 2005 the production was 227 000 m^3, compared to the sales of timber which amounted to 30 million m^3 (The National Forest Holding, 2005). Estimates are that forest residues potential could be up to 35 PJ or almost 10 TWh (Pisarek, Oniszk-Poplawska, & Tymendorf, 2005). Additional wood material could be supplemented from demolition wood up to 30 PJ or 8 TWh, but demolition wood cannot be combusted in conventional plants (Pisarek et al., 2005).

The technical potential of logging residues is estimated to be around 0,5 million m^3, thinning wood 1,6 million m^3 and stumps 1 million m^3. These theoretical are estimates presented in the work by Pisarek et al., (2005) and they need to be adjusted each year if the felling volumes increase.

One of the challenges for production of wood chips from logging residues is low concentration of raw material per unit of area. That is a result of harvesting methods on rather small areas and dispersal of the cuts (Figure 6-2). In order to reduce the costs for felling in smaller areas, there are proposals for utilisation of combined machines, so called harwarders, which can perform several functions. In Finland, integration of forest operations such as harvest of slash and preparation of the soil for the next planting with same machine has already proved to be competitive (Laitila, Asikainen, & Hotari, 2005).

There are also biological limitations. Since coniferous forests are dominated by the Scots pine, the amount of branches is much smaller when compared to Sweden which is dominated by Norway spruce. The ratio of tree crown mass and the timber is substantially bigger in the spruce trees than in the pine trees. Another limitation is long transportation distances (Pigan, 2008).

Some authors have calculated the cost of logging residues in Poland to be 2,2 euro/GJ (de Wit & Faaij, 2010).

Chipping of residues in Poland is done in several combinations, similar to Sweden. The most noticeable difference though, is in technology used. Since the production of wood chips from logging residues is not wide spread business in Poland, expensive machines such as Bruks mobile chippers (Figure 6-4) are not so often. One of the alternatives is manually fed chippers used for the road side chipping (Figure 6-5).

Figure 6-4 Modern mobile Bruks chipper equipped with container

Photo by Mikolaj Rudawski

Figure 6-5 Manually fed chipper

Photo by Mikolaj Rudawski

In the past couple of years due to the relatively good conversion rates between Polish zloty, and euro, a number of private entrepreneurs purchased mechanisation for comminution of residues. Unfortunately, many of them purchased grinders instead of chippers which produce different quality of the comminuted biomass (Figure 6-6). Plant operators are very unhappy with the grinded biomass which is another hindering factor for successful sales (M. Rudawski, personal communication, April 8, 2010).

Figure 6-6 Grinded and chipped wooden biomass

Photo taken by M. Rudawski

Limiting factor to the system is the felling tradition in Poland. The average clear cut area is around 2 ha. Other methods of felling such as shelterwood practices simply make extraction of residues unsuccessful story. In shelterwood method there is a risk of damaging the stand with heavy mechanisation such as harvester. The amount of stumps per area is also small and in order to collect residues, one must go several times during the rotation period. Ultimately this involves manual labour which becomes too expensive and unsupportive to the whole system.

6.4 Concerns

Forests in Poland are considered, by the State Forest Company to be among the most threatened in Europe. The list of threats comprises of both biotic and abiotic factors. Biotic factors include: pest outbreaks, diseases, wildlife and invasive species, while abiotic factors are: aerial pollution, fires, and droughts. Air pollution is, albeit, steadily declining threat. Emissions from fossil fuels burning result in sulphur dioxide and nitrogen oxides. Agriculture is the main source of ammonia. The concentrations of SO_2 is declining each year, while NO_2 oscillates (The National Forest Holding, 2005).

Pest populations are also naturally oscillating. The main groups of pests are moths and sawflies. In 2005 an area of over 100 000 ha was damaged by the sawfly population adding to the total of 320 000 ha of damaged area by all pests in Poland (The National Forest Holding, 2005). Diseases are occurring on a much smaller area. Damage from wildlife expressed in area is approximately one third of the area of the damage from the pests.

The term damage from biotic factors here should be taken with reserve. These are natural occurrences and the damage is primarily associated with economic loss. This type of damage sometimes requires additional input through various treatments. Some pest outbreaks however, do have power to destroy entire stands or at least cause great disturbance, so from sustainable management perspective, these additional inputs are mandatory.

7 Analysis and discussion

The analysis within the analytical framework of the TIS defined by the Bergek et al. (2008) is done in several steps, as it is presented in the chapter 1.6 *Analytical framework*.

7.1 Focus

First step is identification of the focus of the TIS, which in this case is the production of heat and electricity from the logging residues and the supply chain in the production process. In both countries we can say that the supply chain is existing but with large differences. In Sweden, supply chain of logging residues is established long time ago and more importantly, widely recognized and accepted as something that is beneficial for the economy and the environment. In Poland, supply chain is fairly underdeveloped. Although the amount of harvested residues equals roughly little less than half of the technical potential, there are numerous inefficiencies in the system and especially inconsistencies.

Very strong barriers in Polish legislation threaten to diminish the importance of the existing TIS and eventually phase it out.

7.2 Structure

The structure of TIS in observed countries is different as it is summarised in the Table 7-1. In case of Sweden, there is overlap between actors, networks and institutions since some parts of the TIS fall under several definitions. For example, District Heating Association is by default a network, but district heating sector has major influence at the beginning of the development of the bioenergy market.

7.2.1 Actors in Sweden

There are several important actors for the bioenergy market in Sweden. One of the most important one is forestry industry. Forestry industry had significant contribution through its own development of technologies, logistics and strategies for the utilisation of logging residues. District heating sector by nature is defined as a network, but in Swedish context it is also an actor since it was one of the prime movers towards biomass utilisation

Forestry industry

Although reluctant at the beginning, forestry industry became active promoter of utilisation of forest fuels. The reasons are many: utilisation of industrial by-products for production of energy increases cost-effectiveness of the operations, production and sales of wood chips and pellets is great opportunity for extra income, removal of residues makes planting of the new stands much easier, integration of operation increases the output of the companies and so on. What is important for the development of the bioenergy market in Sweden is type of ownership of the forests. Private owners in Sweden, when compared to Polish owners, have much bigger properties in forest area. Also solid organisation, cooperatives and information dissemination makes Swedish owners entrepreneurs that are more easy to engage in new business and accept new ideas.

District heating sector

In the 80s, most of the wood chips from logging residues were consumed in district heating systems. Since 1981 till 2002, the number of biomass powered plants in district heating systems has increased from 1 to over 130 (Junginger, Faaij, Björheden, & Turkenburg, 2005). District heating systems were mostly pressed with carbon tax and they have always been favourable towards the usage of biomass. Changing of fossil-fuel boilers to biomass created huge demand and subsequently it helped a new industry to emerge.

Energy companies

One year after the accession to the European Union Sweden has liberalized the energy market. This has resulted in privatization of energy companies except the large state owned Vattenfall. Price competition has resulted in decreased funds for RD&D (Nilsson et al., 2004).

However, large energy companies Sydkraft and Vattenfall should be mentioned. As Johansson et al. (2002) report, these companies had made significant effort and provided funding for the RD&D of the growing bioenergy market, especially in the late 1980s and in the 1990s. Vattenfall is still providing substantial amount of money for the RD&D of renewable energy. One of the company's goals is to be climate neutral by 2050 (Vattenfall, 2010). This is very important that big companies are intrinsically motivated to change things, especially when operating in international environment.

Large energy companies already started to move down the supply chain of the residues and are trying to negotiate price directly with the forest owner. This reduces cost as it excludes middlemen in the chain. In this case large companies are taking responsibility for some operations such as chipping of the material (H. Nordstrom, personal communication, March 19, 2010).

Government (SEA)

Swedish Government was one of the primary movers in the development of the bioenergy market. Clear dedication to fuels independence defined the goals. Further on, the Government has through taxation of fossil fuels created a demand for biomass. Also, Government is responsible for the allocation of most of the fundings for RD&D in Sweden.

7.2.2 Actors in Poland

There are several important actors in Poland related to the bioenergy market. Virtually all of them are hindering the development of the forest fuels market for various reasons. It is difficult to assess which one is the most influential as they all act in specific way.

Forestry industry

Forestry industry is one of the most dominating actors in the bioenergy market. The role of forestry industry is to provide raw material, preserve habitats and biodiversity and to maximize the ecological functions of the forest in Poland. These are the typical premises from which all arguments are based upon when discussing the position on the forest fuels. Being the monopolist in Poland, State Forest Company is in the control of the majority of the forest fuel. Having the strong hierarchy organisation, the Company is said to resemble an 'army' (Lawrence, 2009). It could be argued that the Company itself is in some instances more than a company: it is a social construct. In some areas the foresters are interlinked with the local communities as some of them are also from the local people. In poor areas where the Company is giving logging residues for free to the poor, it is logical to assume that foresters enjoy high reputation. Indeed, some surveys show that foresters in Poland are ranked among the highest as the trustworthy governmental officers (Lawrence, 2009).

Coal industry

Coal industry is a major influence on the bioenergy market. According to the interviewees, coal mining has always been somewhat privileged and regarded as the backbone of Polish industry. Having in mind the share of coal on the national energy balance, it is clear that the coal mining industry probably wants to maintain business-as usual. Together with the forestry company, it is negatively influencing the development of the bioenergy market for solid biofuels.

Plywood industry

Plywood industry in Poland is the second largest supplier to IKEA (Wikipedia, 2010a). When IKEA came to Poland, it was regarded as the saviour of the Polish economy (J. Neterowicz, personal communication, April 17, 2010). Since then, IKEA built good relationship with Polish suppliers of plywood, and Poland in return became the second largest supplier, after China (Wikipedia, 2010a).

Plywood industry in Poland was often mentioned in the interviews as a powerful lobby group which has great influence on the Government. The fear of competition for raw material probably came from this group and perhaps the from this group lobbying resulted with the issuing of the Regulation from the Ministry of Economy that intends to ban all forest fuels.

Ministries

Ministry of Economy is one of the three Ministries that are relevant actors for the bioenergy market in Poland. Other Ministries include Ministry of Environment and Ministry of Agronomy. It is Ministry of Economy which has issued the Regulation in 2008 that intends to ban all forest fuels by year 2017 (MoE, 2008). Other two ministries have different responsibilities, and are responsible for other legislation, e.g. Environmental Protection Act. In interrelated issues when cooperation between Ministries is essential, the case is quite often the opposite. Ministry of Environment is conservative when it comes to utilisation of forest products, and preferable option is waste and agricultural energy crops. Ministry of Agronomy is naturally supporting agricultural energy crops as well. The lack of horizontal integration was also mentioned by interviewees as one of the big problems.

Energy companies

Energy companies in Poland are important actors. The structure is such that there are Polish companies that own large share of the market and former state units. These include companies such as PGE Group, EDF Group, ZE PAK SA in Konin or EC Bialystok. There is a number of foreign companies with different shares on the market, for example French giant GDF Suez, Dalkia Poland or Vattenfall from Sweden. Most of these companies are seen as not real movers but rather inhibitors to the market which are making solid profit from the trade of certificates. Some energy companies are owned by the Ministry of Treasury and some of them own power plants and the distribution grid, which gives them a lot of influence. The co-firing practice will phase out in 2015 (K. Jablonski, telephone interview, April 19, 2010). All biomass fuels will have to be from agricultural plantations.

7.2.3 Networks in Sweden

Swedish District Heating Association is powerful network with large influence on the Swedish bioenergy market. Today, district heating systems are supplying around 40% of the heat to the residential buildings (Ericsson & Nilsson, 2004). The network started to develop in 1960s, although the first DH system was in function in 1948. The option to produce cheap electricity in CHP plants was one of the reasons why local governments favoured the development of the network. Today, CHP plants are still underdeveloped as most of the DH plants are just heating plants. The development of CHP plants was slowed by the tax reform in the 1990s since electricity in CHP plants was taxed, regardless of fuels. Before the reform, heavy fuel oil was used almost exclusively. After tax reform, dedication to biomass was established for economical and political reasons. Development of such big network created huge demand for biomass. It should be noted that DH systems in Sweden are owned by municipalities and as such are more independent from the government. DH companies hold monopoly in Sweden and sometimes are accused for non-transparency and asked for better pricing of the heat (Johansson et al., 2002).

Kåberger (n.d.) in his article emphasizes the importance and relevance of *Swedish Bioenergy Association* (SVEBIO) and its activity in Sweden. SVEBIO was formed as a powerful lobby group with aim to promote bioenergy. Today it consists of roughly 400 members, mostly industry. SVEBIO managed to vertically integrate all relevant actors on the bioenergy market in Sweden, from the suppliers of raw materials to the producers of boilers. SVEBIO also serves as a forum for discussion about new technologies, policies and business concepts. One of the most important roles of SVEBIO is dissemination of information, both to the bioenergy actors and the society. Indeed, SVEBIO has served as source of information to society which seems to be crucial when it comes to proposals and implementation of new policies.

With time, SVEBIO has always supported and promoted healthy competition among the actors. This was very important at times when Sweden began to import biofuels from abroad. Domestic biofuel suppliers considered that there should be some limitations to the imports to protect the domestic market, but SVEBIO has always been openly in favour of unrestricted imports (Kåberger, n.d.) This in return has ultimately resulted in decreased investment risk for the investors who saw the imports as perhaps the warrant factor for the biomass installations (Kåberger, n.d.).

The Swedish Federation of Forest Owners is also one of the major networks in Sweden that has representative in Brussels on EU level. A lot of forests in Sweden are in hands of private individuals. Naturally private forests play important role in the supply chain and it was very important that the owners have positive attitude towards forest biofuels. The fact that negligible fraction of revenues comes from the sales of the logging residues means that the willingness to participate in the supply chain is not economically driven, not at least when the extraction began in the bioenergy market was being developed.

In the future with increased demand, it could be expected that the owners will have increased income from forest fuels. In the survey done by the Swedish Research Institute, high majority of private owners expressed support to the extraction of residues for production of energy. One third named extra income as prime motivator, one third the care for forest health, and the rest named 'tidiness' and 'practicality' as reason, as well as the reduction of use of fossil fuels. This means that private forest owners have certain awareness about the benefits from combustion of forest biomass as well as the awareness about global environmental problems. What is important here is, the fact that majority of information was transferred to them by purchasers of the residues and forestry magazines. Also, meeting with other forest owners was mentioned as method to obtain information (Norin, 2009). This only stresses the importance of horizontal and vertical integration in Sweden in the whole supply chain.

Swedish Association of Pellet Producers is network of 17 companies that cover 80% of the Swedish market. The Association is responsible for fuel quality certification, development of standards, securing the supply chain, promotion of technology and dissemination of information (Höglund, 2008).

7.2.4 Networks in Poland

The relevant networks for the support of the biomass in Poland are rather weak and very few. There are hardly any industry association except Polish Chamber of Biomass that would give strong support.

Coal industry lobby is probably the strongest network in Poland. The fact that coal is predominant energy carrier in Poland, and the fact that the coal was listed as the strategic resource in the Energy Policy by the Ministry of Economy, shows the position of coal industry in Poland. Ever since communist times, coal miners were somewhat favoured industry and perhaps considered as the backbone of the Polish economy. It is logical to assume that coal mining industry prefers to keep 'business-as-usual', without great disturbances in the energy mix of Poland. Coal industry is probably lobbying against development of the bioenergy market.

Polish Biomass Association (POLBIOM) is existing in Poland, but they are very weak lobby group because the members are mostly university representatives and individuals. The activity of the network is probably very limited and hardly influential.

Polish Chamber of Biomass is much stronger group because they have substantial number of industrial representatives as members (around 100 members). Members are divided into the producers of biofuels, producers of biomass for energy purposes, producers of appliances used in production of biomass and appliances used in utilisation of biomass and sales representatives.

There is also a number of joint-implementation programs and collaboration with other countries in Poland. The most prominent are two international projects.

Bioenergy Network of Excellence is network of 8 institutions in Europe. Polish representative is Institute for Fuels and Renewable Energy. The Network covers all relevant issues about biomass, from forest fuels for energy, transport fuels to socio-economic dimension of biomass.

Swedish-Polish Sustainable Energy Platform is network of collaboration signed by the two countries in Warsaw in 2004. The network is forum for academic and industrial representatives, with purpose of dissemination of knowledge, demonstration of know-how experiences and creation of new business opportunities. Also, this network aims for establishment of long term collaboration between two countries, promotion of renewable energy and support in compliance issues with EU regulations.

The Polish Economic Chamber of Renewable Energy (PIGEO) is network established in 2004 with aim of integration of actors and institutions in Poland, representing them internationally and lobbying and influencing relevant legislation for the renewable energy sector. The Chamber also lists promotion of renewable energy in the public and creation of positive opinion and friendly climate. The position of the Chamber towards forest fuels is unclear though but it is likely that there is no much lobbying as probably Chamber is more focused on other renewable sources (The Polish Economic Chamber of Renewable Energy, n.d.).

7.2.5 Institutions in Sweden

There are several important institutions identified in Sweden. For research and development, the most important institution is the *Forestry Research Institute of Sweden* (Skogforsk in Swedish) and *Swedish University of Agricultural Sciences* (SLU). While SLU as university has wide spectrum of research it is also involved in various studies on forest fuels. Skogforsk is more focused on the whole range of forest operations and thus extraction of forest fuels, logistics and optimisation of the fuel chains.

Swedish Energy Agency (SEA) is governmental body and a public authority that has several functions. It is responsible for keeping record of all energy related statistics in Sweden. Also, SEA is involved in RD&D of various energy topics. It is responsible and involved for meeting country's climate targets and promoting energy efficiency. One of the responsibilities of the Agency is to secure stable supply of energy in economical way. The Agency is responsible for the allocation of the Green Certificates along with the Svenska Kraftnät, national utility that is responsible for the national electrical grid.

Swedish Forest Agency (SFA) is governmental institution that is major authority for forestry policies. The main purpose of the Agency is to serve as advisory body for various forest-related matters. Also it is supervising body for compliance with the Forest Act. The Agency provides services to the forest industry, supports nature conservation efforts, and is responsible for conducting inventories (SFA, 2010a).

7.2.6 Institutions in Poland

The Energy Regulatory Office is government authority that has great influence on the energy market. The Office is involved in pretty much all issues related to energy supply. The Office is responsible for setting various tariffs, allocation of certificates .

National Fund for Environmental Protection and Water Management is described earlier. It is one of the main providers of financial support for the investments in Poland. The Fund supports mostly small scale projects. Institution with similar position is the *EcoFund* which operates under the Ministry of Treasury. The primary focus of both funds is not bioenergy, it is rather financing projects that mitigate direct environmental pollution.

EC Baltic Renewable Energy Centre (EC BREC) and the Institute for Fuels and Renewable Energy (IPiEO) are the two main institutions in Poland that are communicating and promoting renewable energy in Poland and overcoming barriers for the development of the RE sector. EC BREC is the contact institution the European Commission, European scientific institutions, investors and consultant companies. It is unclear how much are both institutions promoting forest fuels.

There are several scientific institutions in Poland that should also be mentioned. Forest Research Institute (IBL) in Warsaw, Faculties of Forestry in Poznan and Warsaw, Mining Technical University in Krakow, Chestohowa Technical University and other agricultural faculties that have merged with technical faculties.

Table 7-1 Summary of the TIS structures in Sweden and Poland

Structural components:	**Sweden**	**Poland**
Actors	Skogforsk, Swedish Energy Agency, Forestry industry, energy companies	State Forests Company, Energy Regulatory Office, Ministry of Economy, State owned energy companies (PGE),
Networks	SVEBIO, Swedish District Heating Association, The Swedish Federation of Forest Owners, Swedish Association of Pellet Producers	Polish Chamber of Biomass, Polish Biomass Association (POLBIOM), Coal industry association, Swedish-Polish Sustainable Energy Platform, Bioenergy Network of Excellence
Institutions	Forestry Research Institute of Sweden, Swedish University of Agricultural Sciences (SLU), Swedish Energy Agency (SEA), Swedish Forest Agency (SFA)	The Energy Regulatory Office , National Fund for Environmental Protection and Water Management, Forest Research Institute (IBL), Mining Technical University in Krakow, Chestohowa Technical University, Institute for Fuels and Renewable Energy (IpiEO), Baltic Renewable Energy Centre (EC BREC),

Role and influence of actors varies within and between observed countries. When big energy companies like Vattenfall set their goals to be climate neutral by year 2050, then they are certainly relevant factor for both research and development and the contribution of the energy balance of the country. Despite the fact that certificate system offers significant premium to the energy producers, it is very important for the country that big companies become prime movers of the change.

7.3 Functions and the assessment of functionality

Due to the limited time, this part of the analysis will not be done. Mapping all possible functions of the structural elements of the TIS is a task that is too big for this thesis. Also, assessment of the functionality of the functional patterns of the TIS can be based only on the responds of the respondents and very little from the literature, at least for the case of the TIS in Poland. Such analysis would hardly be impartial and therefore it will be omitted. Some general comments will be made, nevertheless.

In case of Sweden, general impression is that all elements of the TIS are aligned, and function properly. When asked to grade the functionality of other structural elements of the TIS, pretty much all respondents had similar and very positive answer.

The case was different in Poland. Without judgement on the personal motivation of the actors, and based on the literature, some general conclusions can be drawn:

- The most important actors are successfully opposing the utilisation of the forest biomass.

- State Forest Company suffers from low efficiency of its operations. This is a combined result of the forestry policies, felling practices and mechanisation used.

- State ownership of the forests and the monopoly of the State company results in low entrepreneurial initiatives

- Often amendments of the policies, Regulations and Directives suggest that the work of Ministries is not integrated with other actors.

- In cases where forests are predominantly owned by the government, the trend is that they are undervalued for the eco-system services they provide, because these services are considered to be 'free' to everyone under a tacit agreement (Burger, 2009). Forest ownership is complex matter. In centralised countries forests are traditionally owned by the government with state owned forest company which is usually monopolist. Such example is Poland where forestry is considered as a 'state within a state' (Lawrence, 2009). Market failure is often used as argument to justify the public ownership (Siry, Cubbage, & Ahmed, 2005). However, the losses in government owned forests suggest that the government policies might not be the best option (Siry, Cubbage, & Ahmed, 2005).

The Technology Innovation System in Sweden from this perspective is in growth phase, while in Poland, it is in formative. There are little reinforcing mechanisms and the links between actors are weak.

7.4 Barriers and obstacles

In Poland certificates for renewable energy were given to all hydropower plants. Some argue that this is hindering factor to the development of the biomass, since large number of certificates is pushing the price down and keeps energy from the biomass marginal, when compared to hydropower (European Commission, 2007)

Renewable energy sector began rather late with development. One of the reasons was the old establishment of coal combustion, low prices of energy and subsidies to the conventional energy carriers (Council of Ministries). High investment costs were one of the big problems in the times when strategy for the development of RES in Poland was being made, and they still are. In a document by Council of Ministries, a Strategy for development of renewable energy sector, a framework for promotion and development is designed. The same document had identified five groups of barriers that are hindering development of the renewable energy sector. These are summarised in the Table 7-2.

Table 7-2 Barriers to development of renewable energy sector in Poland

Legal and financial	The lack of program and regulations clearly identifying and steering the strategy for utilisation of RES
	Lack of economic incentives and tax mechanisms that help to overcome high initial costs of investment
	High costs of preliminary works (e.g. hydro-geological surveys)
Lack of information on:	Distribution potential
	Consulting, design and information on manufacturing companies
	Preparation and execution of investments
	Environmental, social and economic benefits from RES
Access to new equipment and technologies	Lack of domestic manufacturers of equipment for RES systems

	Lack of tax preferences for exports/imports of technology and equipment for RES systems
Educational	Lack of education on RES in primary and secondary schools
	Lack of training programs for relevant stakeholders in RES systems
Landscape protection	Lack of proven methods for avoiding conflicts with nature and landscape objectives

Source: (Council of Ministries,, 2000)

This is important to bring, since the document was delivered four years before the accession to the European Union. What can be observed today in Poland is that similar problems are present ten years afterwards. However, the section about the landscape protection is rather vague and remains to be the subject of speculation. Indeed today there are many ways of harvesting the renewable energy without disturbance to the landscape.

7.4.1 Historical context, mindset and motivation

As one of the interviewees underlined, in order to understand Poland and its situation, one must understand the historical context. Throughout recent history Poland had short times of independence-it was claimed by Germany, Austro-Hungarian Empire and Soviet Union. In 1989 it finally rose against communism and Soviet occupation. As one of the respondents said: 'Poland was united and against communism, but it was not for the capitalism. The Soviet times have completely destroyed normal thinking in people.' Although this is normative statement, it has certain weight since it is obvious that Poland is facing challenges in adaptation to market economy. The lack of professionalism is function of historical context.

The lack of cooperation between actors on the market is very obvious. There are very few cluster initiatives and little partnership. Industrial clusters do have meetings but with very little achievements so far. Instead of building the market, Poland is slowly turning to other renewable sources such as wind power. State Forest Company has been criticised for the lack of professionalism and lack of trust, especially to private entrepreneurs. According to Rudawski (2010), the sales departments are marginalized and the regional Directorates usually have only marketing department. Lack of sales departments is a sign of introversion and lack of dedication to the development of business opportunities.

One of the historical factors makes power cheap in Poland because, the investment costs are not included in the price of power, only operational and maintenance costs, personnel and fuel. Majority of the energy infrastructure in Poland was built in communist times and paid by the society. As mentioned earlier, the Energy Policy is anticipating increase in the price of electricity. Perhaps then the alternative domestic sources such as forest biomass will seem as reasonable option not to be overseen.

In Sweden, the anticipated increase in production of wood chips from the forestry could be achieved in the future through utilisation other parts of the timber, such as pulp wood. It is obvious that Poland will not follow the same path since already available residues are not used to the fullest potential. Also, the current legislation in Poland is streamlined towards phasing out the usage of forest fuels for energy.

Sweden has had very strong incentive and motivation in the 70s and early 80s to start its own program and development of indigenous fuels supply. Dependence on the imports and wide spread use of oil made Swedish economy susceptible to volatility of prices of oil. At the same time, Sweden had few alternatives to oil and biomass seemed as the perfect candidate.

Poland is country with rich indigenous resources of coal. It covers most of the demand from the domestic supply. Large quantities of oil are spent in the transport sector but in the production of heat and electricity, coal is the main resource. Protectionism over the coal industry and rich domestic stock provides very little incentive for Polish efforts in the search for alternative fuels. According to the respondents, coal mining sector has 'special' status in Poland ever since the communist times. It is likely to believe that Polish citizens have much lower awareness of the global environmental issues compared to Swedish citizens. Perhaps intensive education about the green house effect would create critical threshold and stimulate the change within. At current situation it seems that Poland is merely fulfilling criteria and targets set by the European Union.

7.4.2 Land Use Change scenarios

Another hindering factor could be a matter of definition of 'land use change'. In the Article 17 of the Renewable Energy Directive (2009/28/EC) there is a set of rules for land suitable for energy production. More importantly this document prohibits conversion of land from the use which it had in January 2008. Land with high biodiversity values, highly biodiverse grassland, continually forested land and wetlands will protected from the conversion to the land designated for the production of biofuels. What is also important, the Directive prohibits change of the land use from the status it had in January 2008.

In short, agricultural land that was used for production for food in January 2008 will not be able to be converted for energy production. Consequently forest land cannot be converted to agricultural land. It will result in many exclusions of the land for establishment of the energy crops. Virtually only contaminated land will be legally suitable for the establishments of energy crops. The aim of this Directive is probably to ensure food supply and to reduce distortions on the market caused by subsidisation of energy crops in the past.

Indeed the land use change is in center of controversy for which European Union was recently accused. In the document called 'Quantification of the effects on greenhouse gas emissions of policies and measures' (AEAGroup, 2009), all annexes with calculations of greenhouse gas emissions are taken out. According to the several agencies, the document shows that production of biodiesel can result in much higher GHG emissions than conventional fuels (Reuters, 2010), a carbon footprint that could kill EU biodiesel business. In addition, around 30% of biodiesel is imported from developing countries, mostly Brazil where conversion of native forests is taking place on a large scale. Although biodiesel is not issue of this thesis, land use and land use change is. The requirements from EU could seriously threaten utilisation of agricultural land in Poland. Perhaps this could be also an argument not to oversee so easily forest material for energy production.

In a work by de Wit & Faaij (2010) a calculation is presented for cultivation of energy crops. Four major categories constitute the cost of production: land costs, labour costs, fertiliser costs and capital costs and miscellaneous. When compared to the rest of the countries in Europe, we can observe that Poland has relatively cheap land suitable for dedicated energy crops, fertilisers are also relatively cheap, but the wages are among the lowest in Europe. If Poland is to pursue the agricultural option for production of energy from biomass, then it will greatly depend on the future prices of the final product. Moreover the price of labour is expected to increase which brings the question of feasibility of such long term strategy.

Agricultural production of biomass in Poland is far from happening as a successful story. In a work by Sinnisov (2006), the whole set of barriers for willow cultivation was identified in the region of Grudziądz. Among the identified barriers, the lack of water or dry seasons were identified as a problem. In the research, some farmers explained that they think that their soil is of too good quality to be used for willow cultivation and should be kept for cultivation of food crops. As expected there is a whole range of economic factors and lack of EU subsidies that could stimulate the willingness of farmers to engage in willow crops business.

7.4.3 Technical barriers

One of the barriers in Poland is certainly the forest cover and the actual technical potential of the residues in the forest. The domination of pine stands over spruce stands is limiting factor. The tree crown mass is significantly lower in Scots pine trees than in Norway spruce. In addition to the smaller availability of the residues, it should be noted that extraction of the stumps in pine stands is also more difficult due to the different root system. While spruce has relatively shallow root system that is relatively easy to take out, deep root and strong roots of the Scots pine are not so easy to extract. Also the pine extraction does not have public support in Poland.

The methodology and the practice of the extraction of timber is also hindering factor in Poland. Although Poland was ranked highest among all countries of Central Europe for the mechanisation level used in the study by Pisarek et al. (29–30 June 2006)**,** of all countries studied, it is far from the situation in Nordic countries. In Sweden the 'no human foot on the ground' is the principle in extraction of wood and fuels from the forests. This means that everything is done by mechanisation which greatly improves the safety of the workers and reduces the number of workers. In Poland the manual cutting with chain saws and domination of adapted agricultural tractors makes extraction of logging residues hardly feasible.

Long transportation distances for wood chips are also one of the barriers for the supply chain in Poland. The majority of the production of energy is done in large blocks or large installations. If the production was more dispersed with smaller units, then the distances from the felling areas would be smaller. Logistical challenges are also a function of mechanisation. At this point truck compositions with large containers (100-120 m^3) are only allowed in Nordic countries. Due to the low energy density of the transported material, large trucks are effective way to reduce costs in the supply chain.

If Poland is to pursue the strategy of only agricultural fuels then several other things need to be brought up. According to the "Development strategy for the renewable energy sector" (2000), the price of straw fired installations is 1,5-2 times higher than wood fired of the same capacity. If Poland is to pursue strategy of utilisation of only agricultural biomass, this could be also hindering factor.

7.4.4 Legislation, policy and politics

The Directive of Ministry of Economy from 2008 that sets the target to eliminate all forest fuels by year 2017 is very straight forward barrier to any future development of the supply chain for the forest fuels. The Regulation targets all installations with capacity bigger than 5 MW. Since majority of the energy is coming from large installations this Regulation is virtually completely phasing out forest fuels from the Polish energy mix. According to the respondents in the interviews, Ministry of Economy was probably influenced by the lobbying from the plywood industry representatives. If this is the case then Ministry is protecting one industry from another. The fear for competition over raw material has proved to be exaggerated in Sweden. In Polish case it could be reasonable however, with Polish plywood industry one of the most important suppliers to IKEA. Plywood industry in Sweden has successfully transformed into the pellet producers. In Poland protectionism by the Ministry of Economy is the biggest limitation to the development of the bioenergy market of forest fuels.

Inconsistency in the policies and often amendments to the existing regulations and Directives was also mentioned by the interviewees. For example the Directive from 2008 has been amended four times until 2010. Certain aspects of the bioenergy market are under jurisprudence of several Ministries. The work of the three mentioned Ministries was often criticised for not being integrated and hardly functional. Horizontal collaboration and integration of the Ministries would certainly add some consistency to the policies.

Political swing of the Governments is also adding to the inconsistency of the policies. So far, the practice has been that after every 4-year mandate the Government is changed. Apparently there are some indices that the ruling Government could win the next elections and that the energy policy could be prolonged and more coherent.

8 Conclusion

Achieving sustainable production of energy is considerable challenge for any country, regardless of its technological development. Transition of economy from fossil fuels to renewable energy sources is slow and gradual change. The primary advantage of the renewable energy sources is domestic supply, or in other words availability of the resources. In this work a broad picture of the two economies was presented, of which one is emerging market and one is fully-fledged with fully developed technologies and supply chains of the observed innovation system.

This work is presentation of the two observed countries and their respective energy policies, markets, actors, networks and institutions. Both Sweden and Poland share certain similarities but also substantial differences. Both countries have similar vegetation types and yet significant differences in the forestry industries. Utilisation of logging residues or primary forest fuels has been regular practice in Sweden for three decades. A lot of research has been done about the optimisation and sustainability of the practice and it is considered to be mature system, but still with some space for improvement. Logging residues are disfavoured in Poland as a fuel by very strict regulations.

The most obvious advantages of forest fuels should be emphasized. Logging residues come as a by-product of highly integrated forestry production. Emission factors from the combustion of forest fuels are superior to all fossil fuels, if they are produced in closed loop. Production of forest fuels creates business opportunities and with the development of the bioenergy market in the Member States of the European Union and worldwide, the demand will continue to grow. Growth of bioenergy market has other distinctive characteristics-it can help in alleviation of poverty in rural area and prevent negative demographic movement from rural areas to urban areas.

Expansion of the bioenergy market will likely affect the utilisation methods of the wooden biomass. In Sweden it is already observable that governmental incentives to producers of energy are already high enough so they can compete with other industries for raw material. This is happening at relatively small scale at the moment and if the current trend continues, it could become large scale change. The prices of certificates are changing with time and there are opposite examples to Sweden in other countries, for example Italy.

The approach to the research was triangulation of the information obtained through archival review of a lot of documents, publications from various institutions, scientific articles and reports. Data collection was supplemented with substantial number of in-depth interviews. The interviews were especially important in case of Poland since significantly less literature is published in English.

The analysis revealed that the TIS in Sweden holds all components critical for the development of the bioenergy from forest residues. The development of successful TIS requires collaboration between actors and markets as well as the networks and institutions. The integration in Sweden is present at all levels: research institutions collaborate with the Government and industry, industry is organised in powerful network that can influence legislation and different decisions.

In plethora of integrated solutions, perhaps two key points should be emphasized. Establishment of the district heating sector that later on have transformed to independent companies meant the establishment of the perhaps the most important actor on the market.

District heating sector has transitioned since 1970s from the oil derivates to the biomass. This has created large demand for the forest biomass which gave birth to the fully fledged supply chain.

Proactive and supportive standpoint of district heating sector towards biomass was a result, next to the political reason, of the carbon taxation of the fuels. Carbon taxation was part of the great tax reform, and although it influenced all producers and end users. The greatest influence was in the district heating sector, for very simple reason. Biomass is up to date still mostly utilized for production of heat and carbon tax is not levied on biomass. Production of electricity and liquid fuels is far from being a mature technology. Also, carbon taxation has special rules for industry because heavy taxation could reduce competitiveness on the international market.

When the TIS is observed from bottom-up approach, then the role of Swedish forestry industry should be emphasized. Most importantly, extraction of forest fuels is nowadays integrated part of forestry operations. Forestry companies rightfully see sales forest fuels as valuable extra income. Extraction of forest fuels has been a subject to decades of practice and improvement through learning-by-doing. High importance to the supply chain gives the felling practices in Sweden and especially the level of mechanisation. Also the ownership type of the forests in Sweden favours entrepreneurship and is more open to new business ideas.

Extraction of forest fuels at this point has few negative environmental impacts and many positive ones. The future of the extraction will be a reflection of today's practice, but any anticipated potential problems are considered to be manageable.

The analysis of Polish situation has revealed many significant differences in the observed TIS. Although the supply chain of forest residues exists, it is justifiable to say it exists only partially in the country and with current legislation, it will cease to exist. The premise of this thesis was that Poland is young and emerging market but considering the given situation, the conclusion leaves big question mark for that statement.

The authors of the used analytical framework used in this paper state that the connection between the components of the system can be very weak or small (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008) and that is the case in Poland. There are very few initiatives and very few industrial clusters. Many problems are emerging due to the legacy of the past-simply said, it takes a lot of time to adjust to the newly created environment of the market economy.

Unlike in Sweden, there is no real prime mover, an actor that would stimulate the development in the positive direction. The actors are scattered, very small with very little influence and lobbying power. Support from the Government is limited to other aspects of the RES in Poland. In fact, Government is intentionally blocking the development of the TIS for the primary forest fuels. According to the analysis of the situation in Poland, there is virtually no actor or networks that is actively promoting the utilisation of forest fuels.

The main supplier of forest fuels, the State Forest Company has several inconsistencies. Although the Company argues that the extraction of forest fuels irrevocably damages the habitat due to the nutrient removal, in some regional Directorates the extraction of residues is happening. In reality, regional Directorates operate differently one from another. From that perspective, it is difficult to negotiate supply of the raw material from a company that is a monopolist in the country.

Inconsistencies can be observed also in the actions of the Ministries as amendments to the existing legislation are quite often. Government is proactively favouring two industries in Poland: plywood industry and coal industry.

From perspective of the forestry industry in Poland, it should be noted that according to the estimates, the potential for extraction of primary forest fuels in Poland is rather limited, especially when compared to Sweden. However, the current level of extraction could be doubled if the fullest potential is to be met. At the beginning of the extraction practices in Sweden the potentials have been estimated much lower than they are today. The extractable potential changes with technology. In Poland investment into more mechanized fellings would increase the potential logging residues, since harvesters produce more slash than manpower. The mechanisation level in Poland is rather low when compared to Sweden.

Given the barriers presented in the Analysis chapter, and especially the strict legislation by the Ministry of Economy it is very hard to suggest recommendation for the Poland and its targets. Bioenergy was once seen as the most promising renewable energy source but combined activities of several actors are blocking the emergence of the market. Poland needs to undergo several structural changes which is a challenge that cannot be met in short time.

There are however certain possibilities:

1. Amendment of the Regulation and either cancellation of the policy, or 'softening' the requirements. Ministry of Economy could extend the deadline for the replacement of the forest fuels with agricultural fuels. There are several reasons for that:

The emergence of the market for the dedicated energy crops is not happening in Poland, at least not at considerable pace. Previous works of some authors have identified the whole set of barriers for the production of Salix crops, of which the most prominent are financial aspects. It is considered that subsidies for establishment of energy crops are not sufficient. There is also a problem of moving from annual to perennial crops.

The demand for biomass is already high in Poland and that is a result of unhealthy certification scheme. There should be a parallel mechanism that would result in decreased use of fossil fuels. Co-firing of coal with 5% share of biomass can hardly be considered renewable energy. For that reason the second recommendation would be:

2. The establishment of carbon tax on fossil fuels. Presumably the carbon tax would be resisted by the Polish public. The tax can have certain exceptions for industry and even a fund could be created to help affected industries. This should be followed by market liberalization and establishment of district heating sector as independent sector from energy companies.

3. Allocation of certain area to be forested by Norway spruce within the National Forest Augmentation program.

One of the primary problems in Poland is probably the motivation. Ten years prior to the accession to the EU, Poland did virtually nothing to increase the share of renewable energy. Motivation comes primarily from the legislation of the EU. Continuous education programs about the environmental drawback of burning of fossil fuels could create critical mass for the change from within. Alternative strategies in dedicated energy crops could meet many barriers in new EU legislation. If the strategy remains unchanged and Poland pursues the energy crops instead of the forest fuels, then detailed analysis of the available land should be conducted with the new estimates of the potentials. Forest fuels should not be overseen lightly and the implementation of the Regulation from the Ministry of Economy should be revised with prolonged targets. This would create more time for necessary adjustments.

Bibliography

AEAGroup. (2009). Quantification of the effects on greenhouse gas emissions of policies and measures. Retrieved April 25, 2010, from http://ec.europa.eu/environment/climat/pdf/ghgpams_report_180110.pdf

Bengtsson, J., Lundkvist, H., Saetre, P., Sohlenius, B., & Solbreck, B. (1998). Effects of organic matter removal on the soil food web: Forestry practices meet ecological theory. *Applied Soil Ecology, 9*, 137-143.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy, 37*, 407–429.

Berggren, M., Ljunggren, E., & Johnsson, F. (2008). Biomass co-firing potentials for electricity generation in Poland-Matching supply and co-firing opportunities. *Biomass and Bioenergy, 32*(9), 865-879.

Bjorheden, R. (2006). Drivers behind the development of forest energy in Sweden. *Biomass and Bioenergy, 30*(4), 289-295.

Björheden, R. (2000). Learning curves in tree section hauling in central Sweden. *International Journal of Forest Engineering, Vol 12*(1).

BorealForest. (n.d.). Sweden-forests and forestry. Changes to boreal forest ecology. Retrieved May 2, 2010, from http://www.borealforest.org/world/world_sweden.htm#top

Börjesson, P. (2000). Economic valuation of the environmental impact of logging residue recovery and nutrient compensation. *Biomass and Bioenergy, 19*, 137-152.

Brukas, V., & Weber, N. (2009). Forest management after the economic transition—at the crossroads between German and Scandinavian traditions. *Forest Policy and Economics, 11*, 586–592.

Burger, J. A. (2009). Management effects on growth, production and sustainability of managed forest ecosystems: Past trends and future directions. *Forest Ecology and Management, 258*, 2335-2346.

Carlsson, D., & Rönnqvist, M. (1998). *Wood flow problems in the Swedish forestry*: Linköpings University, Department of Mathematics.

Central Statistical Office. (2009). *Statistical information and reports-Forestry 2009 [Informacje i opracowania statystyczne-Leśnictwo 2009]*. Warsaw, Poland.

Chalvatzis, K. J., & Hooper, E. (2009). Energy security vs. climate change: Theoretical framework development and experience in selected EU electricity markets. *Renewable and Sustainable Energy Reviews, 13*(9), 2703-2709.

Council of Ministries. (2000). *Development strategy of renewable energy sector*. Warsaw, Poland.

Czajkowski, M., Buszko-Briggs, M., & Hanley, N. (2009). Valuing changes in forest biodiversity. *Ecological Economics, 68*, 2910-2917.

de Wit, M., & Faaij, A. (2010). European biomass resource potential and costs. *Biomass and Bioenergy, 34*(2), 188-202.

EcoFund. (2008). The principles of EcoFund's operation. Retrieved April 22, 2010, from http://www.ekofundusz.org.pl/us/index.htm

Environmental Protection Bank. (2009). Ecological Report. Retrieved April 23, 2010, from http://www.bosbank.pl/pub/files/Raport_ekologiczny_2009_ang.pdf

European Commission. (2007). Poland – Energy mix fact sheet. Retrieved 23 January 2010, from http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_pl_en.pdf

European Commission Energy. (2007). Poland– Renewable Energy Fact Sheet [Electronic Version]. Retrieved 20 January 2010 from http://ec.europa.eu/energy/energy_policy/doc/factsheets/renewables/renewables_pl_en.pdf.

European Comission. (2010). Intelligent Energy Projects. Retrieved May 15, 2010, from http://ieea.erba.hu/ieea/page/Page.jsp?op=project_list&searchtype=3

Europe's Energy Portal. (2010). Fuel prices across the EU. Retrieved May 16, 2010, from http://www.energy.eu/#Domestic

Energy Platform. (2009,). Background. Retrieved 21 January 2010 from http://www.energyplatform.net/background

Eriksson, E. (2006). Thinning operations and their impact on biomass production in stands of Norway spruce and Scots pine. *Biomass and Bioenergy, 30*(10), 848-854.

Ericsson, K. (2007). Co-firing – A strategy for bioenergy in Poland? *Energy - The International Journal, 32*, 1838–1847.

Ericsson, K., & Nilsson, L. J. (2004). International biofuel trade-A study of the Swedish import. *Biomass and Bioenergy, 26*(3), 205-220.

Eriksson, H. M., Hall, J. P., & Helynen, S. (2002). 1 Rationale for forest energy production. In J. Richardson, R. Björheden, P. Hakkila, A. T. Lowe & C. T. Smith (Eds.), *Bioenergy from sustainable forestry: guiding principles and practice*. New York: Kluwer Academic Publishers.

Eriksson Ljusk, O., & Bjorheden, R. (1989). Optimal Storing, Transport and Processing for a Forest-Fuel Supplier. *European Journal of Operational Research, 43*(1), 26-34.

Energy Regulatory Office. (2010). Map of renewable sources of energy. Retrieved 15 May, 2010, from http://www.ure.gov.pl/uremapoze/mapa.html

European Biomass Industry Association (EUBIA). (2007). Recovery of forest residues [Electronic Version]. Retrieved 27 January 2010 from http://www.eubia.org/191.0.html.

Cogen Europe. (2007). COGEN Challenge Poland Factsheet. Retrieved April 22, 2010, from http://www.cogeneurope.eu/challenge/Downloadables/CC071201_Factsheet_Poland%20-%20FINAL07.pdf

EUROSTAT. (2009). Energy. Monthly statistics-Issue number 12/2009. Retrieved April 29, 2010, from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-BX-09-012/EN/KS-BX-09-012-EN.PDF

EUROSTAT. (2010). Electricity statistics –Provisional data for 2009. Retrieved April 29, 2010, from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-10-014/EN/KS-QA-10-014-EN.PDF

Foundation of Assistance Programmes for Agriculture (FAPA). (2006). Foundation of Assistance Programmes for Agriculture. Retrieved April 23, 2010, from http://www.fapa.com.pl/index.php?ln=en

Gunnarsson, H., & Lundgren Jan, T. (2004). Supply chain modelling of forest fuel. *European Journal of Operational Research, 158*(1), 103-123.

Hakkila, P., & Parikka, M. (2002). 2 Fuel resources from the forest. In J. Richardson, R. Björheden, P. Hakkila, A. T. Lowe & C. T. Smith (Eds.), *Bioenergy from sustainable forestry: guiding principles and practice*. New York: Kluwer Academic Publishers.

Hillring, B. (1998). National strategies for stimulating the use of bioenergy: policy instruments in Sweden. *Biomass and Bioenergy, 14*(5-6), 425-437.

Höglund, J. (2008). PiR – Swedish Association of Pellet Producers. Retrieved May 16, 2010, from http://www.aebiom.org/IMG/pdf/Hoglund_Swedish_Pellets_Assoc.pdf

Holgen, P., & Bostedt, G. (2004). Should planting of broad-leaved species be encouraged at the expense of spruce? An economic approach to a current southern Swedish forestry issue. *Journal of Forest Economics, 10*(3), 123-134.

Hong, B. D., & Slatick, E. R. (1994). Carbon Dioxide Emission Factors for Coal. Retrieved May 10, 2010, from http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html

Hörnsten, P., Johansson, K., & Lindstedt, A. (2007). *The general public's view on the Swedish forestry sector 1985-2007*: Swedish Forest Industries Association.

International Energy Agency (IEA). (2010a). Act on electricity production from cogeneration. Retrieved April 21, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=3975&action=detail

International Energy Agency (IEA). (2010b). Addressing Climate Change. Policies and Measures. Retrieved March 31, 2010, from http://www.iea.org/textbase/pm/?mode=cc&action=view&country=Poland

International Energy Agency (IEA). (2010c). Biofuels targets 2008-14. Retrieved April 21, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=4297&action=detail

International Energy Agency (IEA). (2010d). Breakdown of sectoral final consumption by source-Poland. Retrieved May 2, 2010, from http://www.iea.org/stats/pdf_graphs/PLBSFC.pdf

International Energy Agency (IEA). (2010e). Electricity/Heat in Poland in 2007. Retrieved May 3, 2010, from http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=PL

International Energy Agency (IEA). (2010f). Energy Law Act. Retrieved April 21, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=3633&action=detail

International Energy Agency (IEA). (2010g). Final consumption by sector-Poland. Retrieved May 13, 2010, from http://www.iea.org/stats/pdf_graphs/PLTFC.pdf

International Energy Agency (IEA). (2010h). Loans from the National Fund for Environmental Protection and Water Management. Retrieved April 21, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=4303&action=detail

International Energy Agency (IEA). (2010i). Long-term Programme for Promotion of Biofuels or Other Renewable Fuels. Retrieved March 31, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=3631&action=detail

International Energy Agency (IEA). (2010j). Programme for renewable energy and high efficiency cogeneration projects. Retrieved March 31, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=4339&action=detail

International Energy Agency (IEA). (2010k). Renewable Energy Tax Excise. Retrieved 21 April, 2010, from http://www.iea.org/textbase/pm/?mode=cc&id=3634&action=detail

Ignaciuk, A. (2005). Energy policies and their impact on establishing nature areas in Poland - an AGE analysis: European Regional Science Association.

The Swedish Forest Industries. (2009). *Facts and figures 2008*. Stockholm, Sweden.

Johansson, B. (2000). *Economic Instruments in Practice 1: Carbon Tax in Sweden*. Stockholm, Sweden: Swedish Environmental Protection Agency.

Johansson, B., Börjesson, P., Ericsson, K., Nilsson, L. J., & Svenningsson, P. (2002). *The use of biomass for energy in Sweden-critical factors and lessons learned*. Lund: Department of Environmental and Energy System Studies, Lund University.

Johansson, J., Liss, J. E., Gullberg, T., & Bjorheden, R. (2006). Transport and handling of forest energy bundles-advantages and problems. *Biomass and Bioenergy, 30*(4), 334-341.

Junginger, M., Faaij, A., Björheden, R., & Turkenburg, W. C. (2005). Technological learning and cost reductions in wood fuel supply chains in Sweden. *Biomass and Bioenergy, 29*, 399-418.

Kåberger, T. (2007). History of nuclear power in Sweden. *Estudos Avançados, 21*(59).

Kåberger, T. (n.d.). Environmental Impacts from Bioenergy – a view from Sweden. Retrieved May 6, 2010, from http://www.bioenergy-noe.com/Resources/user/Kaberger%20Environmental%20Impacts%20from%20Bioenergy%20-%20a%20view%20from%20Sweden.pdf

Kärhä, K., & Vartiamäki, T. (2006). Productivity and costs of slash bundling in Nordic conditions. *Biomass and Bioenergy, 30*(12), 1043-1052.

Koziol, C. (n.d.). National Policy on Forests in Poland and forest management in the Carpathians [Electronic Version]. Retrieved 18 December 2009 from http://www.carpathianconvention.org/NR/rdonlyres/493D924E-1E56-4823-BC23-1D6289EED6EA/0/NationalPolicyonForests_Koziol_Poland.pdf.

Laitila, J., Asikainen, A., & Hotari, S. (2005). Residue recovery and site preparation in a single operation in regeneration areas. *Biomass and Bioenergy, 28*(2), 161-169.

Lawrence, A. (2009). Forestry in transition: Imperial legacy and negotiated expertise in Romania and Poland. *Forest Policy and Economics, 11*(5-6), 429-436.

Leszczynski, S., Brzychczyk, P., & Sekula, R. (1997). Review of biomass as a source of energy for Poland. *Energy Sources, 19*(8), 845-851.

Lindelöw, A., & Schröder, M. (2008). The Storm "Gudrun" and the Spruce Bark Beetle in Sweden [Electronic Version]. *Forstschutz Aktuell*, 44, 5 - 7. Retrieved May 20, 2010 from http://www.waldwissen.net/themen/waldschutz/insekten/bfw_barkbeetle_sweden_2008_EN.

Mederski, P., Jakubowski, M., & Karaszewski, Z. (2009). The Polish landscape changing due to forest policy and forest management. *iForest, 2*, 140-142.

Mederski, P. S. (2006). A comparison of harvesting productivity and costs in thinning operations with and without midfield. *Forest Ecology and Management, 224*(3), 286-296.

Ministry of Economy (MoE) (n.d.). Poland's Energy Policy until 2030. Retrieved 22 January 2010, from http://www.mg.gov.pl/English/Programmes/Polands+Energy+Policy+until+2030.htm

Ministry of Economy. (2008). on the specific scope of responsibilities of obtaining and presenting to remit a certificate of origin, payment of substitute fee, purchase of electricity and heat generated from the renewable sources and the obligation to confirm the data on the amount of electricity generated from the renewable sources [w sprawie szczegółowego zakresu obowiàzków uzyskania i przedstawienia do umorzenia świadectw pochodzenia, uiszczenia opłaty zastępczej, zakupu energii elektrycznej i ciepła wytworzonych w odnawialnych źródłach energii oraz obowiązku potwierdzania danych dotyczących ilości energii elektrycznej wytworzonej w odnawialnym źródle energii] (Vol. 156, pp. 8372-8377): Official Gazette.

Ministry of Economy (MoE). (2009a). *Assessment of implementation of energy policy since 2005 onwards. Appendix 1. to draft "Energy Policy of Poland until 2030"*. Warsaw, Poland.

Ministry of Economy (MoE). (2009b). *Projection of demand for fuels and energy until 2030. Appendix 2 to draft "Energy Policy of Poland until 2030"*. Warsaw, Poland.

National Fund for Environmental Protection and Water Management. (2009). Absorption of foreign founds. Retrieved March 31, 2010, from http://www.nfosigw.gov.pl/en/absorption-of-foreign-founds/

National Fund for Environmental Protection and Water Management. (n.d.). NFOŚiGW. Retrieved April 21, 2010, from http://www.nfosigw.gov.pl/en/nfosigw/

Nilsson, L. J., Johansson, B., Åstrand, K., Ericsson, K., Svenningsson, P., & Börjesson, P. (2004). Seeing the wood for the trees: 25 years of renewable energy policy in Sweden. *Energy for sustainable development : the journal of the International Energy Initiative, 8*(1), 67-81.

Nilsson, L. J., Pisarek, M., Buriak, J., Oniszk-Poplawska, A., & et al. (2006). Energy policy and the role of bioenergy in Poland. *Energy Policy, 34*(15), 2263-2278.

Nohrstedt, H.-Ö. (2010). SLU conference on forest pests [Electronic Version]. *Sustainability-Journal from the Swedish research council formas*. Retrieved May 4, 2010 from http://sustainability.formas.se/en/Issues/Issue-2-April-2010/Content/Articles/SLU-conference-on-forest-pests/.

Norin, K. (2009). Survey finds forest owners in favour of extracting logging residues. *Från Skogforsk, 20*.

Orzechowski, M. (n.d.). Principles of forest cultivation. Clear-cuts of mature stands: Faculty of Forestry, Warsaw Agricultural University.

DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC(2004/8/EC).

Parliament, E. (2009/28/EC). on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC: Official Journal of the European Union.

Pigan, M. (2008). *The availability of biomass from National Forest for the power sector in the perspective of 20 years [Dostępność biomasy z Lasów Państwowych dla energetyki zawodowej w perspektywie 20 lat]*. Warsaw, Poland.

Pisarek, M., Laitila, J., Ala-Fossi, A., & Tymendorf, Ł. (29–30 June 2006). *The implementation patterns of modern CTL and energy wood production technologies in forestry industry in CEE countries.* Paper presented at the „Quo vadis, Forestry?" Sękocin Stary, Poland.

Pisarek, M., Oniszk-Poplawska, A., & Tymendorf, Ł. (2005, 17-21 October). *The assessment of the forestry wood potentials for energy and forecast to 2020 in Poland.* Paper presented at the 14'th European Biomass Conference and Exhibition. Biomass for Energy, Industry and Climate Protection, Paris.

Reuters. (2010). Once-hidden EU report reveals damage from biodiesel. Retrieved April 25, 2010, from http://in.reuters.com/article/worldNews/idINIndia-47879220100421

Rogulska, M. (2010). *The Market for Sustainable Energy in Poland*. Warsaw, Poland: Institute for fuels and renewable energy.

Rogulska, M., Pisarek, M., & Wiśniewski, G. (2002). Bioenergy in Poland [Electronic Version]. Retrieved 1 December 2009 from http://www.iea.org/work/2002/baltics/Ba5.pdf.

Rykowski, K. (1997). Forest Policy Evolution in Poland. *Journal of Sustainable Forestry, 4*(3), 119-126.

Saarsalmi, A., Tamminen, P., & Kukkola, M. Whole-tree harvesting at clear-felling: Impact on soil chemistry, needle nutrient concentrations and growth of Scots pine. *Scandinavian Journal of Forest Research, 25*(2), 148-157.

Swedish Association of Pellet Producers (SAPP), (2010). Delivery Market Statistics Sweden. Retrieved May 11, 2010, from http://www.pelletsindustrin.org/web/Leveransstatistik.aspx

Swedish Energy Agency (SEA). (2008). *Energy in Sweden 2008*. Eskilstuna: Swedish Energy Agency.

Swedish Energy Agency (SEA). (2010). *Energy in Sweden 2009*. Eskilstuna: Swedish Energy Agency.

Swedish Energy Agency (SEA). (2010a). *The electricity certificate system, 2009*. Eskilstuna: Swedish Energy Agency.

Swedish Energy Agency (SEA). (2010b). Price sheet for biofuels and peat.

Swedish Energy Agency (SEA). (2010c). Sweden becomes net exporter of electricity. Retrieved March 22, 2010, from http://www.energimyndigheten.se/en/Press/Press-releases/Sweden-becomes-net-exporter-of-electricity/

Swedish Environmental Protection Agency (SEPA). (2009). Local Investment Programmes (LIP). Retrieved March 29, 2010, from http://www.naturvardsverket.se/en/In-English/Menu/Legislation-and-other-policy-instruments/Economic-instruments/Investment-Programmes/Local-Investment-Programmes-LIP/

Swedish Environmental Protection Agency (SEPA) (2009a). Climate Investment Programmes (Klimp). Retrieved March 29, 2010, from http://www.naturvardsverket.se/en/In-English/Menu/Legislation-and-other-policy-instruments/Economic-instruments/Investment-Programmes/Climate-Investment-Programmes-Klimp/

Swedish Forest Agency (SFA). (2009). 7 Felling and Wood Measurement. In J.-O. Loman (Ed.), *Swedish Statistical Yearbook of Forestry 2009* (pp. 163-184). Jönköping: Swedish Forest Agency.

Swedish Forest Agency (SFA). (2009a). 11 Wood Fuel. In J.-O. Loman (Ed.), *Swedish Statistical Yearbook of Forestry 2009* (Vol. 235-246). Jönköping: Swedish Forest Agency.

Swedish Forest Agency (SFA) (2009b). The Swedish Forestry Act. Retrieved March 30, 2010, from http://www.skogsstyrelsen.se/episerver4/templates/SNormalPage.aspx?id=12677

Swedish Forest Agency (SFA) (2009c). Conifers dominate. Retrieved March 30, 2010, from http://www.skogsstyrelsen.se/episerver4/templates/SNormalPage.aspx?id=11507

Swedish Forest Agency (SFA). (2009d). 3 Forest and Forest Land. In J.-O. Loman (Ed.), *Swedish Statistical Yearbook of Forestry 2009* (Vol. 235-246). Jönköping: Swedish Forest Agency.

Swedish Forest Agency (SFA), (2010). Forests in Sweden. Retrieved March 30, 2010, from http://www.skogsstyrelsen.se/episerver4/templates/SNormalPage.aspx?id=11504

Swedish Forest Agency (SFAa). (2010a). Swedish Forest Agency. Retrieved May 19, 2010, from http://www.skogsstyrelsen.se/episerver4/templates/SNormalPage.aspx?id=11310

Swedish National Board of Forestry, (2002). *Recommendations for the extraction of forest fuel and compensation fertilising*: Swedish Forest Agency.

Simberloff, D. (2001). Management of Boreal Forest Biodiversity - A View from the Outside. *Scandinavian Journal of Forest Research, 16*(2-supplement-3), 105-118.

Sinnisov, L. (2006). *Barriers to Dedicated Energy Crop Cultivation in Poland. The Case of Willow in the Grudziądz Region* (Master's thesis). Lund University, Lund.

Siry, J. P., Cubbage, F. W., & Ahmed, M. R. (2005). Sustainable forest management: global trends and opportunities. *Forest Policy and Economics, 7*, 551-561.

Siry, J. P., & Newman, D. H. (2001). A stochastic production frontier analysis of Polish State Forests. *Forest Science, 47*(4), 526–533.

Spence, J. R. (2001). The new boreal forestry: adjusting timber management to accommodate biodiversity. *Trends in Ecology and Evolution, 16*(11), 591-593.

StatisticsSweden. (2010). Annual Energy Balances. Retrieved May 1, 2010, from http://www.scb.se/Pages/TableAndChart____24657.aspx#Fotnoter

SVEBIO. (2004). Wood fuels. *Focus Bioenergy* Retrieved March 13, 2010.

The National Forest Holding. (2005). *Annual report 2005*. Warsaw, Poland

The Polish Economic Chamber of Renewable Energy, (n.d.). About the Chamber. Retrieved May 7, 2010, from http://www.pigeo.org.pl/index.php?lang=EN

The State Forests Information Center. (2006). *Forests in Poland 2006*. Warsaw, Poland.

United States Nuclear Regulatory Commission (USNRC) (2009). Backgrounder on the Three Mile Island Accident. Retrieved March 24, 2010, from http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

Vasaitis, R., Stenlid, J., Thomsen, I. M., Barklund, P., & Dahlberg, A. (2008). Stump removal to control root rot in forest stands. A literature study. *Silva Fennica, 42*(3), 457–483.

Vattenfall. (2010). Research and development. Retrieved May 19, 2010, from http://www.vattenfall.com/en/research-and-development.htm

Verdonk, M., Dieperink, C., & Faaij, A. P. C. (2007). Governance of the emerging bio-energy markets. *Energy Policy, 35*(7), 3909-3909.

Voytenko, Y., Israilava, A., & Peck, P. (2009). *Bioenergy co-benefits in Ukraine and Belarus: realities on the ground.* Paper presented at the 17th European Biomass Conference & Exhibition: From Research to Industry and Markets, Hamburg, Germany.

Walmsley, J. D., Jones, D. L., Reynolds, B., Price, M. H., & Healey, J. R. (2009). Whole tree harvesting can reduce second rotation forest productivity. *Forest Ecology and Management, 257*(3), 1104-1111.

Wikipedia. (2010a). IKEA. Retrieved May 13, 2010, from http://en.wikipedia.org/wiki/IKEA

Wikipedia. (2010b). Poland. Retrieved April 22, 2010, from http://en.wikipedia.org/wiki/Poland

World Resources Institute. (2003). Energy and resources-Sweden [Electronic Version]. *Earth Trends*. Retrieved 27 January 2010 from http://earthtrends.wri.org/pdf_library/cp/ene_cou_752.pdf.

Appendix I

List of interviewed people in Sweden:

1. Håkan Rosenqvist, PhD, professor and researcher at the Lund University. Telephone interview. February 24, 2010.

2. Thomas B. Johansson, PhD, former president of the International Industrial Institute for Environmental Economics, Lund University. Personal interview. March 4, 2010.

3. Hans Nordström, expert on biofuel at Vattenfall AB Nordic Heat. Personal interview. March 18, 2010.

4. Peter Staland, Msc, energy expert at the Swedish Federation of Forest Owners. Personal interview. March 18, 2010.

5. Lars Erik Axelsson, Energy Director at the Forestry Industry Association. Personal interview. March 18, 2010.

6. Jonas Höglund, Biologist and Forester at the Swedish Bioenergy Association (SVEBIO). Personal interview. March 19, 2010.

7. Kjell Anderson, Information Secretary at the Swedish Bioenergy Association (SVEBIO). Personal interview. March 19, 2010.

8. Matti Parikka, PhD, Project Manager at the Swedish Energy Agency (SEA). Personal interview. March 19, 2010.

9. Anders Bruks, owner and CEO of the AllanBruks AB Company. Telephone interview. March 30, 2010.

10. Johan Saltin, PhD, Project and Business Manager at the VEAB AB Company, Växjö. Personal interview. April 17, 2010.

11. Rolf Bjorheden, PhD, leader of the research program dealing with system and technical development of forest based energy at the Forest Research Institute (Skogforsk). Telephone interview. April 20, 2010.

List of interviewed people in Poland:

1. Marzena Rutkowska-Filipczak, specialist at the Institute for Fuels and Renewable Energy. Personal interview. April 6, 2010.

2. Jozef Neterowicz, expert on renewable energy, Association of Polish Counties. Personal interview. April 7, 2010.

3. Mikolaj Rudawski, Energy Resource Purchasing Manager at the Stora Enso Timber. Personal interview. April 8, 2010.

4. Marcin Pisarek, Business Analyst, Vattenfall Warsaw, Poland. Personal interview. April 9, 2010.

5. Mikolaj Czajkowski, Assistant Professor, Center for Ecological Economics, Department of Economics,University of Warsaw. Personal Interview. April 9, 2010.

6. Henryk Pyrka, Polish Chamber of Biomass, Office Director. Personal interview. April 9, 2010.

7. Malgorzata Bastian, Specialist, Baltic Energy Conservation Energy. Personal interview. April 12, 2010.

8. Adam Rajewski, Assistant Lecturer, Institute of Heat Engineering, Faculty of Power and Aeronautical Engineering, Warsaw University of Technology. Personal interview. April 13, 2010.

9. Krystof Jablonski, Adjunct Teacher, Department of Forest technology, Faculty of Forestry, Poznan University Of Life Sciences. Telephone interview. April 19, 2010.

10. Dr. Krzysztof Jodłowski, research worker, Department of Forest Resources, Forest Research Institute. E-mail questionnaire. May 20, 2010.