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SOLID WOOD-BASED FUELS IN ENERGY PRODUCTION IN FINLAND

Masters' thesis

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Political incentives often have a central role in bioenergy production. Influence of these incentives is expected to increase, because conventional fossil fuels are draining and the climate change forces policy makers to react. Hence, the demand for biofuels is also expected to grow. Wood-based fuels are the most important biofuel and renewable energy source in Finland. Wood-based fuels are almost equally divided into liquid by-products of the pulp industry and solid wood-based fuels. This study focuses on solid wood-based fuels, because these solid fuels have markets unlike e.g. black liquor and because these shares increase. In this study, the solid wood-based fuels include forest chips, bark, sawdust, industrial chips, recycled wood and pellets.

One aim of the study is to formulate a general view of the Finnish wood-based fuel markets. The demand is analysed by using the statistics of The Finnish Forest Research Institute (Metla) and the supply by using existing literature. Metla compiles statistics about the utilization of wood-based fuels from over 700 energy facilities, comparing several categories of wood-based fuels. This study overwiews the period from 2003 to 2007. Energy facilities are divided into four different so that the specifics of the demand can be identified.

Another aim of the thesis is to study the impact of emissions trading on wood-based fuel utilization. Emissions trading is the most important instrument for improving the competitive advantage of renewable energy production for energy facilities that belong to the scheme, producing heat or electricity with over 20 MW nominal effect. The growth in the credit price of co_2 emissions increases the demand for biofuels and reduces the demand for fossil fuel in energy facilities of over 20 MW. Empirical analysis are carried out for different energy facility categories. Large community facilities are more sensitive to the changes of credit price than the forest industry`s plants. Energy facilities with 5-20 MW nominal capacities reduce the wood-based fuel utilization, when the credit price rises. This flux diminishes the effect of the emissions trading. On the other hand, it seems that changes in credit price do not affect the wood-based fuel consumption in energy facilities of less than 5 MW.

The utilization of wood-based fuels will change due to the stuctural changes in the forest industry. The production of by-products, such as bark, decreases with diminishing quantaties of traditional forest industry products. If the increasing demand was met, forest chip utilization should be added. However, especially the restriction of production in the sawmill industry decreases the supply of harvesting residues chip and forest chip production shifts more towards energy wood thinning. Also, the use of wood-based fuels among different energy facilities is changing. The utilization of wood-based fuels has traditionally been centralized in the forest industry units using industrial by-products. Nowadays, it is also an important energy source for the energy production facilities of the communities due to different policy instruments. This has affected that the trade of wood-based fuels has increased.

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Tiivistelmä – Referat – Abstract

Poliittiset kannustimet ovat usein keskeisiä bioenergian kilpailukyvylle. Bioenergian tuotantoa tukevien kannustimien merkityksen odotetaan lisääntyvän tulevaisuudessa, koska esimerkiksi fossiilisten polttoaineiden ehtyminen ja ilmaston lämpeäminen kannustavat päättäjiä entistä voimakkaampiin tukitoimiin. Näin myös biopolttoaineiden kysynnän odotetaan kasvavan. Puupolttoaineet ovat tärkein Siomessa käytettävä biopolttoaine ja uusiutuvan energian muoto. Puupolttoaineet jakautuvat määrällisesti lähes tasan selluteollisuuden jäteliemiin ja kiinteisiin puupolttoaineisiin. Tämä tutkimus keskittyy kiinteisiin puupolttoaineisiin, koska jäteliemillä ei ole markkinoita ja niiden osuuden odotetaan pienenevän. Kiinteillä puupolttoaineilla tarkoitetaan tutkimuksessa metsähaketta, kuorta, sahanpurua, teollista haketta, kierrätyspuuta ja pellettejä.

Tutkimuksen tavoitteena on muodostaa kokonaiskuva suomalaisista puupolttoainemarkkinoista. Kysynnän ja käytön analyysi perustuu Metlan keräämään aineistoon ja tarjonta analyysi olemassa olevaan kirjallisuuteen. Metla tilastoi vuosittain yli 700 lämpö- ja voimalaitoksen puupolttoaineiden käyttöä, jossa erotellaan eri kiinteät puupolttoaineet toisistaan. Tutkimuksessa tarkastellaan puupolttoaineiden käyttöä vuosina 2003-2007. Tutkimuksessa puupolttoaineita käyttävät laitokset jaetaan neljään ryhmään, jotta kysynnän erityispiirteet eri ryhmien välillä voidaan tunnistaa.

Toinen tutkimuksen tavoite on tarkastella päästökaupan vaikutusta puupolttoaineen käyttöön. Päästökauppa on tärkein uusiutuvan energian kilpailukykyä parantava kannustin päästökaupan piiriin kuuluville yli 20 MW:n laitoksille. Päästöoikeuden hinnan nousu kasvattaa biopolttoaineiden kysyntää ja vähentää fossiilisten polttoaineiden kysyntää laitoksissa, jotka kuuluvat päästökaupan piiriin. Päästökaupan vaikutusten tarkastelu tehdään tutkimuksessa eri puupolttoaineille ja eri laitosryhmille. Aineiston perusteella huomataan, että korkea päästöoikeuden hinta kasvattaa puupolttoaineiden käyttöä enemmän yhdyskuntien kuin metsäteollisuuden suurissa voimalaitoksissa. Korkea päästöoikeuden hinta puolestaan vähentää puupolttoaineiden käyttöä keskisuurissa voimalaitosissa, mikä vähentää päästökaupan tehoa. Päästöoikeuden hinnan muutokset eivät vaikuta pieninpien laitosten puupolttoaineiden käyttöön, mikä voi johtua esimerkiksi laitosten polttoteknologiasta.

Puupolttoaineiden käyttö tulee muuttumaan metsäteollisuuden rakennemuutoksen seurauksena. Metsäteollisuuden tuotteiden tuotantomäärien pinentyessä myös kuoren ja muiden sivutuotteiden määrät vähenevät. Puupolttoaineiden käytön kasvattaminen edellyttää metsähakkeen käytön lisäämistä. Kuitenkin erityisesti mekaanisen metsäteollisuuden tuotannon supistuminen vähentää päätehakkuiden määrää, jolloin metsähakkeen tuotannon kasvu painottuu harvennuksiin. Puupolttoaineiden käyttö muuttuu myös eri laitosryhmien välillä. Perinteisesti metsäteollisuus on hyödyntänyt prosessiensa sivutuotteena syntyvät sivutuotteet energiaksi vastaten lähes kokonaan puupolttoaineiden hyödyntämisestä. Nykyisin puupolttoaineiden käyttö on levinnyt yleisesti yhdyskuntien energiantuotantoon, jolloin puupolttoaineiden kauppa ja kysyntä on kasvanut.

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1 INTRODUCTION

1.1 Biomass in energy production

Availability and prices of energy have a central role in the development of the world economy. Changes in energy costs in industrial production and transportation have remarkable effects on economic growth in many countries (FAO 2008). Currently, an increasing trend in energy prices has boosted the interest of bioenergy in Finland and all over the world. Many countries are searching for alternative sources of energy to complete their energy base. Biomass has the potential of becoming one of the major energy sources during the next 100 years (Berndes et al. 2002).

The reasons for increasing utilization of biomass in energy production globally are fear of depletion of fossil fuels, environmental concerns, such as global climate change, and a surplus of agricultural land (Lundmark 2006). Increased utilization of forest biomass can improve also the profitability of the forestry sector. Karttunen (2006) found out that it is more profitable to include energy wood harvesting into the forest management scheme at the present subsidy level in Finland, when the price of market allowance for CO_2 emissions is higher than 15 euros (€) per ton. Aarnos et al. (2007) reviewed several authors that have forecasted that the allowance price will stay above €20 per tons of carbon dioxide (tCO_2) during 2008-2012. Additionally, Kara et al. (2008) estimates that the probable price is €10-20/tCO_2 during the same period. Current forest management recommendations do not include energy wood thinning. However, an increasing land area for bioenergy production is seen to improve rural conditions and employment, particularly in Finland (Antikainen et al. 2007). Domestic bioenergy production also reduces the dependency of the foreign energy import, thus it improves energy security. Hetemäki et al. (2006) sum up that the price development of fossil fuels, as well as energy and climate policies are the reasons for increased bioenergy utilization.

The future of bioenergy and its scale of utilisation are largely dependent on public policy. Particularly, investments in bioenergy require public subsidies (FAO 2008).

The European Union (EU) has a common bioenergy policy, but European countries have independent policy instruments of their own, which vary significantly. For example, feed-in policy instruments that are effective to reduce investment risks are used in Germany, Spain, Estonia and Lithuania, while their levels and applications vary greatly. Within the Nordic countries, Sweden has a green certificate system, which is another instrument to support the competitiveness of bioenergy. Finnish policy is considered more closely in Section 3.6. Without such a public support, market forces would create only limited applications for bioenergy production (Menanteau et al. 2003).

The EU has traced many major decisions about its energy and climate policy that concern bioenergy during the last ten years. For example, the EU set new political energy goals in the spring of 2008. According to the goals, the share of renewable energy should average 20% of the primary energy consumption in member countries by 2020. Wind energy, solar power, geothermal energy, hydropower, ocean energy and bioenergy are included in renewable energy production (EREC). The goal is not equally divided among member countries. Every country has an individual objective, because national conditions, starting points and biomass resources vary much among them. The EU has observed the Finnish conditions and obliges that Finland raise the share of renewable energy from approximately 25% to 38% (Statistics Finland). The most important renewable energy source is biomass, with over 80% of the share in Finland in 2006 (Pöyry 2007). The overall share of biomass in renewable energy production is about two-thirds in all of Europe (Toivonen et al. 2000).

Emissions trading is another remarkable political decision related to bioenergy in the European Union. Emissions trading is a cost-efficient policy instrument to achieve reductions in the emissions of pollutants. In the European Union Emission Trading Scheme (EU ETS), the European Commission approves all National Allocation Plans for every country, covering the overall CO_2 emission amount of each country. National authorities in each country allocate initial emission credits to industrial units, which are included into the scheme. The European Union's common target for greenhouse gases reduction is 20% by 2020, if the reduction is unilaterally made by EU. It is engaged to increase the target to 30%, if other developed countries and more advanced developing countries also commit themselves to emission reductions

(EC 2008). Chapter 3 discusses the economic theory that is related to the emission trading. This theory forms the theoretical framework in this study.

Because of significant forest resources, wood-based energy production is a natural way to respond the regulated policy in Finland. According to Hakkila (2006), Sweden and Finland stand as technological forerunners for the forest fuel utilization. Finland has undertaken to increase wood-based bioenergy production in many energy and forest policy decisions. For example, forest fuels have a major role in the latest National Forest Program 2015. One objective of the program is increase the utilization of forest chips to 8-12 million meters cubed (m^3) annually. According to Fagerblom et al. (2007), a level of 9 million m^3 of forest chips would raise the Finnish share of renewable energy by 3% if other energy conditions remain constant. The former National Forest Program 2010 set a goal to achieve a level of 5 million m^3 in the use of forest chips by 2010.

1.2 Energy substitution

Energy substitution of biofuels refers to organic biomass as a substitute for conventional fossil fuels in energy production. Energy production produces negative externalities in fuel combustion, which are composed of, for example, carbon dioxide, sulphur dioxide and nitrous emissions. A sustainable energy source, harvested biomass is considered to be carbon neutral. Biomass substitutes for fossil fuels reduce the emergence of negative externalities in energy production, making the energy substitution of biofuels favourable. For example, due strong incentives, even pulpwood is often allocated to the energy production in Central Europe (Rintala et al. 2007). Because different fossil fuels produce CO_2 emission differently, they have their own emission coefficients in the emission trading scheme. That coefficient illustrates how rewarding the substitution is in the scheme.

Even though all biofuels are considered to be carbon neutral, the production chain of biofuels causes some emissions. Wood-based fuels have a better greenhouse gas balance than agricultural crops in bioenergy production, because their production does not consume as much energy. Energy wood also offers an advantage over many agricultural crops from the producer’s point of view, because the harvest time can be chosen according to price fluctuations (FAO 2008 s. 31).

Also, sulphur dioxide and nitrous emissions lessen when wood-based fuels are substituted for fossil fuels (Hyvönen 2007). Externalities form one reason, which justifies public interventions in socio-economic thinking. Menanteau et al. (2003) say that public intervention to increase renewable energy production is justified, because the externalities restrain markets from achieving the best allocation from the society's point of view. They also mention that renewable energy technologies are often quite immature, which offer a competitive advantage for fossil fuels and nuclear energy. However, the level of policy interventions should be quantified correctly and energy wood subsidies should not affect the pulp and logwood markets, nor the traditional forest industry in general.

Wood-based fuels are recognized as the most important bioenergy source in Finland. As it is earlier mentioned, many political comments propose the increase of wood based fuel utilization. The use of forest chips has grown rapidly in energy production in Finland during the last decade. The growth has developed mainly due to cofiring of peat and forest chips. The cofiring of coal and biomass is considered as one of the most efficient ways to reduce the carbon dioxide emissions and increase biofuels use in energy production (Baxter 2005). The cofiring does not require large investments and therefore can often be a cost-efficient activity (Hillring 2003). The suitable proportion of biomass blended with other fuel depends on the boiler technology, but Kjellström et al. (2005) state that on average, the share of 15% of the total input can be reached with minor technical modifications. In some cases, biofuels and conventional fossil fuels can be complements with each other (Hakkila 2006).

Generally speaking, bioenergy is not an adequate solution to problems in energy production in the future, nor will it not replace fossil fuels completely. However, there is a lot of potential in increasing biomass use in parallel with fossil fuels in many countries (FAO 2008). There is need for many different policy instruments to mitigate the climate change, because none of the existing ones can prevent it alone.

1.3 The aim of the study

The objective of this study is to present an overview of the features of wood-based fuels in Finnish energy production. The features are composed of the utilization and the supply for different wood-based fuels. The heterogeneity of wood based fuels makes this study challenging. For example, the procurement chain and quality of forest chips differ from those of bark significantly, which affect their utilization. There is also a remarkable difference in the demand and supply of forest chip between different areas in Finland (Pöyry 2006). Because of relatively low energy content, long transportation distances are not economically feasible.

The approach of this study is descriptive. The Finnish Forest research Institute (Metla) has collected forest energy information since 2000 and has a valuable database about the utilization of wood-based fuels including forest chips and industrial by-products. This thesis divides energy facilities into different categories and forms the database in a panel form. The panel form allows better time horizon review and the division enables the identification of different market behaviour between energy facilities.

This study focuses on both the demand and supply of wood based fuels. Understanding the wood-based fuel market is important not only for industry, but also for efficient policies. Tromborg et al. (2008) say that understanding the market place, supply, demand and trade are essential for developing efficient policies. The wood-based fuel utilization, and bioenergy production in general, is an issue in which the significance of policy analysis is emphasized. In further studies, basic market knowledge is essential for developing models that illustrate this subject in a more sophisticated manner. These models could be used, for example, in different policy analyses.

The study pays particular attention to the effect of emissions trading on wood-based fuel utilization. Public policy has often a major role in biofuel utilization. Because this study divides the energy facilities into different groups, it enables an analysis of how the emissions trading affects the wood based fuel utilization within different groups. The time period of the panel data is from 2003 to 2007. This period provides an advantageous opportunity to study the effect of the emissions trading, because the emissions trading scheme was launched in 2005 and the price of the allowance collapsed in 2007. Also other political incentives, such as subsidies to sustainable forest management (so called "Kemera" subsidies) and investment subsidies, are introduced in this thesis, but the time period is not suited to reviewing their effects.

1.4 Structure of the paper

The structure of this study is organized as follows: chapter 2 contains a review of earlier studies dealing with wood-based fuel utilization in Finland and forest fuel supply. The supply studies are particularly notable, because Pöyry (2007) predicts that the supply constricts the growth in the wood-based fuel utilization. It also raises a concept of modelling the energy wood supply from the forest economic approach. Chapter 3 presents a theoretic framework for this study. It involves general background information about emissions trading. It also illustrates analytically how emissions trading increases the demand for biofuels, such as wood-based fuels.

Chapters 4 and 5 are mostly based on the analysis of the Metla's database. Chapter 4 discusses the current state of wood-based fuels in Finland. At first, it presents different sources of wood-based fuels and their utilization quantities. The chapter also discusses the supply and demand for wood-based fuels. The chapter deals also with the cost structure of forest chips, because the magnitude of forest chip utilization is predicted to grow. Chapter 5 considers the effect of the emissions trading on the wood-based fuel utilization. It also presents other political incentives related to the topic.

The last chapter of this thesis sums up the conclusions. The discussion focuses on to the future of wood-based fuels and how the structural change in the forest industry will affect it.

2 REVIEW OF EARLIER STUDIES

2.1 Recent studies about wood-based fuels in Finland

Hakkila (2006) presents an overview of the current state and prediction of Finnish wood-based fuels, focusing on forest chips. The overview includes the review of political incentives related to wood-based fuels and other factors driving the development of forest energy. The study concludes that many problems have been solved in relation to forest chip practices. The study states that if the progress continues, the target of 5 million m^3 of forest chip utilization can be attained by 2010. Ericsson et al. (2004) present also an overview of bioenergy policies in Finland and Sweden. They conclude that both countries have not fully utilized their biomass resources and the infrastructure in energy production is able to increase biomass use if, for example, new policy instruments are introduced. Both studies deal with the period before the emissions trading, which currently is the most important political incentive for increasing the wood-based fuel consumption.

Consulting company Pöyry has published two public reports about wood-based fuels in Finland recently. These studies focus on modelling the equilibrium between the demand and the supply by studying both of them. The first one, conducted for the Ministry of Agriculture and Forests in 2006, discusses only forest chips. The second report, conducted for the Ministry of Employment and the Economy in 2007, covers the wood-based fuels more extensively. Chapter 4 discusses these studies in more detail, because they form the basis of the supply assumptions in this thesis. These studies form regional equilibriums related to wood-based fuel markets, but do not analyze the use of wood-based fuels in more detail.

Pöyry (2007) predicts that demand for wood-based fuels is increasing and the supply constricts the growth in the wood-based fuel utilization in near future. It warrants a closer study of the wood-based fuel supply. However, this thesis focuses more on the demand side. By studying the demand for wood-based fuels, it is possible to estimate how likely it is that Pöyry´s predicted scenario will be realized.

2.2 Bioenergy studies in Scandinavia and in the USA

Energy production related to wood based fuels has been studied also elsewhere. Hillring (2006) states that the interest for increasing wood-based fuels utilization will expand when the Kyoto Agreement and its instruments has been introduced. He also finds out that the instruments enhance the demand for wood-based fuels especially outside the forest product industry that has traditionally utilized wood-based residues for energy purposes.

The most popular research subject deals with wood-based fuel resources in the literature of bioenergy. The most common purpose of these studies has been to estimate the state of bioenergy in energy markets in the future (Lundmark 2006). Berndes et al. (2003) review in their study 17 different biomass supply studies and note that the studies can broadly be divided into two different approaches. Studies either discuss the potential availability of biomass resources or the competitiveness of biomass in energy production from the user's point of view. Bjornstad (2004) says that the most considerable weakness of the resource-focusing approach is that they do not pay attention to the cost structure. However, Berndes et al. (2003) conclude in their review of comparing studies that the future bioenergy production may multiply tenfold from the current level globally.

There have been a couple of studies focusing on demand and supply in Scandinavia. Scandinavian studies are interesting because the operational environment is similar in Finland. Studies have been conducted from an engineering economic approach, in which harvesting cost functions have been developed (Lundmark 2006, Bjornstad 2005). Lundmark (2006) forms the cost function for harvesting residues and round wood separately. The functions are compounded of cutting, forwarding, chipping, road transportation, and overhead costs. The base of this method is that a marginal cost function is equivalent to a supply function. The marginal cost function is the derivative of the total cost function with respect to harvested quantity. Lundmark (2006) estimated that there are approximately 12 TWh of economically untapped quantity of harvesting residues in Sweden. After that, round wood becomes a cheaper alternative for energy production. The most important result of this study is that from an economic perspective, the unutilized forest energy resources have been overestimated in earlier studies.

North America is another geographical area whose bioenergy studies are reasonably relevant from the Finnish point of view. Structural change in the forest industry has developed further in the USA and Canada than in Finland. The structural changes affect the wood-based fuel utilization. The structural change converts traditional forest industry into the new form and adjusts production quantities to the lower level. For example Gan and Smith (2007) review consequences of the structural change in Texas. Six large and thirteen small sawmills, five plywood mills, and three pulp and paper mills have closed because of overcapacity between 1982 and 2003. That adjustment affects the timber markets. Mayfield et al. (2007) say that the downturn in the pulp wood market affects forestry remarkably. The stumpage price declined by 26% for pine saw logs and 65% for pulpwood in Texas during 1998 to 2001.

According to the Energy Information Administration (EIA), bioenergy covers about 53% of renewable energy consumption in USA in 2007. The share of wood-based fuels is about 30% from bioenergy production and has been quite stable during this decade. According to Hazel and Bardon (2008), forest industry by-products are the most important wood-based fuel in the USA, but future woody biomass energy markets will have to be based largely on forest chips. The potential of harvesting residues in energy production have also piqued among researchers in the USA, even though literature dealing with it is still rare (Gan and Smith 2006b).

Gan and Smith (2006b) studied the potential of harvesting residues in energy production in the USA. They concluded that recoverable logging residues could generate 67.5 terawatt hours (TWh) of electricity annually, which would displace approximately 3% of total carbon emission from the US electricity sector. They also found out that the cost of this displacement would range from €10.7 to €14.3 per tonne of carbon dioxide ($\times t^{-1} CO_2$). This cost also means that if there was an emissions trading system in the USA and the price of credit was over that, it would be cost-efficient to use that amount of logging residues for electricity production. After that study, Gan (2007) developed a supply curve for logging residues based on farm gate costs and transportation costs, in other words, from the engineering economics approach. Also, Walsh (2008) uses approach in her study. Figure 1 presents the draft of the results. The supply includes harvesting residues and other residues, such as energy wood from pre-commercial thinning or timberland clearing because of urban development.

Mayfield et al. (2007) studied opportunities, barriers and strategies for forest bioenergy and discovered that more collaboration is needed with energy and forest industries. Gan and Smith (2007) found that forest biomass is not cost-competitive with fossil fuels in the USA. They state that it would be competitive if environmental and socio-economic benefits and costs were taking into account. Thus, justified and correct policy instruments could shift the competitiveness. Also, energy wood procurement is associated to the mitigation of wildfire risks, which is serious concern in many areas (Graham et al. 2002). On the other hand, Hazel and Bardon (2008) note that energy facilities could realize a remarkable cost savings in energy production when they are using also wood-based fuels. For example, they conclude that small-scale community power plants could be most potential to increase forest chips utilization in North Carolina possibly other states.

2.3 The relation between bioenergy studies and forest economic approaches

Energy wood is an essential part of industrial wood growth in forests. Additionally, forest management decisions of energy wood and industrial wood cannot usually be separated from each other. The harvesting residue and stump chip production offer additional parts for final felling. Energy wood thinning is mostly a silvicultural operation from the forest owners' point of view, which improves the growing conditions of stand (Pöyry 2006). On the other hand, economical and silvicultural operations can also intersect. Stump chip production can also be seen as soil preparation or a prevention of stump mycosis. Energy wood procurement from young stands can be seen as an act that increasing amenity values. These interactions and their impacts on the wood-based fuel utilization will be considered more closely in Discussion section.

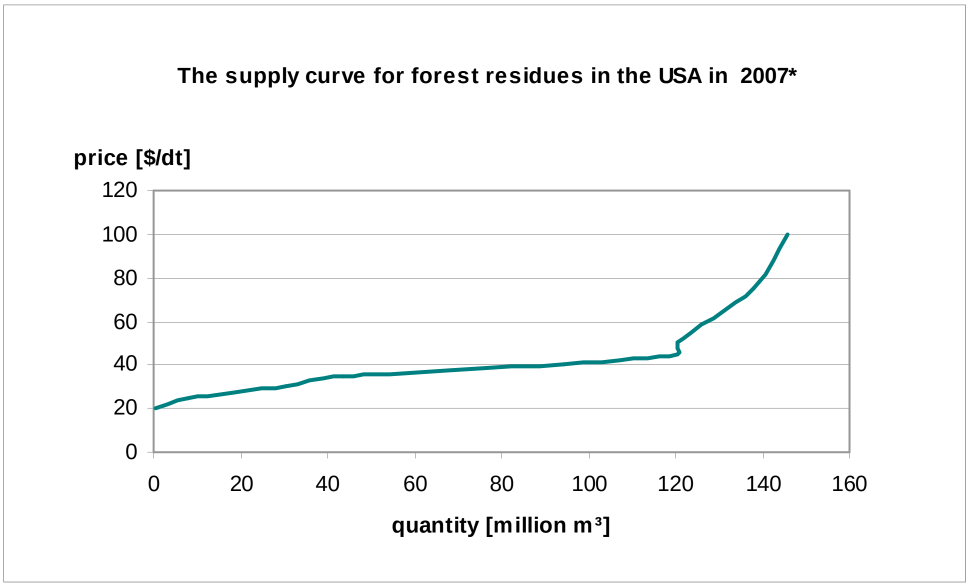

Figure 1. The supply curve for forest residues in the USA in 2007. Modified from the source Walsh 2008.

However, the methods and approaches of the industrial wood supply studies are in contrast to the methods and approaches of bioenergy studies. One important fact is that 70% of Finnish timber stock is owned by non-industrial private forest (NIPF) owners (VMI 10). The implementation of forest management and harvesting activities is depending on the utility of forest owners. The utility that NIPF owners get from their forests differ from industrial forest owners. These resource or demand focusing approaches of the energy wood supply studies do not take non-monetary amenity values into account, even though they are important in a forest owners` decision making process. Finnish forest owners are not typically economically dependent on their forest property, which emphasizes the effect of amenity values. Because of this, it would be a more reliable method to model the energy wood supply by using forest economics models that model forest owners` behaviour more realistically, including amenity values.

Describing and forecasting NIPF owners’ behaviour constitute a complex and difficult task. The behaviour relates to economical and biological questions of forest land and the objectives of each individual NIPF owner. NIPF owners are a heterogeneous group, because the size of the forest stand, age, educational background, occupation and other factors all affect forest management behavior (Hänninen et al. 2006). Rämö et al. (2001) notice also that the size of the forest property improves the attitude towards the energy wood supply among forest owners. Thus, a forest owner’s characteristics relate to the industrial timber supply and consequently affect the energy wood supply both directly and indirectly.

According to Ollikainen (1999), industrial roundwood supply has been traditionally modelled by using either the Faustman's rotation model or the two-period biomass harvesting model in the forest economic literature. According to Favada et al. (2007), utility-based rotation models have more or less replaced the two-period biomass harvesting model in the forest economic studies in Nordic countries. The main purpose of these studies has been to model market behaviour and develop a supply function. Berndes et al. (2003) say that in an economic sense, the term ‘potential’ is equivalent to a supply curve. Thus, all these approaches try to find a similar final result, which is to develop a supply function.

Different industrial timber assortments are often separated in forest economic studies. It is justified to assume that also energy wood could be treated in these studies as a third timber assortment.

2.4 Literature on effects of emissions trading

Empirical studies of the EU CO_2 emissions trading are still rare. Kara et al. (2008) study the impacts of the emissions trading on electricity markets, but that study only briefly discusses wood-based fuel utilization. The study concluded that the emissions trading evokes a competitive advantage to renewable energy, for example bioenergy production, but does not speed up investment decisions about new energy facilities in the short run.

3 THEORETHICAL FRAMEWORK

3.1 The emissions trading

In the European Union emissions trading, companies and other parties which belong to the system are issued emission permits. They are required to hold an equivalent number of credits, which represent the right to pollute a given amount. Companies or groups which need to increase their emissions have to buy more of those credits from a party which has an excess surplus of them. A market-based cost of carbon dioxide is formed and those parties that can reduce their emissions are rewarded. In theory, the reduction of emissions is made there where it is economically best to do so, thus the cost of the reduction is developed as the lowest possible cost to society.

Bioenergy is one way to reduce carbon dioxide emissions, because it is considered carbon neutral. Therefore, the emissions trading system has raised energy producers` ability to buy biofuels and, consequently, it has increased the demand for biomass (EU 2007). Additionally, the mechanism channels the utilization of bioenergy to the countries in which it is cheapest. An analytic example, presented next, demonstrates how the price of an emission credit affects the demand for different fuels.

3.2 Analytical example

3.2.1 Implicit model

Following Uusivuori (2008), an energy producer's profit maximization problem can be modelled as follows. Assume that a descriptive energy producer has two inputs: a fossil fuel and renewable biofuel. The Biofuel is considered a carbon neutral raw material, thus the emissions, *E*, from energy production is formed only from the usage of fossil fuels. The producer belongs to the emissions trading scheme and has received permitted amount of emissions, $\bar{e}$.

The energy producer maximizes its profits though the following profit maximization problem, where a profit function is concave and a cost function is convex:

$$\underset{x_b, x_f}{MAX}\, \pi = p\eta(x_b + x_f) - c(x_b, x_f) - p_{CO_2}(\varepsilon_f x_f - \bar{e})$$

$$= \underset{x_b, x_f}{MAX}\, \pi = p\eta x_b + p\eta x_f - c(x_b, x_f) - p_{CO_2}\varepsilon_f x_f + p_{CO_2}\bar{e} \qquad (1)$$

Because of the nature of energy production, the production function is simply assumed to be $\eta(x_b + x_f)$. p is the price of the output. x_b is biofuel input and x_f is fossil fuel input measured in energy unit. η illustrates efficiency that converts input energy into output energy, which is the same for both fuels. $c(x_{b,} x_f)$ is the cost function. p_{co_2} refers to the price of an emission credit and ε_f is the relation of fossil fuel to emissions.

According to Chiang (1984), following conditions should be satisfied for a concave profit function:

$$\frac{\partial \pi(x_b, x_f)}{\partial x_b} < 0, \quad \frac{\partial \pi(x_b, x_f)}{\partial x_f} < 0, \quad \frac{\partial^2 \pi(x_b, x_f)}{\partial x_b^2} < 0, \quad \frac{\partial^2 \pi(x_b, x_f)}{\partial x_f^2} < 0, \quad \pi_{ff}\pi_{bb} > \pi_{bf}^2$$

where π_{bf}, the cross derivative is the following:

$$\frac{\partial^2 \pi(x_b, x_f)}{\partial x_b \partial x_f} = \frac{\partial^2 \pi(x_b, x_f)}{\partial x_f \partial x_b} < 0$$

The first order conditions for profit maximizing are the following:

$$\frac{\partial \pi}{\partial x_f} = p\eta - c_f - p_{co_2}\varepsilon_f = 0 \qquad (2)$$

$$\frac{\partial \pi}{\partial x_b} = p\eta - c_b = 0 \qquad (3)$$

The effect of p_{co_2} on the demand for biofuels remains ambiguous. More information and relevant comparative statistics from the model can be obtained by taking total differentiation and using Cramer's rule. The total differentiation of the first order conditions produces the following:

$$\eta dp + pd\eta - c_{ff} dx_f - c_{fb} dx_b - p_{CO_2} d\varepsilon_f - \varepsilon_f dp_{CO_2} = 0 \tag{4}$$

$$\eta dp + pd\eta - c_{bb} dx_b - c_{bf} dx_f = 0 \tag{5}$$

The direction of the effect of p_{co_2} on the demand for fossil fuels and biofuels can be solved. Assume that $dp = d\varepsilon_f = d\eta = 0$. Note that $\pi_{ff} = -c_{ff}$, $\pi_{bb} = -c_{bb}$, $\pi_{bf} = \pi_{fb} = -c_{bf} = -c_{fb}$

$$\pi_{ff} dx_f + \pi_{fb} dx_b = \varepsilon_f dp_{CO_2} \tag{6}$$

$$\pi_{bb} dx_b + \pi_{bf} dx_f = 0 \tag{7}$$

These equations are divided by dp_{co_2}:

$$\pi_{ff} \frac{dx_f}{dp_{CO_2}} + \pi_{fb} \frac{dx_b}{dp_{CO_2}} = \varepsilon_f \tag{8}$$

$$\pi_{bb} \frac{dx_b}{dp_{CO_2}} + \pi_{bf} \frac{dx_f}{dp_{CO_2}} = 0 \tag{9}$$

and formed into the matrix form:

$$\begin{bmatrix} \pi_{ff} & \pi_{fb} \\ \pi_{bf} & \pi_{bb} \end{bmatrix} \begin{bmatrix} \dfrac{dx_f}{dp_{CO_2}} \\ \dfrac{dx_b}{dp_{CO_2}} \end{bmatrix} = \begin{bmatrix} \varepsilon_f \\ 0 \end{bmatrix} \tag{10}$$

The determinant of Hessian matrix is the following:

$$\Delta = \begin{vmatrix} \pi_{ff} & \pi_{fb} \\ \pi_{bf} & \pi_{bb} \end{vmatrix} = \pi_{ff} \pi_{bb} - \pi_{bf}{}^2 \tag{11}$$

which is positive, due to the defined function forms.

Next, the Cramer´s rule is applied. Solving with Cramer's rule for dx_f / dp_{CO_2} gives

$$\frac{dx_f}{dp_{co_2}} = \frac{\begin{vmatrix} \varepsilon_f & \pi_{bf} \\ 0 & \pi_{bb} \end{vmatrix}}{\Delta} = \frac{\varepsilon_f \pi_{bb}}{\pi_{ff}\pi_{bb} - \pi_{bf}^2} < 0 \tag{12}$$

This implies that p_{co_2} has negative effect on the demand for fossil fuels.

Similarly, solving with Cramer's rule for dx_b / dp_{CO_2} gives

$$\frac{dx_b}{dp_{co_2}} = \frac{\begin{vmatrix} \pi_{ff} & \varepsilon_f \\ \pi_{bf} & 0 \end{vmatrix}}{\Delta} = \frac{-\varepsilon_f \pi_{bf}}{\pi_{ff}\pi_{bb} - \pi_{bf}^2} > 0 \tag{13}$$

if the inputs are substitutes, i.e. $\frac{\partial^2 \pi(x_b, x_f)}{\partial x_b \partial x_f} < 0$. This implies that p_{co_2} has positive effect on the demand for biofuels.

3.2.2 Explicit model

Modifying Uusivuori (2008), the same the profit maximization problem in this given two alternative input model can be model in an explicit form as follows:

$$\underset{x_b, x_f}{MAX}\ \pi = p\eta(x_b + x_f) - w_b x_b - A_b x_b^{\alpha 1} - w_f x_f - A_f x_f^{\alpha 2} + Bx_b x_f - p_{co_2}(\varepsilon_f x_f - \bar{e})$$

(14)

including constraints $\alpha_1 > 1$, $\alpha_2 > 1$, $-1 < B < 1$

The production function is modelled similarly as in the implicit model. The costs of production are composed of three different components: unit fuel prices w_i, transportation costs terms $A_i x_i^{\alpha i}$ and synergy cost term $Bx_i\, x_j$ *. The latter term refers to the effects of e.g. cofiring. *B* is a constant that can have positive or negative values. The positive value means that the two fuels are complements and the negative value that the fuels are substitutes in costs with each other. This will be shown below in expressions 33 and 39. The effect of emissions trading is also modelled similarly as in the implicit model.

The first order conditions of this explicit model are following:

$$\frac{\partial\pi}{\partial x_f} = p\eta \; - w_f - \alpha_1 A_f x_f^{\alpha 1-1} + Bx_b - p_{co_2}\varepsilon_f \; = 0 \tag{15}$$

$$\frac{\partial\pi}{\partial x_b} = p\eta \; - w_b - \alpha_2 A_b x_b^{\alpha 2-1} + Bx_f \; = 0 \tag{16}$$

The demand functions for x_1 and x_2 can be solved from the first order conditions:

$$x_f = \left(\frac{p\eta - w_f - p_{co_2}\varepsilon_f + Bx_b}{\alpha_1 A_f} \right)^{\frac{1}{\alpha 1-1}} \tag{17}$$

$$x_b = \left(\frac{p\eta - w_b + Bx_f}{\alpha_2 A_b} \right)^{\frac{1}{\alpha 2-1}} \tag{18}$$

The demand functions demonstrate that output prices have a positive effect on the demand for the inputs. Fuel prices have a negative effect on the demand for inputs and p_{co_2} has a negative effect on the demand for fossil fuels. Subsidies that support biofuels decrease their fuel cost, and thereby have positive effect on the demand. Similarly, by taking a total differentiation and applying the cramer´s rule relevant information can be obtained.

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* Kangas et al. (2009) model cofiring costs through a parabola cost term - $B\left(\frac{x_2}{x_1 + x_2} - \sigma_2 \right)^2 \left(x_1 + x_2\right)$, where the parameter σ_2 is the technical optimal share of biofuels of the total fuel consumption.

The total differentiation of the first order conditions is the following:

$$pd\eta + \eta dp - dw_f - \left[A_f x_f^{\alpha 1-1} + \alpha_1 A_f x_f^{\alpha 1-1} \ln(\alpha_1 - 1)\right] d\alpha_1 - \left[(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2}\right] dx_f -$$

$$p_{co_2} d\varepsilon_f - \varepsilon_f dp_{co_2} + Bx_f dx_b + x_b dB = 0 \tag{19}$$

$$pd\eta + \eta dp - dw_b - \left[\ A_b x_b^{\alpha 2-1} + \alpha_2 A_b x_b^{\alpha 2-1} \ln(\alpha_2 - 1)\ \right] d\alpha_2 - \left[(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2}\right] dx_b$$

$$+ Bx_b dx_f + x_f dB = 0 \tag{20}$$

The second order conditions:

$$\frac{\partial^2 \pi}{\partial x_f^2} = -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} < 0 \tag{21}$$

$$\frac{\partial^2 \pi}{\partial x_b^2} = -(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2} < 0 \tag{22}$$

$$\frac{\partial^2 \pi(x_b, x_f)}{\partial x_b \partial x_f} = B \tag{23}$$

$$\frac{\partial^2 \pi(x_b, x_f)}{\partial x_f \partial x_b} = B \tag{24}$$

The determinant of Hessian matrix in this explicit model is following:

$$\Delta = \begin{vmatrix} \pi_{x_f x_f} & \pi_{x_f x_b} \\ \pi_{x_f x_b} & \pi_{x_b x_b} \end{vmatrix} = \begin{vmatrix} -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} & B \\ B & -(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2} \end{vmatrix} = \tag{25}$$

$$\left[-(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2}\right]\left[-(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2}\right] - B^2 \ > 0$$

which is positive because of concavity.

Assume that $d\eta = dp = dw_i = dA_i = d\alpha_i = d\varepsilon_f = dB = 0$, which leads to the total differentiation equations:

$$\left[\;-(\alpha_1-1)\alpha_1 A_f x_f^{\alpha 1-2}\;\right]dx_f + Bx_f\,dx_b = \varepsilon_f\,dp_{co_2} \tag{26}$$

$$Bx_b\,dx_f + \left[\;-(\alpha_2-1)\alpha_2 A_b x_b^{\alpha 2-2}\;\right]dx_b = 0 \tag{27}$$

These equations are divided by dp_{co_2} and formed into the matrix form:

$$\begin{bmatrix} \pi_{x_f x_f} & \pi_{x_f x_b} \\ \pi_{x_b x_f} & \pi_{x_b x_b} \end{bmatrix} \begin{bmatrix} \dfrac{dx_f}{dp_{CO_2}} \\ \dfrac{dx_b}{dp_{CO_2}} \end{bmatrix} = \begin{bmatrix} \varepsilon_f \\ 0 \end{bmatrix} \tag{28}$$

Using the adapted specification, the preceding equation can be written:

$$\begin{bmatrix} -(\alpha_1-1)\alpha_1 A_f x_f^{\alpha 1-2} & B \\ B & -(\alpha_2-1)\alpha_2 A_b x_b^{\alpha 2-2} \end{bmatrix} \begin{bmatrix} \dfrac{dx_f}{dp_{CO_2}} \\ \dfrac{dx_b}{dp_{CO_2}} \end{bmatrix} = \begin{bmatrix} \varepsilon_f \\ 0 \end{bmatrix} \tag{29}$$

Using Cramer's rule:

$$\frac{dx_f}{dp_{co_2}} = \frac{\begin{vmatrix} \varepsilon_f & \pi_{x_f x_b} \\ 0 & \pi_{x_b x_b} \end{vmatrix}}{\Delta} = \frac{\begin{vmatrix} \varepsilon_f & B \\ 0 & -(\alpha_2-1)\alpha_2 A_b x_b^{\alpha 2-2} \end{vmatrix}}{\Delta} < 0 \tag{30}$$

$$\frac{dx_f}{dp_{co_2}} = \frac{\varepsilon_f\left(-(\alpha_2-1)\alpha_2 A_b x_b^{\alpha 2-2}\right)}{\left[-(\alpha_1-1)\alpha_f A_1 x_f^{\alpha 1-2}\right]\left[-(\alpha_2-1)\alpha_2 A_b x_b^{\alpha 2-2}\right]-B^2} < 0 \tag{31}$$

The negative outcome illustrates that p_{co_2} has negative effect on the demand for fossil fuels. Cramer´s rule is also used to solve the relation between p_{co_2} and biofuels.

$$\frac{dx_b}{dp_{co_2}} = \frac{\begin{vmatrix} \pi_{x_f x_f} & \varepsilon_f \\ \pi_{x_b x_f} & 0 \end{vmatrix}}{\Delta} \quad = \quad \frac{\begin{vmatrix} -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} & \varepsilon_f \\ B & 0 \end{vmatrix}}{\Delta} \tag{32}$$

$$\frac{dx_b}{dp_{co_2}} = \frac{-\varepsilon_f B}{\left[-(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} + Bx_b\right]\left[-(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2} + Bx_f\right] - B^2} \tag{33}$$

The sign of B determines the effect of p_{co_2} on the demand of biofuels. The negative sign, i.e. fuels are substitutes, determines a positive result, which indicates that an increase in p_{co_2} affects the demand for biofuels positively and vice versa. The synergy parameter can also be positive, due to, for example, the balance of reduced sulphur dioxide emissions and corrosion maintenance costs. (Hakkila (2006) states that peat and wood-based fuels are complements of each other.)

Similarly, the effect of w_f on the demand for biofuels can be solved. Assume that $d\eta = dp = dw_b = dA_i = d\alpha_i = d\varepsilon_f = dB = dp_{co_2} = 0$, which leads to the total differentiation equations:

$$[\ -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2}\ ]dx_f + Bx_f dx_b = dw_f \tag{34}$$

$$Bx_b dx_f + [\ -(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2}\ ]dx_b = 0 \tag{35}$$

The equations are divided by dw_f and formed into the matrix form:

$$\begin{bmatrix} \pi_{x_f x_f} & \pi_{x_f x_b} \\ \pi_{x_b x_f} & \pi_{x_b x_b} \end{bmatrix} \begin{bmatrix} \dfrac{dx_f}{dw_f} \\ \dfrac{dx_b}{dw_f} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{36}$$

$$\begin{bmatrix} -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} & B \\ B & -(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2} \end{bmatrix} \begin{bmatrix} \dfrac{dx_f}{dw_f} \\ \dfrac{dx_b}{dw_f} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{37}$$

Using Cramer's rule:

$$\frac{dx_b}{dw_f} = \frac{\begin{vmatrix} \pi_{x_f x_f} & 1 \\ \pi_{x_b x_f} & 0 \end{vmatrix}}{\Delta} = \frac{\begin{vmatrix} -(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} & 1 \\ B & 0 \end{vmatrix}}{\Delta} \tag{38}$$

$$\frac{dx_b}{dw_f} = \frac{-B}{\left[-(\alpha_1 - 1)\alpha_1 A_f x_f^{\alpha 1-2} + Bx_b\right]\left[-(\alpha_2 - 1)\alpha_2 A_b x_b^{\alpha 2-2} + Bx_f\right] - B^2} \tag{39}$$

Similarly, in the case of allowance price, the sign of B determines the result. When fossil fuels and biofuels are substitutes, the increase in w_1 enhances the demand for biofuels and vice versa.

3.3 Emissions trading in practice

The European Union launched the emissions trading system to mitigate CO_2 emissions in 2005. The first round of emissions trading was performed during 2005-2007. All over, 20 MW energy facilities, the steel industry, the forest industry, the mineral industry and the oil refinery units were included in the trading scheme. The emissions trading and the price of credit have an effect on the prices of fossil fuels. Peat is defined as slowly renewable energy by the EU, but in the emission trading scheme, it is parallel with fossil fuels (Laitila et al. 2008b). Because wood-based fuels are substitutes for peat in Finnish energy facilities, the emissions trading has strong influence on the demand for wood-based fuels in energy facilities which belong to the scheme. The emission coefficient of peat is 0.38 tCO_2/MWh in the emissions trading scheme, which means that when biofuels substitute for peat in energy production, every MWh of produced energy reduces computationally 0.38 a ton of CO_2 emissions (Pöyry 2006).

A relation between peat price and allowance price can be outlined with an equation. Asikainen (2007) calculates a peat price (p_{Peat}) for energy facilities over 20 MW, using equation 40:

$$p_{Peat} = 8{,}5 + 0{,}384 \times p^{CO_2} \text{ €}/MWh \qquad (40)$$

By using equation 29, the price of peat is €20.02/MWh when the allowance price is €30/tCO_2 in power plants over 20 MW. Respectively, when the allowance price is €10/tCO_2 the price of peat is €12.34/MWh. Thus, when the price of the emissions credit is over 30 €, it is profitable to replace peat with forest chips in plants over 20 MW, if the production cost of forest chips are under €20/MWh. Further, in Section 4.5, it will be noted that the production cost of pulpwood for energy purposes are less than €20/MWh. In that case, it would be profitable to substitute pulp wood for peat.

The price of emissions credit affect also forest chip prices for energy facilities which do not belong to the emissions trading scheme. When power plants over 20 MW, considered large plants, are able to pay €20/MWh for forest chips, a smaller unit which operates in the same region, cannot buy forest chips much cheaper than large units from the markets. Large heat and power units can also secure their energy wood procurements with contracts, which reduce the amount of available energy wood for small and medium size energy facilities in the markets (ET Bioenergy 2005). Thus, wood-based fuel prices rise due to emissions trading for small and medium size energy facilities. In that case, the use of peat increases in smaller heat and power plants and the use of forest chips funnels to the large plants. This flux reduces the impact of emissions trading on the climate change mitigation. On the other hand, this mechanism reduces small particle emissions, because large units are equipped with more effective particle separators. Thus, the increased use of forest chips in energy production does not inflict more externalities from small particle emissions.

Hillring (2003) finds out that small energy facilities are often not able to invest in co-firing technology that would allow wide selection of different fuels. Small energy facilities with fixed bed combustion boilers are not always been able to substitute peat for forest chips. This means that the demand for high-quality whole tree chips is not price elastic in small units. It also causes the emissions trading to raise their expenses. It could be warranted to analyze the whole tree chip market separately from other chip forms in further studies.

4 FOREST ENERGY IN FINLAND

4.1 The scheme of wood based fuels

Wood-based biomass is perceived as the most important bioenergy source in Finland and in Europe (Hetemäki et al. 2006, Maidell et al. 2008). Other biofuels such as crop biomass, community, agricultural and industrial organic waste are also utilized, but their quantities are significantly lower.

Wood-based bioenergy can be produced by combusting wood-based fuels in an energy facility, where the energy content can be released. Wood-based biomass can be refined into the chip, pellet or liquid form before releasing its energy content. It can be used straight for energy production by combusting it or it can be refined further before end use. Wood-based fuels can be raw materials of upgraded energy products for a modern biorefinery that produces liquid transportation fuel among other products.

For an energy producer, the source of wood-based fuel is not essential. Only the energy content, price and properties of fuel are significant factors. Flyktman (2004) notices that the moisture content is the most important fuel property. Because of this, it is justified to discuss industrial by-products and pellets among forest chips in this wood-based fuel study, even though the Finnish policies are concentrated on forest chips. This study defines energy wood as the raw material of forest chip.

Figure 2 presents the sources of wood based fuels. It demonstrates that wood-based fuels form a heterogeneous energy source, in which fuel production is often linked with other activities. The production of secondary residues are the linear function of production of forest industry products. Also, primary residues are often dependent on industrial timber procurements, because most of the forest chip procurements are a supplementary part of the final fellings. Considering these interdependencies, without political interferences structural change in the forest industry will reduce the wood-based fuel supply significantly and diminish the utilization of these biofuels.

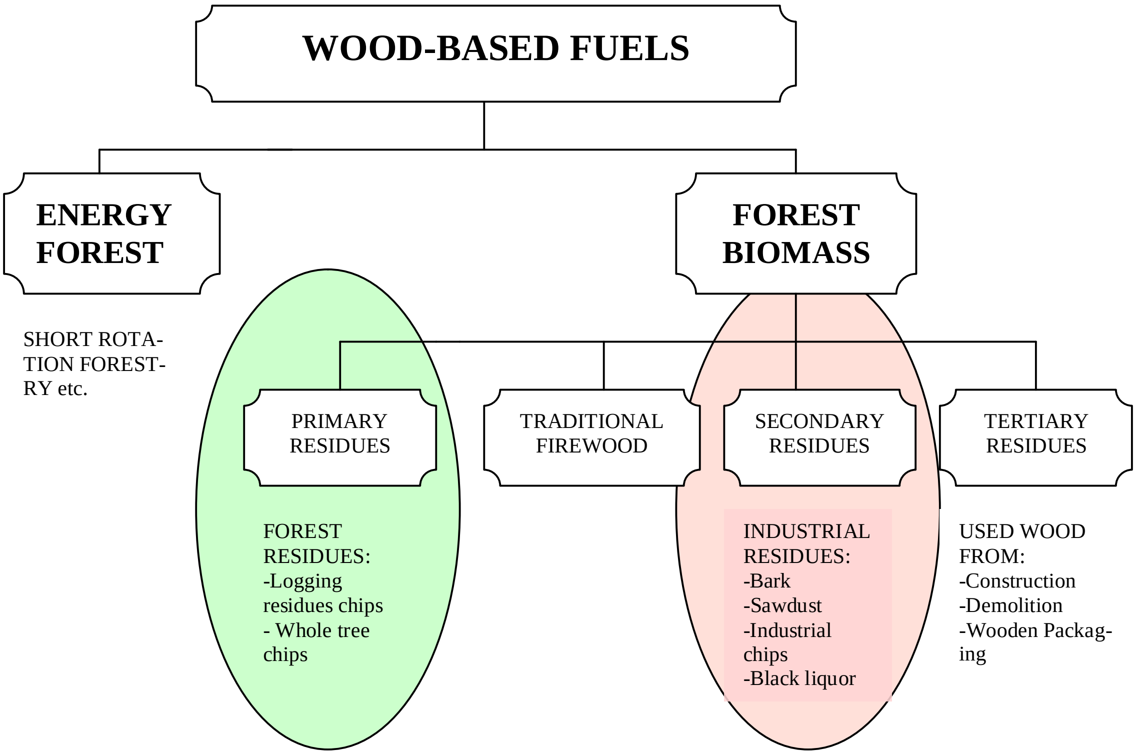


Figure 2. The Scheme of wood-based fuels (Röser et al. 2008). The significance of primary residues increases (green), while the significance of secondary residues diminishes (red).

Pöyry (2007) estimated that wood-based fuels have a 20% share of the overall energy production in Finland in 2006. This 20% is approximately equivalent to 83 TWh per year. The black liquor and other liquid by-products of the pulp industry consist of 51% from wood-based fuels, which is equivalent to over 42 TWh. According to the Metla's statistics, solid wood-based fuels that are combusted in energy plants consist of 34% from wood-based fuels. The energy content of solid fuels was about 28 TWh, in which bark formed 57% and forest chips 21%. The rest of the wood-based fuel utilization, approximately 15%, was composed of traditional firewood.

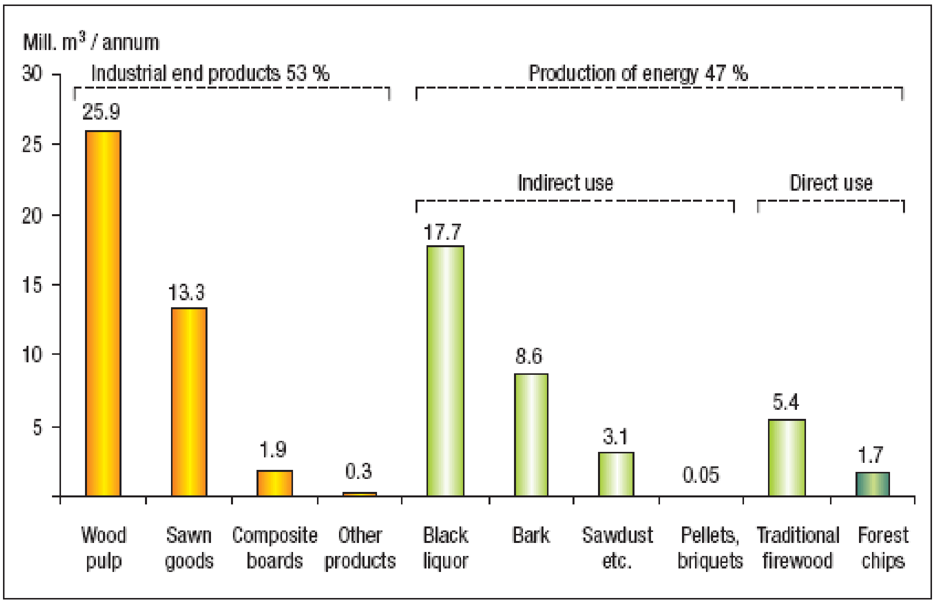


Figure 3. The distribution of the timber consumption in Finland in 2002. (Hakkila 2004)

Figure 3 presents the direct and the indirect use of wood in energy production. Even though the data in this figure are from 2002, the shares of wooden energy sources have been still quite stable despite pressures for change. It is important to notice that 47% of the annual timber consumption ends up in energy production through various means.

This study focuses on solid wood-based fuels, excluding traditional firewood, namely bark, sawdust, pellets and forest chips, as seen in Figure 3. Also, recycled wood is included in this study. These given solid wood-based fuels are tradable and usable in typical energy facilities. Energy facilities that utilize black liquor differ from other boilers, notably in their technology. These energy facilities have another function along with energy production; recovery boilers which distinguish chemicals of the pulp process from the organic material. Chemicals are restored to the process and organic material is burned.

Hetemäki (2006) predicts that the share of forest chips and other solid wood-based fuels will double by 2020, while the amount of liquid residues decreases. This also warrants the restriction to analysing only solid wood-based fuel in this study emphasizing its future importance. Figure 4 presents the prediction of the wood-based energy base in Finland.

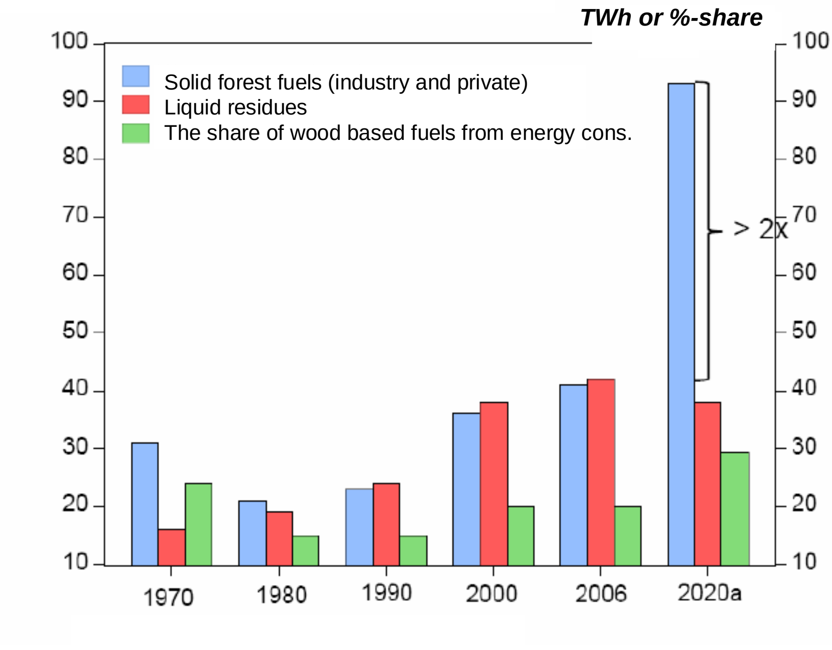


Figure 4. The use and the share of forest fuel in Finland. (Hetemäki 2007).

The share of forest chips is comparatively small in wood-based fuel consumption nowadays, because of the massive forest industry production in Finland. Only 2.7 million m³ of forest chips was utilized in energy production in 2007, which is equivalent to approximately 5.4 TWh. The main reason why energy and forest policies focus on forest chips forcefully is that the utilization of forest chips is increasing rapidly and it has not reached most of its potential yet. Forest industry by-products are fully utilized in Finland, on the other hand, and their utilization is rather declining due to the structural change. The energy and forest industry are also interested in forest chips.

The quality of different wood-based fuels varies significantly. Industrial by-products such as bark, sawdust and industrial chips have their own specific properties. Also, forest chips can be divided into three basic groups depending on their source and properties. The different groups are logging residue chips, whole tree chips from small diameter energy wood and stump chips. Also, an insignificant amount of large timber tree is chipped in Finland, which are attached whole tree chips in this study. Because of the different properties of chip forms, they are inconsistently suited for different end users. According to Asikainen (2007), the best raw material for forest energy would be large timber trees. However, because the energy industry does not have as high capability to pay as the forest industry from wood, industrial wood is allocated for forest industry purposes. The next sections present three different chip forms, the most common industrial by-products and pellets and their qualities briefly.

4.1.1 Logging residue chips

Logging residue chips are produced from branches and treetops of final harvests. According to the Metla database, logging residue chips were the dominant forest chips, forming a share of 57% in energy facilities in 2007. That covers approximately 12% of total solid wood-based fuel consumption. Accumulation rations of logging residue are compared with saw timber accumulation in Table 1. There are remarkable logging residue accumulations, especially in spruce dominant forests.

According to Helynen (2004), the quality of logging residue chips is fluctuating. There are more phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and chlorine (Cl) in needles and slim branches, which can incur problems in combustion. Additionally, the moisture content of logging residue chips vary often remarkably, which reduces the effective energy content of fuel and hinder the controlling property of the combustion process. The moisture content of logging residues is often reduced, for instance, by use of covers on roadside storages.

Logging residue chips can also be produced from commercial thinning residues. However, it is not profitable with current energy prices and harvesting technology, because energy wood accumulation per hectare is much lower than from final fellings. But if forest management practices turned in favor of more commercial thinnings instead of final fellings in the future, energy wood procurements of logging residue chips should expand to there to respond to the demand.

Table 1. Energy wood accumulation in relation to logwood accumulation from final harvests. (Laitila et al. 2008b)

	Pine	Spruce	Broad-leaved trees
Southern Finland	0,21	0,44	0,21
Northern Finland	0,28	0,68	0,36

4.1.2 Whole tree chips from young forests

The term ‘whole tree chips’ refers to chipped biomass from pre-commercial thinning all forms in this study. These pre-commercial thinnings are committed to prevent economic losses in forest stands where the growing rate has already suffered from over thick stands (Fredriksson 2005, p. 126). Sapling management is usually less rigorous than forest management recommendations suggest, or it is totally neglected in these stands (Harstela 2005). The typical accumulation of whole tree chips is approximately 50 m^3 per hectare.

The quality of whole tree chips is greater than other chip forms. Properties are more uniform than the properties of logging residue chips, so they are more suitable for smaller power and heat plants. According to the Metla database, the share of whole tree chips from total use of forest chips was 31% in power and heat plants in 2007. It covers 7% of the consumption of total solid wood-based fuels. This figure includes also large wood that is burned because of defects in quality.

4.1.3 Stump chips

Stump biomass can be collected as a separate operation of final felling from spruce dominant forests. Spruce stumps are more suitable for the forest chip production, because of a remarkable difference in the structure of the roots. The taproot of pine makes it more difficult to gather stump biomass in pine dominant forests (Hakkila 2004). Figure 5 presents the difference between pine and spruce roots.

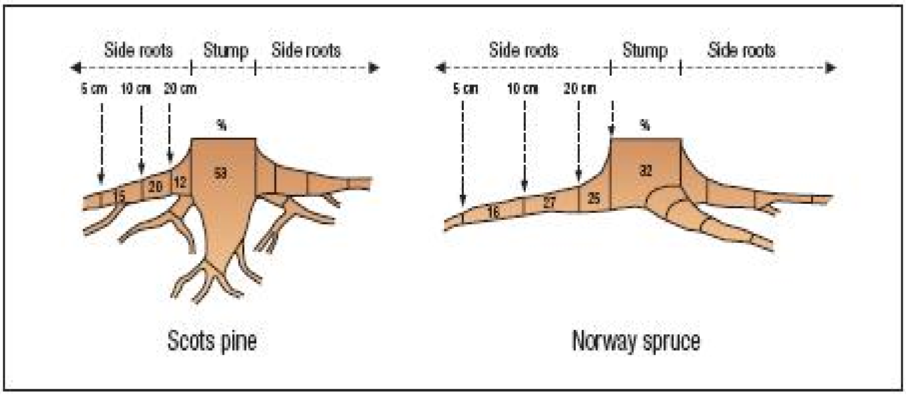


Figure 5. The profiles of Scots pine and Norway spruce stumps. (Hakkila 2004).

The energy content of pine stump chips is higher than whole tree chips or harvesting residues, but among other species, it is almost equivalent (Aarnio et al. 2001). Soil and grit that is sticks in roots, as well as the shape of biomass, causes troubles in combustion and comminution. However, despite impurities, stump chips are usable for biofuel. The accumulation of stump biomass can be up to 100 m³ per hectare, which reduces the unit procurement costs (Hetemäki 2007). The solid mass is more coarse and the moisture content is lower in stumps than in other chip forms (Halonen et al. 2001). Because of the lower moisture content, the effective energy content of stump chips is higher than other forest chips. When fuel has high moisture content, more energy is consumed to vaporize the water.

Soil, which is carried along with biomass, causes difficulties, especially in fixed be combustion, which is the most popular combustion technique in small energy facilities (Lehtilä et al. 2005 s.49). Because of that, the use of stump chips has centred in large heat and power plants, emphasized in Figure 11. The figure describes the utilization of stump chips among different energy facility categories. According to the Metla database, the share of stump chips from the total use of forest chips was 12% in energy facilities and 3% of total solid wood-based fuel consumption in 2007.

4.1.4 Bark, industrial chips and sawdust

Bark is the most important solid wood-based fuel in Finland. The use of bark was approximately 13.5 TWh in power and heat plants in 2007. According to the Metla database, over 90% of bark was utilized in energy facilities that relate to the forest industry. The quality of bark fluctuates. According to Karhunen (2008), dry bark has large energy content because of high lignin portion. In practice, high ash and moisture content diminish the properties of bark in energy production. Bark is typically burned with sawdust or with other by-products.

The use of sawdust and cutter flakes for energy production was 3.5 TWh in 2007. Industrial chips are typically chipped from the residues of the sawmill industry, such as endings and crosscut ends. The use of industrial chip was 1.8 TWh in 2007. According to Pöyry (2007), primary application for the two latter by-products is in the forest industry, instead of energy production. The use of sawdust for energy purposes is moderate compared with bark, even though Flyktman (2004) says that the forest industry produces almost equivalent amount of bark and sawdust. The forest industry has again higher capability to pay for raw material, which allocates industrial chips and sawdust mostly for forest industry purposes.

4.1.5 Pellets

Pellets are a further refined energy product, made from sawdust and cutter flakes. Pellets are dense with moisture content from 8% to 10%, which is substantially lower than other wood based fuels in general. These factors lead to a rather high energy density, which reduces the transportation costs significantly. The use of pellets was approximately 0.2 TWh in energy facilities in 2007.

4.2 Supply of wood-based fuels

4.2.1 Wood-based fuel potentials

All wood-based fuels are derived from the forest resource. There are approximately 20.16 million hectares forests in Finland (Korhonen et al. 2006). In ratio to total land area, three- fourths of the land area is covered by forests. Korhonen et al. (ibid) estimates that there are 2,176 million m^3 of solid wood in the Finnish forest reserve. The reserve has grown since the 1960s, because the annual natural removal and harvesting levels have been less than the annual growth.

There are fundamental differences between the supply of primary and secondary residues. The supply of secondary residues is formed by the production of traditional forest industry products while the supply of primary residues depends on forest owners' decisions. The supply of secondary residues follows the business cycles of the forest industry, whereas the supply of primary residues follows forest owners' actions when utility is maximized in theory. This study discusses next the supply studies of primary residues, because these fuels are expected to replace diminishing by-product utilization.

The supply of primary residues has been traditionally estimated by tracing the accumulating untapped forest resources. Rintala et al. (2007) say in their report that the annual growth of the Finnish forest biomass is approximately 280 TWh, while the total Finnish primary energy consumption was approximately 414.4 TWh in 2006 (Statistics Finland). The share of trunk wood biomass is almost 190 TWh and the rest of biomass growth is in form of branches and stumps. Approximately 95 TWh of biomass that is not suitable for forest industry processes, could be used as a raw material for energy production. This is equivalent to about 47.5 million m^3 of solid wood, given the energy content of Finnish tree species and a moisture content of about 40%. Hakkila (2004) estimated that the theoretical energy wood potential is about 45 million m^3 of solid wood in Finland.

The annual growth of biomass does not actually describe energy wood potential in energy production. The figures discuss the overall amount of biomass in Finland. A considerable number of studies have assessed the biomass potential for energy purposes in Finland. Those assessments have estimated that approximately 25 million m^3 of energy wood could be annually harvested, in theory (Helynen et al. 2007, Pöyry 2007, Asplund et al. 2005). Theoretical harvesting potentials are usually formulated by multiplying harvested industrial wood by the proportion of energy wood and industrial wood.

Although large amounts of energy wood may potentially be available in Finnish forests, the costs are often too high for economically viable extraction. Surveys study the potential that is economically available as a follow up to energy wood potential. Studies usually set biological, technical and economical constraints in theoretical harvesting surveys. According to this approach, Pöyry (2006) estimates that the techno-economically harvestable potential of forest biomass is 12 million m^3 and Laitila et al. (2008b) 15.9 million m^3. Pöyry (2007) reduces its estimation and calculates that the techno-economically harvestable potential will be 10 million m³ in 2020.

However, there is still a vast difference between the economical and technical potential and actual supply. This vast difference can be illustrated by comparing the results of studies and forest chip utilization. The Figure 6 illustrates several results of the potential studies, the use of forest chips in 2006 and the targets of three different programs. Also section 4.6 discusses the difference between the potential and utilization rate from the perspective of production costs. Figure 7 shows the result of economical potential studies more closely.

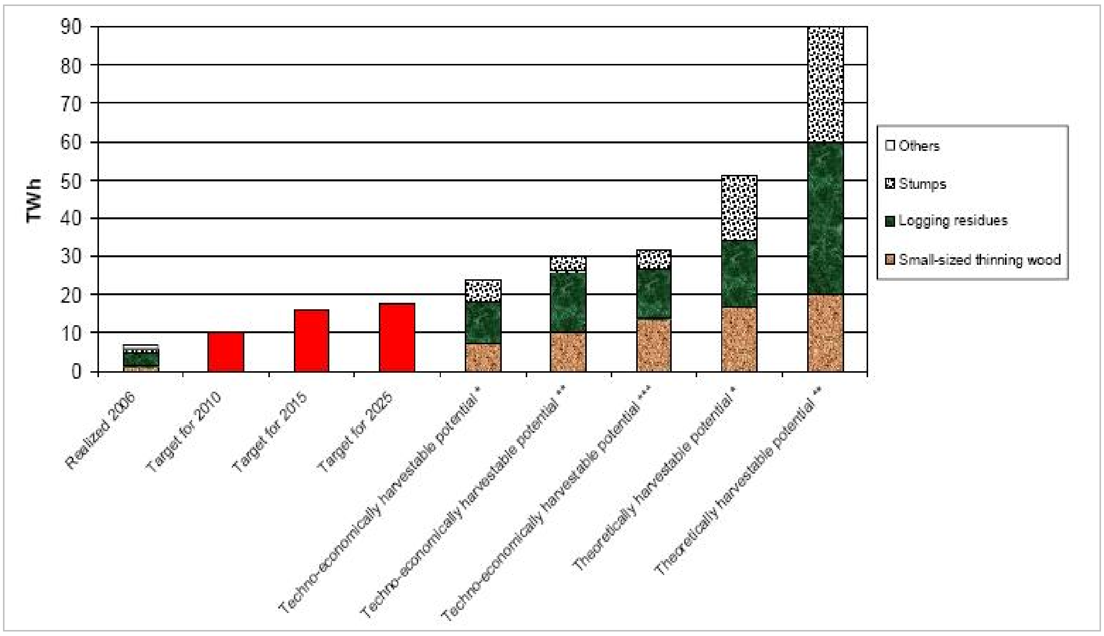


Figure 6. Different assessments of the forest chip potential. Pöyry 06*, Hakkila 04**, Helynen et al. 07 *** (Jokinen 2008)

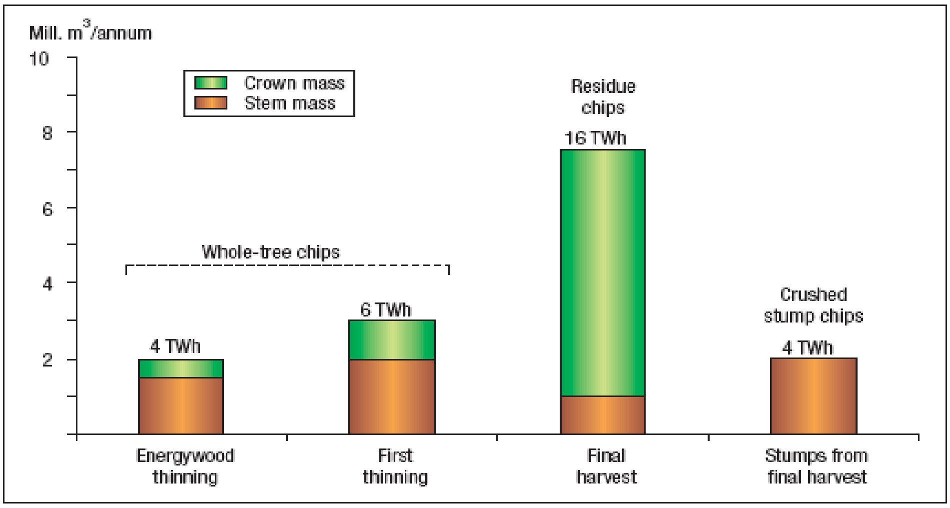


Figure 7. The more accuracy separated potential estimation. (Hakkila 2004)

Pöyry (2007) estimates energy wood potential using final felling data from 2002 to 2004. The extensive countrywide data covered industrial round-wood accumulations and data from over 55 000 final felling stands. Techno-economically harvestable potential estimations restrict energy wood potential because of long forest transport distances and low energy wood accumulation. The period was mistimed to describe a normal supply for industrial roundwood that could cause an overestimation about the forest chip potential. The level of timber supply was exceptional high, because of the transition period of the forest taxation.

4.2.2 The willingness to assign energy wood

Pöyry's predicted annual supply of forest chips and the predictions of the other studies vary from the annually utilized forest chips quantities considerably. In real terms, the supply is constrained by forest owners' willingness to assign harvesting residues for energy production, the fluctuation of the industry wood supply and energy wood policy (Helynen et al. 2007). Particularly, the forest owners' willingness to assign energy wood is problematic. A forest stand is private property, for which consumption decisions are made by the forest owner. Thus, a forest owners` forest management behaviour and attitudes have a great effect on the supply. Also, forest owners' attitudes towards energy wood can change with increased knowledge, making supply evaluations even more difficult (Maidell et al. 2008). Forest management associations are important information source for Finnish forest owners (Tanttu 2003). Orenius (2007) studied attitudes toward forest energy among different interest groups and noticed that forest management associations representing forest owners, have favorable attitude to energy wood and therefore may potentially boost the forest owners' attitudes in the future.

Järvinen et al. (2006) studied the forest owners' attitudes toward energy wood in Finland and noticed that the willingness to assign energy wood depends on energy wood forms and vary a lot among forest owners. According to the enquiry, one fourth is not willing to assign energy wood in any way. One interpretation is that in order for the forest owner to assign energy wood, the monetary compensation for energy wood should be considerable. On the other hand, the enquiry reveals that one-fourth are willing to assign their available energy wood for free.

Compensation for harvesting residues affects the forest owner's behaviour. The compensation can be divided into monetary, silvicultural and amenity benefits. Monetary benefits refer to stumpage price, while silvicultural benefits refer to acceleration in the growing rate of remaining stands due to energy wood thinning, thereby accruing more income in the future. Amenity benefits are formed because most Finnish forest owners consider energy wood procurement as improving the scenery and recreation values of the stand (Järvinen et al. 2006). The compensation is needed because removing harvesting residues or energy wood thinnings involves costs for a forest owner. There are several costs related to energy wood procurement from the forest owner point of view. Concerns for losses in soil fertility are only one example. These losses can slow down the growth of the next generation or a remaining stand. More research is needed as to the nutrient loss effect, but uncertainty about the effects of it reduces the energy wood supply (Gronalt and Rauch 2007).

Another remarkable cost factor can arise if energy wood thinning operations cause damages to a remaining stand. It is more common that damages occur in energy wood thinning than in industrial wood thinning (Äijälä 2007). Damages can inflict on mycosis transmission or decrease the quality of the remaining stand in general.

If a forest owner is willing to give up energy wood without stumpage price compensation, it means that increased amenity values or the growth acceleration are enough to cover expenses. Amenity benefits of energy wood thinning are an important aspect, if forest owners appreciate more amenity values over monetary values in the future. That change in NIPF owners' objectives would not decrease energy wood supply (Rämö et al. 2001).

Maidell et al. (2008) added a factor to their study of forest chips potential, which describes the forest owners’ willingness to assign forest energy and applied it to their techno-economically harvestable potential. The factor was derived from an enquiry that was done among non-industrial forest owners during 1999-2000. They discovered that when forest fowners' decision making processes are taken into consideration, total potential is notably smaller than techno-economically harvestable potential. They concluded that the final potential of energy wood is about 7.9 million cubic metres in Finland.

4.3 Demand for wood-based fuels

Wood-based fuels can be divided into three different categories of end-users: the forest industry, community heat and power plants and private users. This study divides the community energy facilities further into small, medium size and large plants, because of technological differences. Additionally, the effect of the emissions trading varies depending on plant size. Despite that forest industries and large community energy plants are often technically similar, they are addressed separately in this study.

The energy production facilities of the forest industry are, on average, larger units than the energy plants of the communities and they do not usually generate electricity to the national grid. They also use less forest chips with relation to their size, but the wood-based by-products are their most important energy source. The forest industry energy facilities face a quite stable demand for heat all round the year, while the demand fluctuates remarkably in community plants. There is also a possibility that the forest industry will begin to refine forest chips further, producing more value-added energy products in the near future, when their end-products would differ from the end-products of community plants.

The forest industry generates 60% of its own energy consumption by utilizing the by-products and residues of its processes. Fossil fuels and forest chips are also used in their energy plants as additional fuels. Large and medium size community energy facilities are using forest chips with fossil fuels in their boilers. Small community boilers, of less than 5 MW, often utilize only forest chips and generate only heat. The third category is private users, which include private households, farms and business premises. They use combusting pellets, forest chips or solid wood in their small scale boilers, fire places or sauna stoves.

4.3.1 Forest industry

The forest industry is the most significant wood-based energy producer in Finland with over 64% share in 2007. Hakkila (2005) reveals that the forest industry has pioneered the development and utilization of wood-based fuels. Most of it can be expounded on the utilization of bark, sawdust and industrial chips. The overall share of the forest industry by-products from solid wood-based energy is 85% and most of this is utilized next to the production plant. Figure 8 illustrates that the forest industry has the dominant share of the bark utilization in 2007.

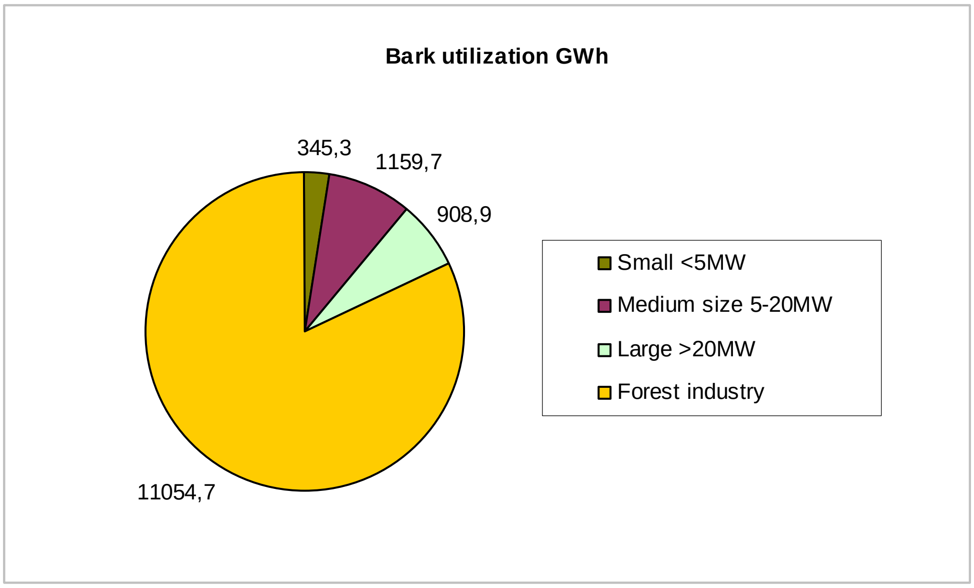


Figure 8. The distribution of the bark utilization among energy facility categories in 2007. (The Metla database)

The processes of the forest industry are extremely energy intensive. The forest industry consumes approximate 30% of all electricity in Finland (Tilastokeskus 2007). However, the forest industry is not a dominant user of forest chips, because their prime biomass is derived from their processes as a by-product. The share of the forest industry was approximately 38% of total forest chip utilization in energy facilities of over 20 MW in 2007. Black liquor, bark, sawdust and other wood-based by-products are cheaper wood-based fuel for them than forest chips. In practice, forest chips can substitute for fossil fuels, if the technical maximum of biomass utilization is not realized because of the by-products combustion. There is a plenty of regional variation in the forest chip utilization among the forest industry. For example, the forest industry formed over 90% of total regional forest chip demand in area of the Central Finland forest centre in 2007.

The share of the forest industry in wood-based fuel utilization has declined during the period 2003 to 2007, but the trend may change in the future. It is expected that energy and energy products have a major role in forest industry processes in the near future. Various scenarios are predicting that pulp mills will transform into biorefineries, which produces pulp in parallel with energy products and chemicals. Especially, wood-based transportation fuels such as biodiesel and ethanol may have an important role in product portfolio among traditional forest products in the future.

This is another issue, as in bioenergy generally, where political decisions have a major role in ensuring a balance between bioenergy and conventional forest products. FAO (2008) states that energy products among traditional forest industry products is a means to reduce risks and improve profitability and forest management.

This development has affected the forest and energy industries in forming strategic alliances (Roberts 2008). For example, a forest product company, Stora-Enso, in co-operation with Neste Oil, intends to start production in a pilot biorefinery plant in 2009, which is integrated with a paper factory in Varkaus (Neste Oil). The pilot plant will produce heat and electricity, which are consumed in the factory, and biowax, which will be refined further into biodiesel in an oil refinery. If they are able to solve current challenges of production and achieve profitable production costs, they will build a large scale plant. Roberts (2008) says that cellulose feedstock is more abundant than grains, but processing technology is still more expensive, even though processing costs are declining. However, a commercial-scale biorefinery would have quite a large risk as an investment (FAO 2008).

Commercial-scale biorefineries would change demand for forest chips regionally, because new energy products can be produced from lower quality raw-material. This means that energy wood becomes a source of their raw materials for their main products. The pilot plant in Varkaus requires about 50,000 m^3 of biomass. The planned large-scale biorefinery with 250 MW nominal effects would produce approximately 100,000 t of biowax and would require a million cubic meters of solid biomass annually (Pöyry 2007). Roberts (2008) says that economies of scale are critical in reducing the unit costs of cellulose ethanol. This is probably the case also in biodiesel production.

The sawmill industry has conveyed its interest in increasing energy production if more powerful public support of bioenergy production, such as feed-in tariffs, is introduced in Finland (Hetemäki 2007). A combined heat and power plants (CHP) next to a sawmill would offer synergy benefits of the biomass procurement and plants would have a natural application for heat. This change in the demand of forest chips could occur more rapidly than changes related to biorefineries. Forest chips would be co-combusted with the by-products of sawmill processes. That scenario would be a transitional form of the energy production facilities of the forest industry and communities, because electricity would be generated mostly for the national grid.

4.3.2 Community heat and power plants

Community energy facilities can be divided into three categories: condensing power plants, CHP plants and heat plants. Condensing power plants generate only electric power by combusting fuels such as coal, peat or biomass. CHP plants generate electric power and heat, when the energy content of fuel is tapped more efficiently. The forest industry energy plants are mostly CHP-plants. According to Rintala (2007) the typical efficiency of CHP plant is approximately 85%, while a condensing power plant can extend to 40% effiency maximum. Electricity is a more valuable end product and has less seasonal variation in the electricity demand than heat, which compensates slightly for lesser efficiency. Location restricts heat production more than electricity production, because a long distance heat transfer is not feasible. Energy facilities that generate only heat are usually small units.

Combustion technology varies according to size. Boilers of less than 5 MW are typically grounded on fixed bed combustion technology, while larger ones are grounded on fluidised combustion technology. Especially fixed bed boilers require high standard forest chip quality, such as whole tree chips, and peat can not always be substituted for forest chips. Figures 9, 10 and 11 confirm this. These figures show how different chip forms are divided between the energy production facilities of the forest industry and different size of community energy facilities.

Figure 9 shows that approximately 85% of logging residue chips is allocated to energy facilities of over 20 MW. Figure 10 shows that the share of small energy facilities in whole tree chip utilization is considerably large. According to Pöyry (2006), small facilities are also willing to pay more for whole tree chips. The price information of the Metla database and the utilization information above support also that finding.

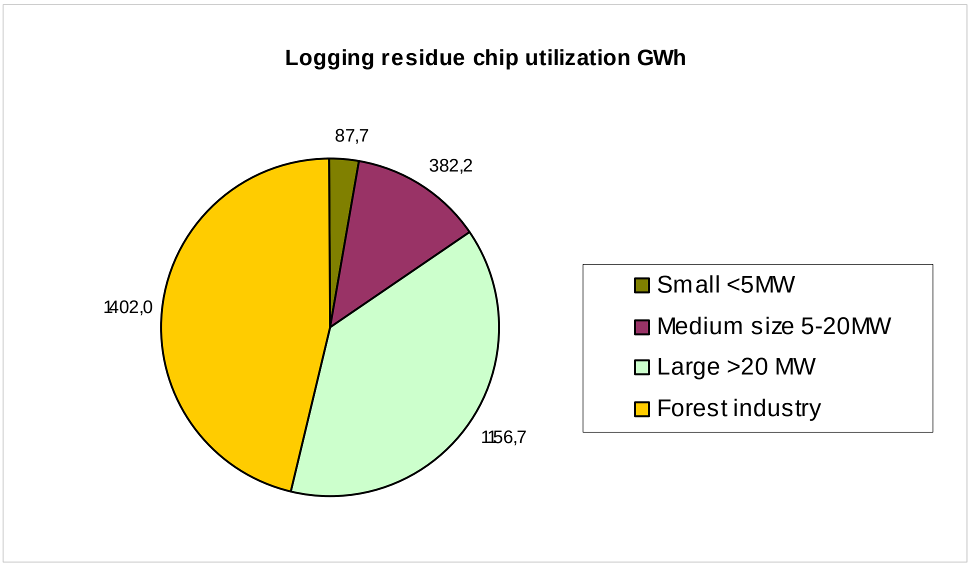


Figure 9. The distribution of the logging residue chips utilization among energy facility categories in 2007. (The Metla database)

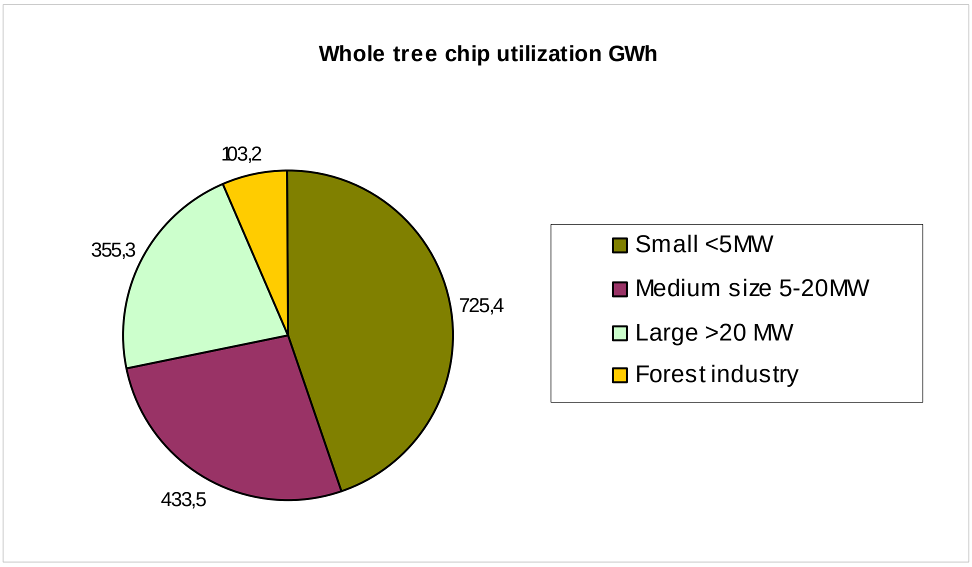


Figure 10. The distribution of the whole tree chips utilization among energy facility categories in 2007. (The Metla database)

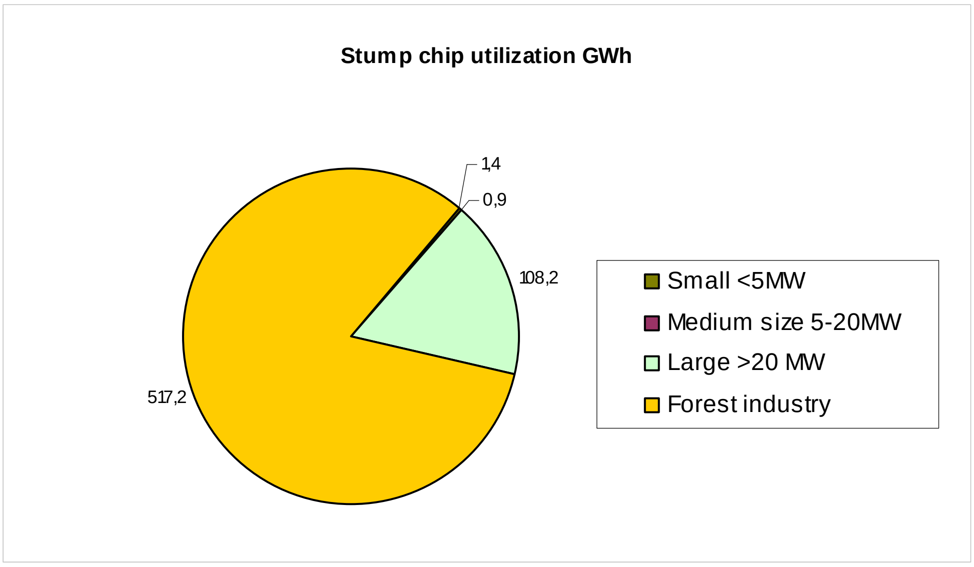


Figure 11. The distribution of the stump chips utilization among energy facility categories in 2007. (The Metla database)

According to the Metla database, there were 420 energy facilities which utilized forest chips in energy production in 2007. When also considering the utilization of by-products, recycled wood and pellets, the number of energy facilities is 753. Table 2 presents the rough size distribution of the former energy facilities by dividing plants in four categories. Table 2 also illustrates also accumulative nominal capacities and accumulative inputs of forest chips according to the same categories. Table 3 illustrates the same information as Table 2, when all solid wood-based fuels are included.

Different size-categories of energy facilities are not evenly distributed throughout Finland. Because of this, it is not relevant to draw conclusions on the regional use of wood-based fuels or forest chips based on country wide mean values. Figure 12 shows that there is a lot of variation in forest chip utilization between different energy-facility categories.

Table 2. The profile of different end-users of forest chips in 2007. (The Metla database)

	Small < 5MW	**5MW ≤ Medium < 20MW**	**Large >20 MW**	**Forest industry**
Number	~300	69	33	21
Heat capacity	309,44 MW	587,92 MW	2311 MW	5338,3 MW
Electricity capacity	0 MW	4,3 MW	1120,4 MW	1554 MW
Forest chip Input	825,42 GWh	839,97 GWh	1620,19 GWh	2021,75 GWh
Share of forest chip use %	15,6	15,8	30,5	38,1

Table 3. The profile of different end-users of solid wood-based fuels in 2007. (The Metla database)

	Small < 5MW	5MW ≤ Medium < 20MW	Large > 20MW	Forest industry
Number	561	112	35	45
Heat capacity	~600 MW	969,5 MW	2365 MW	8328,6 MW
Electricity capacity	0 MW	8,8 MW	1021 MW	2234 MW
Wood based fuel Input	1891,29 GWh	3128,84 GWh	4020,54 GWh	15805,15 GWh
Share of total wood based fuel use %	7,6	12,6	16,2	63,6

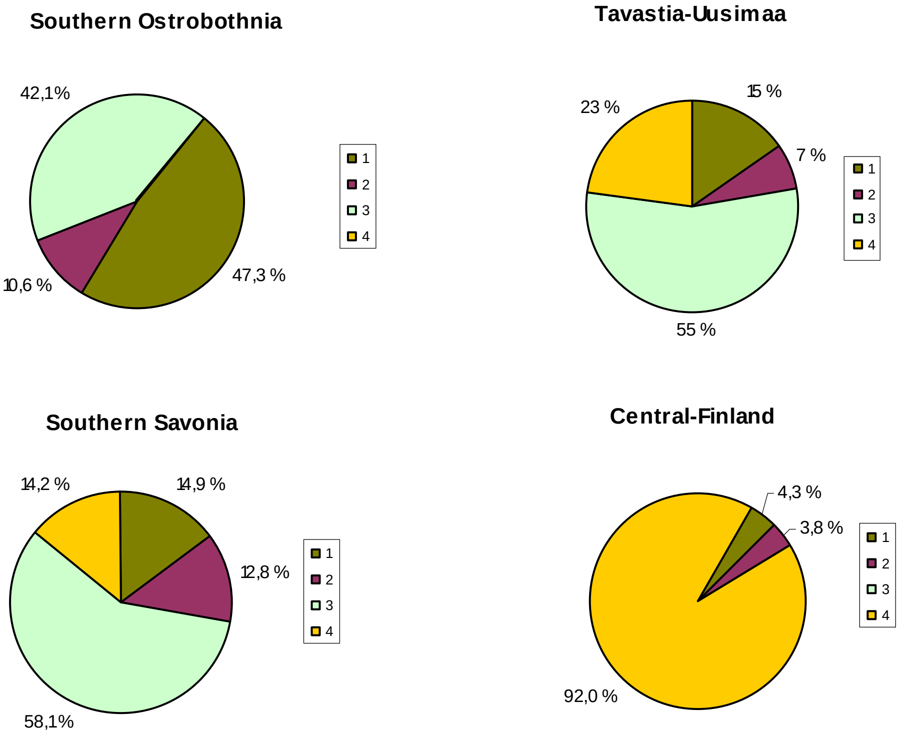


Figure 12. The shares of forest chip inputs among different categories in four forest centers. Appendix 1 illustrates the shares of the other forest centers. (The Metla database)

Investment and capital costs are significant factors in the cost structure of energy production, as typical in the processing industry. This leads to the economies of scale, because the share of investment costs from the production costs decreases when a unit size grows. Also, from the environmental point of view, forest biomass utilisation is favourable in large units with advanced boiler technology (EU 2007). On the other hand, long distance energy wood procurement is not profitable.

The technical properties of boilers restrict the use of forest chips as well as transportation costs. According to Helynen (2004), the ash of forest chips differs from peat and coal ash. Rintala et al. (2007) say that sulphur compounds in peat are an advantage from the user point of view, because they reduce the corrosion and grime of boilers. Thus, wood-based fuels can often substitute for only a certain proportion of fossil fuel. The waste burning directive is also restricting the use of pure wood-based fuels in some cases. The directive regulates the maximum level of small particle emission. Because the combustion of forest fuels produce typically more small particle emissions than peat or fossil fuels, the lower small particle emission is achieved by co-firing wood-based fuels with other fuels (Hyvönen 2007). Small particle emissions are known to inflict health hazards. Small energy facilities are not typically equipped with small particle separators, in which case the properties of fuel affect small particle emissions directly (Lehtilä et al. 2005 s.16).

4.3.3 Private users

Privet users are the most important end users of wood-based energy producer from a global perspective. It is worth noting that bioenergy, including wood energy, is the dominant source of energy for 1 to 2 billion people, mostly in developing countries where wood is burned inefficiently for cooking purposes (IPCC 2008). Arnold et al. (2003) state that traditional biomass utilization covers 10% to 15% of the global energy production. Especially in Finland, the private users account for relatively small portion of the total wood-based fuel consumption.

There are approximately 2.2 million fire places in Finland, from which 1.4 million are in residential buildings and 0.8 in summer cottages (Alakangas et al. 2007). Traditional firewood was combusted approximately 5.4 million cubic meters in these fire places in 2002, which is equivalent to 15% of total wood based fuel consumption (Hakkila 2004). Hetemäki (2007) estimates that the share of private users was about 16% from the total wood-based fuel consumption in 2006. The private use of forest chips is about 0.4 million cubic meters and it has been stable during the recent years (Kuusinen and Ilvesniemi 2008). This means that private users burn a lot of high quality wood in their fire places, but do not participate significantly in the forest chip markets. Figure 13 shows how the Finnish proportions of different end users segments differ from European ones, mainly due to the strong forest industry in Finland.

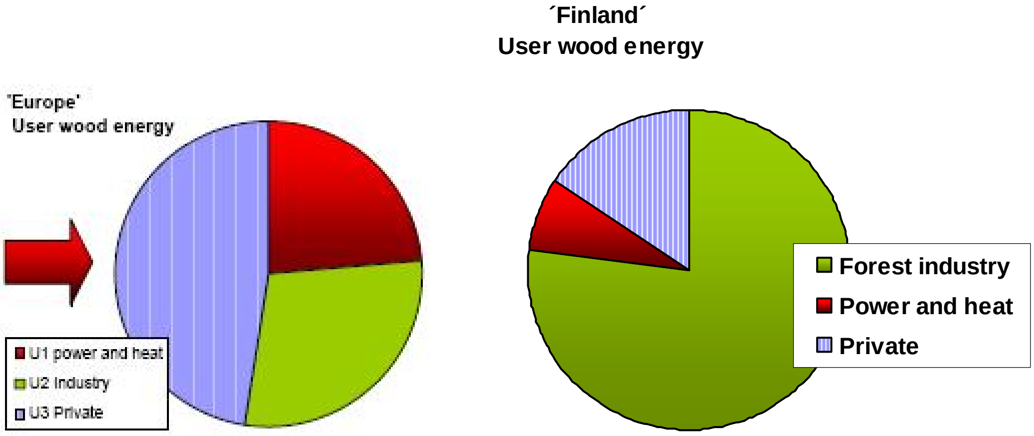


Figure 13. The distribution of the forest fuel utilization between different users in Europe and Finland. Modified from the source UNECE 2007.

4.4 Cost structure of forest chips

Because the feasible growth of the wood-based fuel utilization is mostly derived from the use of forest chips, a presentation of the cost structure of forest chip procurement is warranted. Rintala et al. (2007) state that the price of biomass is defined according to an alternative fuels in the energy market. In principle, alternative fuel defines the maximum price of biofuel. In Finland, the alternative fuel is typically peat, which has a relatively constant price without the effect of the emissions trading (Helynen et al. 2007). The price of forest chips for an energy facility is comprised of its production costs. The production costs can be divided into different components, determined by the harvesting technology.

Figures 14 and Figure 15 illustrate that Pöyry (2006) divides the production costs of forest chips into five different cost components: stumpage price, harvesting, comminution, transportation and overhead costs. The level of stumpage price in energy wood is considerably lower in comparison with pulp wood. It is important to notice that the cost difference between logging residue chips and whole tree chips is also considerable. The cost structure shows that expensive felling and a bunching raises the production costs of whole tree chips. Another factor that causes the difference between the relative costs of energy wood thinning and final felling are higher accumulations of energy wood in final felling.

Subsidies (so called "KEMERA" subsidies) based on the law for sustainable forestry make whole tree chips competitive. Figure 15 notes public interventions in the energy wood procurement and the subsidies have included whole tree chip production cost structure. Chapter 5 discusses more these subsidies and public policies further.

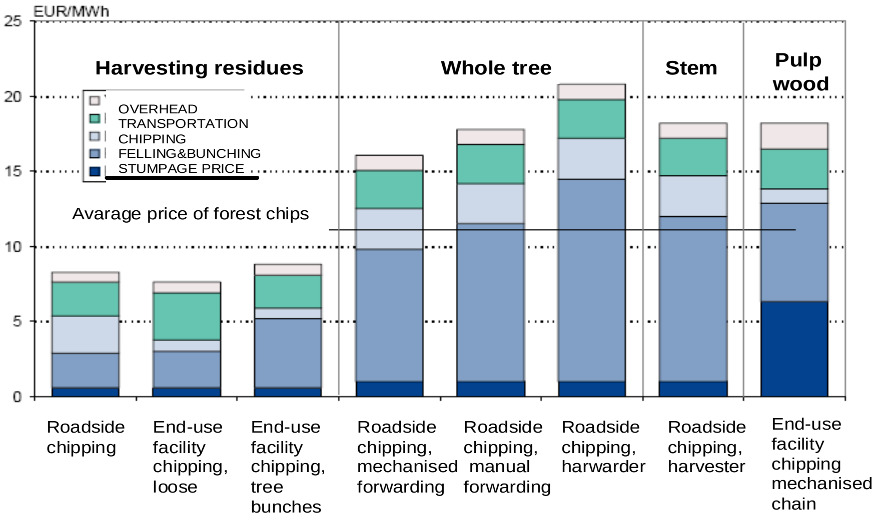


Figure 14. The cost structure of forest chips depends on the chip form and procurement chain. (Pöyry 2006).

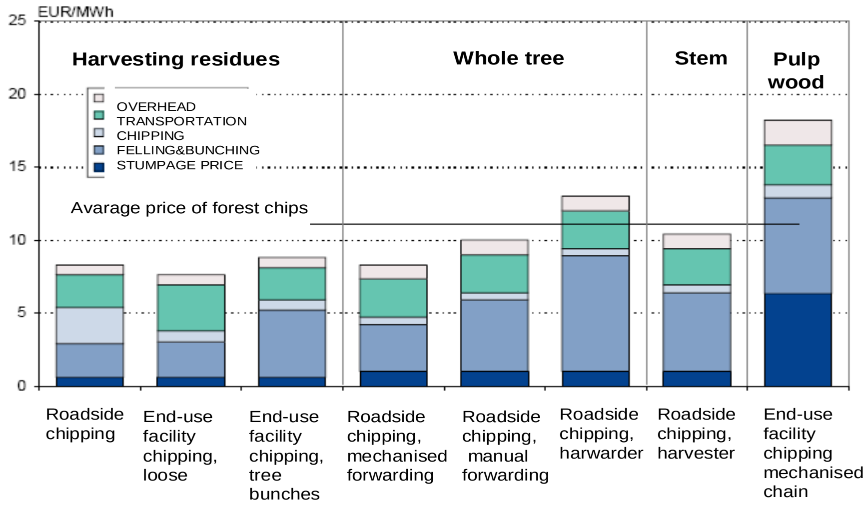


Figure 15. The cost structure of forest chips depends on the chip form and procurement chain. Subsidies to sustainable forest management are observed. (Pöyry 2006)

The biggest cost items in energy wood procurement are felling bunching, transportation and comminution. Relative shares depend on different harvesting technologies and procurement chains. Particularly, the place of the comminution defines the size of relative cost factors. Transportation costs of energy wood are relatively high because of low density and a high moisture content of energy wood (Bjornstad 2005). It is possible to influence density and moisture content factors of transportation with the choice of the procurement chain. Every chain has weaknesses and strengths.

Production costs vary a lot among different forest stands. The location and properties of the stand are factors which determine the level of procurement costs. For example, a short forwarding distance reduces the harvesting costs and a short distance to an end-user reduces the transportation costs. When the properties of stands vary, the strengths and weaknesses of different procurement chains vary as well. There is no one right method in energy wood procurement (Gunnarson et al. 2004). Two different procurement chains are presented next briefly.

4.4.1 Roadside chipping

A procurement chain based on a roadside chipping is the most common in Finland. According to Kärhä (2008), the share of this type of chain is approximately 60% among harvesting residue procurements. The main advantage of roadside chipping is that the density of chips exceeds of harvesting residues, reducing the transportation costs. On the other hand, the chipping costs are quite high because of inefficient chipping. According to Laitila (2008a), roadside chipping is the most cost-efficient chain in the whole tree chip production and the most common chain with the share of 73%.

4.4.2 Terminal or end use facility chipping

The advantages of terminal and plant chipping chains are related to effective chipping and effective use of harvesting machines. This can be seen in Figure 14 and Figure 15, which show the chipping costs of plant chipping are much lower than in roadside chipping. Another advantage is that terminals and storages near end-use facility operates as a buffer storage, which offers more secure supply and more flexible management of supply (Laitila 2008a). A seasonal variation is better controlled (Gunnarsson et al. 2004). Investments in chipping machines are higher, because the capacities of terminal or plant, chippers are also higher. Also, the transportation costs of loose energy wood are quite high.

In stump chip production, the terminal, or plant based, chipping chain is dominant, because the comminution of stump biomass usually requires more effective machines. The difference between terminal and end-use facility chipping is that terminal chipping requires intermediate storage that can serve several plants. Transportation from terminal to end use facility can be operated by truck, train or ship.

4.5 The development of production costs and prices

Forest chip price information is based on two different sources in this study. The main price data of forest chips was collected from 2000 to 2006 by Metla. There is no separation of the different chip forms in that database, but the samples are quite extensive. The database consists of over 700 boilers in Finland, but only one-fifth of energy facilities gave price information. The rest of price information was collected by Koneyrittäjien liitto, which has committed an enquiry among its members. The different chip forms are separated in this enquiry, but the results are only suggestive, because of the small sample.

The analysis of the price information shows that the properties of chips are reflected in the prices. The whole tree chips are the most expensive and harvesting residues chips are the cheapest. Small heat plants can not always utilize equally harvesting residue chips and whole tree chips. Due to that fact, they are willing to pay more for better quality energy wood. The data also shows, interestingly, that there is more variation in prices among small units. One possible explanation is that larger units are able to negotiate better prices.

Table 4 shows average prices from the data collected by Metla. There is a distinct increasing trend in forest chip prices. Table 5 shows the price changes among different forest chip forms in 2008.

Table 4. Purchase prices of forest chip depending on the size of power plant. (The Metla database)

	Small	***Medium size***	***Large***	***Forest industry***
	<5MW	Between 5MW and 20MW	>20MW	>20MW
2003	12,80	10,66	8,88	9,21
2004	13,45	10,80	9,76	9,57
2005	15,81	11,49	10,63	10,13
2006	14,62	13,16	11,95	11,04

Table 5. Purchase prices of forest chip depending on the chip form. (Koneyrittäjien liitto 2007)

	Harvesting residue chip	***Whole tree chip***	***Stump chip***
2008	[€/MWh]	[€/MWh]	[€/MWh]
1-5 MW	15	17,5	16
>5 MW	12,25	13,75	12,88

The development of forest chip prices can be estimated crudely by a linear model, in which quantities are the independent variable and prices are the dependent variable. Asikainen (2008) extrapolates with the linear model formed from data during 2000 to 2006 that the marginal price would €17.2/MWh, if the annual use of forest chips was 8 million cubic meters. Respectively, the marginal price would be €22.2/MWh if the use of forest chips reached 12 million m³ annually. The model assumes that the share of whole tree chips would increase with the growth of annual use. From 12 million m³ of forest chips, 5 million m³ would be harvesting residue chips, 5 million m³ would be whole tree chips and 2 million m³ stump chips. When the effect of present subsidies to sustainable forest management on prices is ignored, the marginal price would be €19.5/MWh at the level of 8 million m³ and €24.8/MWh at the level of 12 million m³ annual use. The results have been calculated with the following equation:

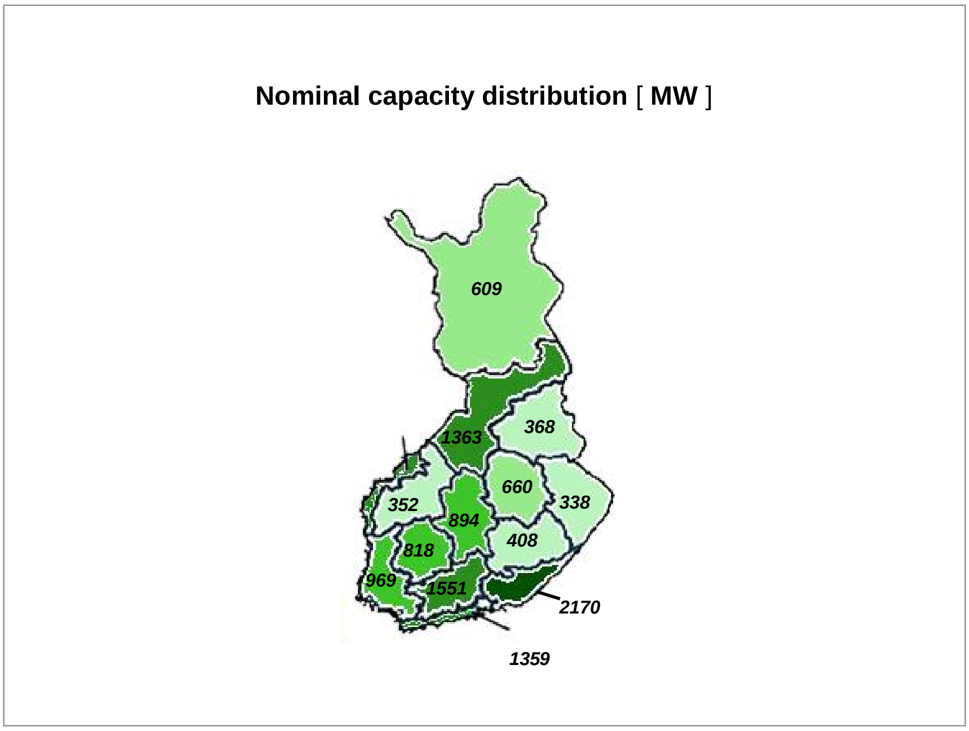
$$Price\ [€/MWh] = 7{,}28039 + 0{,}001242 \times volume \times 10^3 m^3 \tag{41}$$

This bullish price development can be explained by the forest chip production costs. When an annual procurement volume increases, procurements are forced to extend to lower quality stands (Laitila et al. 2008b). Long distance forwarding and transportation have a great effect on the production costs. Also, the share of more expensive whole tree chips increases because there is more untapped biomass potential in energy wood thinning than harvesting residues. Hakkila (2005) estimated that from the level of 5 million m³, one third should be procured from young stand energy wood thinning and the rest from final felling.

Harvesting residue chips can also be procured from commercial thinning. This raises the production costs, because the productivity of the chain is lower. The procurement chain is similar to that of final felling, but the accumulation per hectare is smaller. Thus, the unit costs of forest chips are higher.

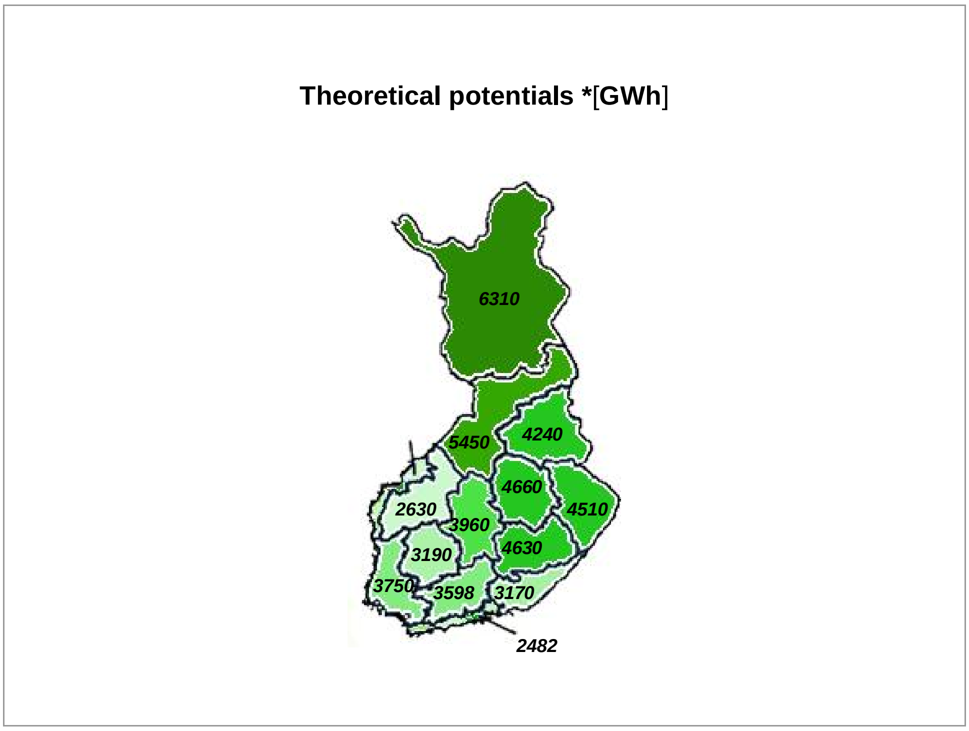
The increase in forest chip utilization does not automatically affect high production costs everywhere in reality. The demand for and supply of forest chips are unevenly distributed in Finland. For example, there is strong demand in relation to potential in Central Finland. There are also certain areas where the supply of energy wood from convenient stands exceeds the regional demand. According to Laitila et al. (2008b), North Savo is an example of an area where a considerable rise in the demand would be possible without an increased in production costs. Maidell et al. (2008) estimate that the current use of forest chips covers only 8% of the techno-economically harvestable potential in that area.

Figures 16, 17, 18 and 19 show the same issue by presenting the regional diversity of the demand and supply of wood-based fuels. Figure 16 shows the suggestive demand distribution between forest centres. The regional demand distribution has been formed from nominal capacities of energy facilities which have utilized forest chips between 2005-2007. The distribution does not take into consideration the technical issues of different boilers that affect the feasibility of forest chip utilization for energy purposes. Figure 17 presents the estimations of the regional energy wood potentials. Figure 18 illustrates the forest chip utilization in different forest centres, quantified in GWh. It can also be interpreted as the regional equilibrium of the demand and the supply of forest chips in regional circumstances. Figure 19 illustrates regional by-product utilization. The distribution adopts the nominal capacity distribution narrowly. It emphasizes that industrial by-products are much more utilized wood-based fuels than forest chips. However, because of this regional diversity, it is important that market analyses focus on specific areas.



Nominal capacity distribution [MW]

Figure 16. The nominal heat and electricity capacity distribution in 2007. Energy facilities which have utilized forest chips during 2005-2007 are included. (The Metla database)



Theoretical potentials *[GWh]

Figure 18.The regional forest chips supply potentials. Modified from Pöyry (2007).

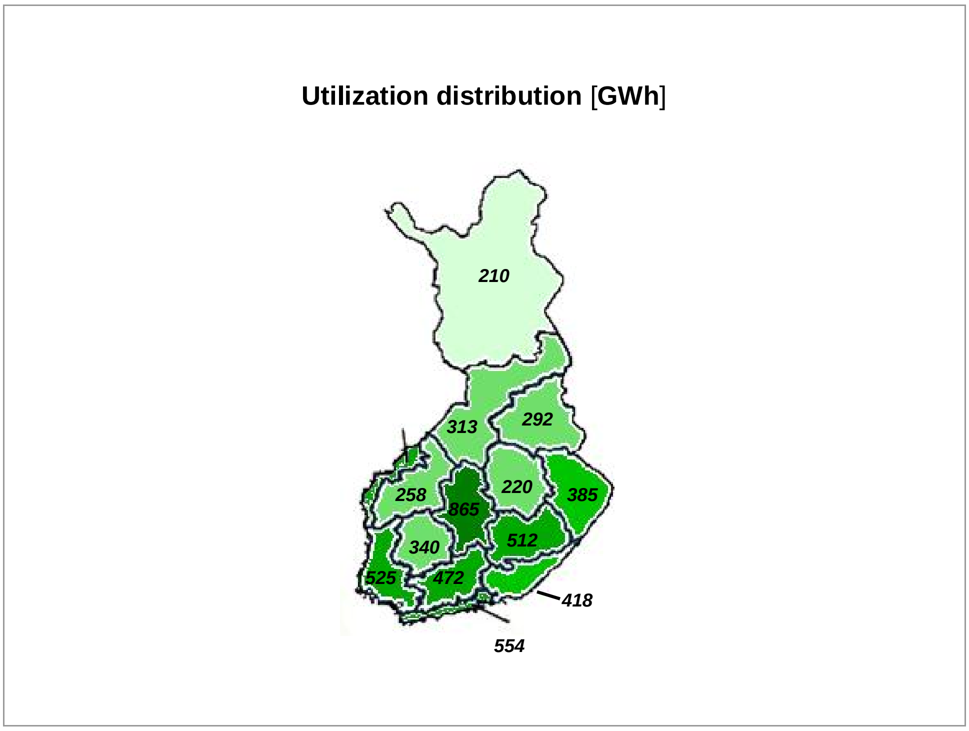


Figure 19. The regional distribution of the forest chip use in 2007. (The Metla database)

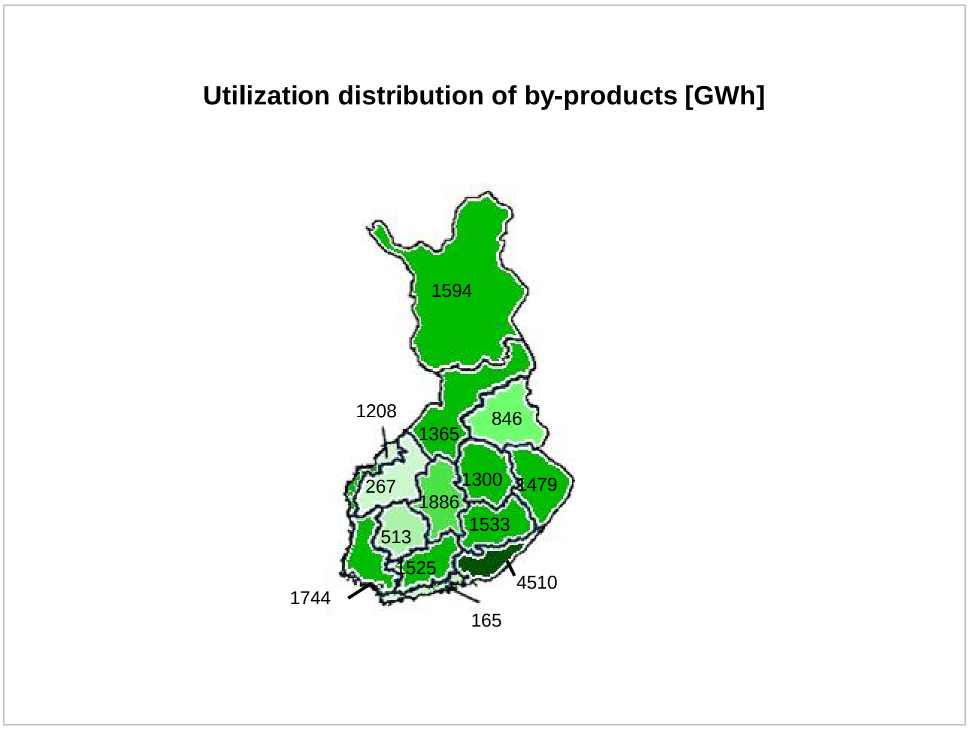


Figure 20. The regional distribution of solid wood-based by-products. (The Metla database)

Innovations in harvesting technology and development of the procurement chain could reduce the energy wood production costs in the future. According to Helynen et al. (2007), the integrated procurement of pulp and energy wood could be a promising path to develop procurements. In this integrated procurement chain, lower total costs could be achieved than with separate operations. A feasible method would be that energy wood is separated from pulpwood at the debarking phase at the pulp mill (Jylhä and Laitila 2007). That operative model could be natural for a biorefinery. Even though there has been research on that, a cost efficient way has not yet been achieved.

5 THE IMPACTS OF PUBLIC POLICIES

5.1 Need for public incentives

As this study has already emphasized, public policy has a major role in bioenergy production and its development. The emissions trading and other Finnish incentives are partially overlapping instruments, because when the credit price rises, the need for other incentives decreases (Pohjola and Uusivuori 2008). Next, the study evaluates the effects of the emission trading. Other policy instruments are only introduced because the levels of these instruments have stayed comparatively constant during the period.

5.2 The effects of emissions trading

The time period of the panel data is from 2003 to 2007. Even though the first round of the emissions trading started in 2005, the first year is not a suitable point of comparison to study the effect of the emissions trading on the wood-based fuel utilization among the forest industry energy facilities. Additionally, the total use of wood-based fuels between 2004 and 2005 cannot be compared. The forest industry declared a lock-out due to the deadlocked collective wage bargaining in 2005, which led to the six week interruption of almost the whole forest industry. The interruption decreased the production of the industrial by-products and demand for energy significantly. This caused the change in utilization between 2006 and 2007, reliable illustrating the effect of the emissions trading. The change of credit price between these years is sufficiently strong. Figure 20 shows the price development of EUA 2007 and EUA 2008. The first depicts the credit price during 2005-2007 and the latter the future price of Kyoto-period in 2008-2012.

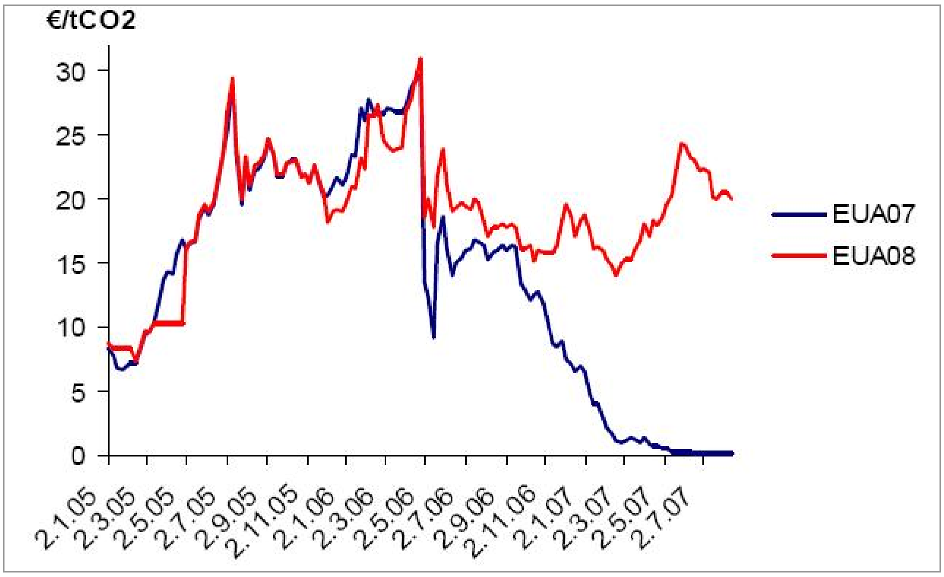


Figure 20. Price development of European Union credits (POMAR 2007)

According to the Metla database, the total use of solid wood-based fuels was 27.3 TWh in 2006, from which 22.7 TWh was utilized in energy facilities of over 20 MW. In smaller plants, which do not participate in the emission trading, the use of wood-based fuels was approximately 4.6 TWh in 2006. The price of the credit collapsed in 2007 and the use of wood-based fuels reduced to 24.9 TWh. In energy facilities of over 20 MW, the reduction was 12% while in the smaller facilities, the use of wood-based fuels increased 8%. These findings support the hypothesis that when when the credit price is high, wood-based fuels are competitive enough to replace fossil fuels in energy facilities that belong to the emission trading scheme. In Finnish conditions, the emissions trading mechanism shifts the demand and the low price of credit decreases the utilization of wood-based fuels.

The same effect of the emissions trading can be seen even more clearly in the forest chip utilization. According to the Metla database, the total use of forest chips was 3.1 million m³ in 2006, from which 2.3 million m³ was utilized in large plants. In smaller plants, which do not participate in the emission trading, the use of forest chips was approximately 0.7 million m³ in 2006. The price of the credit collapsed in 2007 and the use of forest chips decreased for the first time during this decade to 2.7 million m³. In large energy facilities the reduction was 21% when in the smaller ones, the use of forest chips increased 13%.

When only the utilization of industrial by-products is analysed, the effect of the emissions trading is not self-evident. The emissions trading notably affects wood-based fuels that are purchased from the market more intensely than by-products. The forest industry utilized over 90% of bark in 2007. Because the forest industry does not usually use intermediaries in their procurements of bark, less than 10% of bark was tradable. Alternatively, forest chips, pellets and recycled wood are fuels that are generally supplied from the market. There is a slightly decreasing trend in the utilization rate of by-products, despite the emissions trading during 2003-2007. For example, the use of bark decreased 7% in large energy facilities and 3 % in smaller ones from 2006 to 2007.

Figure 21 presents the bark utilization in Finland from 2003 to 2007. When it is compared to the industrial raw wood utilization, a clear relation is apparent. The utilization of bark follows the adjustment of the industrial raw wood utilization directly, because there are no other applications for bark available and long term storage is not feasible. This further argues for the point that emissions trading does not significantly affect bark utilization.

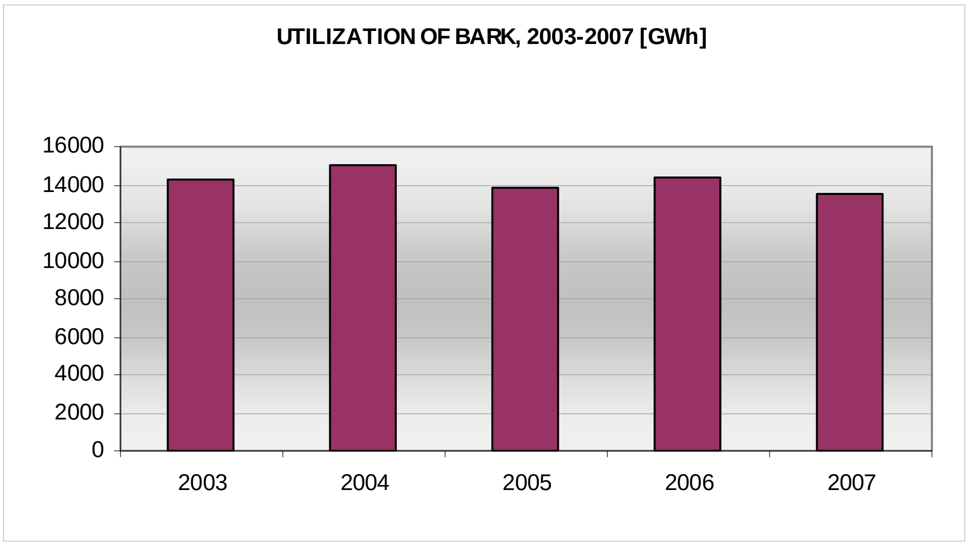


Figure 21. The bark utilization during 2003-2007. (The Metla database)

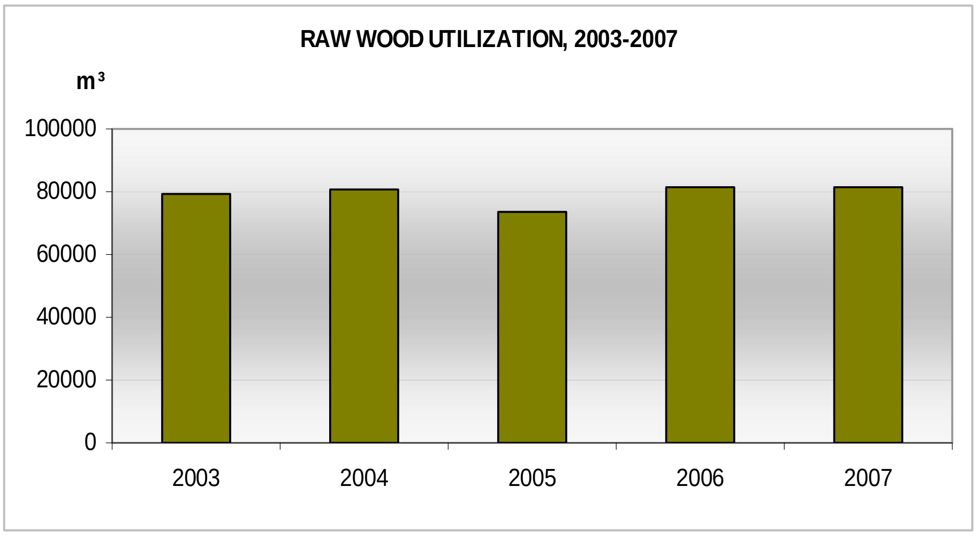


Figure 22. Industrial roundwood utilization during 2003-2007. (The Metla database)

Emissions trading has stronger effects on the industrial chip and sawdust utilization than on bark utilization. This follows the fact that main applications for these sources are in the processes of the pulp and particle board industry. The sawdust utilization decreased by 5% in energy facilities within the emission trading scheme, while it increases 15% among smaller units in 2007. The trend was the same with industrial chips. This illustrates that the high allowance price decreases the gap the capability to pay for wood between the energy and the forest industry. Pöyry (2007) notices that the pulp industry pays on average €18/MWh. The application of equation 40 displays that when the price of credit is over €25 it is more profitable to use industrial chips for energy purposes.

When the shifts of the wood-based fuels consumption among different energy-facility categories are analysed, significant differences are found. It appears that the wood-based fuel utilization in community energy facilities that belong to the emission trading scheme is most sensitive for changes in the credit price. The wood based fuel consumption decreased 19% in these energy facilities in 2007, while the shift was only 10% within the forest industry. The launch of the emission trading increased by 14% the wood-based fuel utilization among the large energy production facilities of communities in 2005. Middle-sized energy facilities reduced by 3% the wood based fuel consumption in 2005, which caused a flux in the emissions trading.

Reduced utilization outside the emission trading scheme diminishes the impact of the instrument. On the other hand, the statistics illustrates that the emissions trading has not affected the wood-based fuel consumption in small energy facilities. The utilization has grown in these facilities every year during the period. Table 6 gleans the development of the wood-based fuel utilization among the energy facility categories during 2003-2007.

Figure 23 illustrates an estimation of the wood-based fuel trade. The trade accumulation is based on the assumption that energy facilities related to the forest industry utilize only by-products of their own processes. A comparison between Figure 23 and the total utilization of solid wood-based fuels in Figure 24 shows that from 34 to 42% of solid wood-based fuels are traded during 2003-2007. Sawdust and industrial chips that are allocated to the forest industry are ignored in this figure. As the comparison implies, wood-based fuel trade is increasing and emissions trading further increases it.

Table 6. The growing rates of the wood-based fuel utilization in different energy facility categories during 2004-2007. (The Metla database)

	Small < 5MW	**Medium sized 5-20 MW**	**Large > 20MW**	**Forest industry**
2004	25 %	3 %	5 %	9 %
2005	9 %	-3 %	14 %	-8 %
2006	7 %	1 %	11 %	4 %
2007	7 %	8 %	-19 %	-10 %

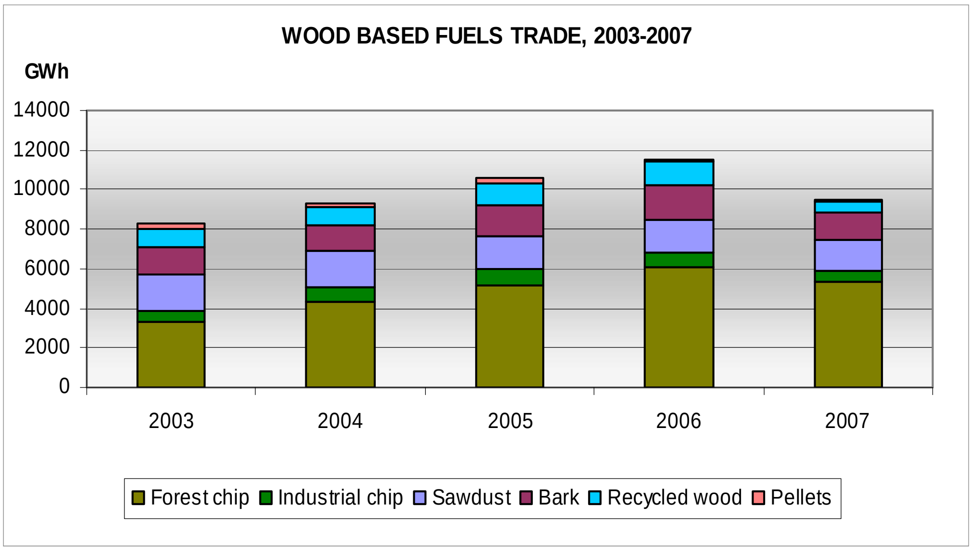


Figure 23. Estimation of the wood-based fuel trade. (The Metla database)

The total utilization of wood-based fuels remained relatively stationary during 2003-2007. Even though the emissions trading has enhanced the utilization in 2005 and 2006, the downward trend of the forest industry production has balanced the development. Figure 24 presents the overall wood-based fuel utilization from 2003 to 2007.

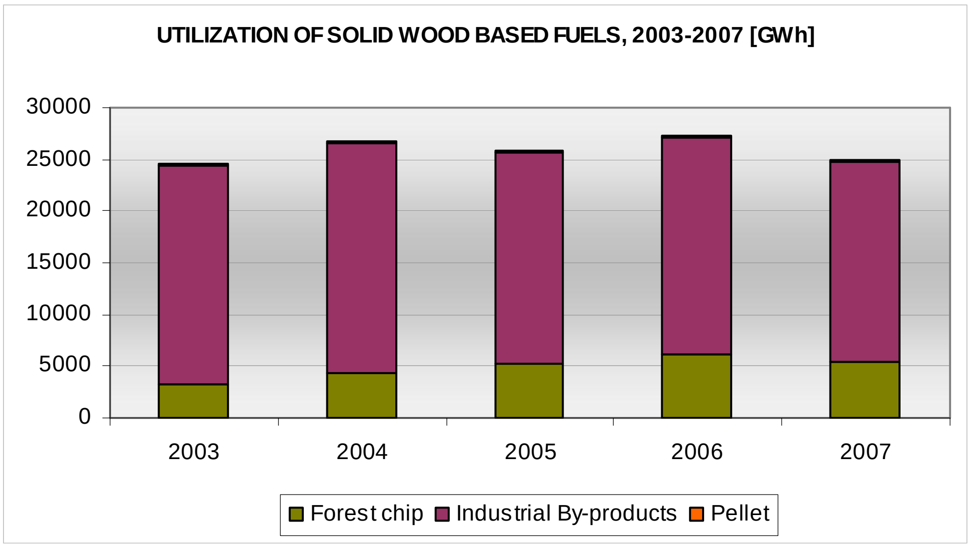


Figure 24. Total utilization of wood-based fuels during 2003-2007. (The Metla database)

5.3 Subsidies to sustainable forest management and other public interventions in Finland

Toivonen et al. (2000) suggest that an energy policy has not been incorporated into agriculture or competition policies in the EU. Rather, the EU focused on setting targets and guidelines for member countries. Therefore, even though there is EU-wide policy, such as the emissions trading, individual nation-wide policies are required for countries to realize the goals that the EU has set. That also explains the vast variation in European bioenergy policies. Fischer and Newell (2008) reveal that an optimal portfolio of policies is a more cost-efficient way to reduce emissions than any single policy.

Public interventions to boost bioenergy production can be divided into demand and supply sides incentives. Another public policy tool is subsidies for R&D, but it does not affect the market equilibrium directly. The demand side activities raise the capability of paying for raw-material. Those tools can be investment subsidies, taxes for alternative fuels, tax deductions, exemptions or subsidies for bioenergy production or feed-in policies. The supply side activities such as forestry subsidies lower the cost of production and improve the competitiveness of certain material instead.

Other public instruments, such as investment subsidies, are allocated mostly for small or medium-sized energy facilities to prevent the flux of the emissions trading. These activities are often required, because otherwise the wood-based fuel utilization is not a competitive alternative. The need for other public incentives for energy facilities that belong to the emission trading scheme depends on the price of the allowance. According to Pohjola and Uusivuori (2008), large energy facilities do not need additional support in the case of the annual utilization of 8 million m^3 of forest chip, if the credit price is over €25. Smaller energy facilities would require computationally €8.9 /MWh on top of subsidies of sustainable forest management in the same case.

Finnish bioenergy policy promotes the use of wood-based fuels with investment and electricity subsidies from the demand side. The electricity subsidy is €6.9/MWh for an energy facility smaller than 40 MW that generates electricity from wood-based fuels. Energy wood is also excluded from the excise duty, which improves its competitiveness in heat production. Investment subsidies for energy facility can meet up to 40% of the eligible costs if an investment is directed in new technology. An investment subsidy in existing technology can meet up to 30% of those costs. Investment subsidies that encourage increasing energy wood consumption are discretionary incentives, which can be applied for new renewable capacity projects or to improve energy management security. The applications are discussed and subsidies are allocated by either the employment and development centres or from the Ministry of Employment and the Economy. The former allocates subsidies to projects with a budget of under €2 million. The latter allocates subsidies to projects under €20 million or those projects that focus on new all projects that focus on new technology. The maximum subsidy for a project is €4.5 million if a new technology is applied.

Different incentives are directed to different energy facility categories. An exemption from the excise duty is the only incentive which equally affects all energy facilities, regardless of their size. In energy production as well as almost every other process industry, the share of investment capital costs is large in their production cost structure, which emphasizes the importance of investment subsidies. However, because of the maximum expense restrictions of investments and the scarce budget, investment subsidies are allocated mostly for small and medium size units. The electricity subsidy is allocated mostly to large community plants, because electricity production in medium size plants is marginal and forest industry units are larger than 40 MW. Figure 25 presents the development of the allocated investment subsidies to enhance wood-based energy production.

There has been speculation about additional incentives that could be introduced in Finnish energy policy. The Finnish government is drafting the foresight report on climate and energy policy and will present it to the parliament in the spring of 2009. A feed-in policy to enhance biomass based electricity production is one option, which is under consideration. The most common feed-in policy instrument is feed-in tariffs, which guarantee a minimum price for renewable based generated electricity for a specified period (Menantenau et al. 2003). It would also be an instrument which would channel consumption of wood-based fuels to the large community energy plants. The energy production facilities of the forest industry are not typically self-sustaining in electricity production, which means that they would not benefit from the introduction of the feed-in tariffs. Additionally, it could reduce their forest chip and recycled wood consumption, if tariffs raise the price of these fuels due to increased demand from the large community plants.

The supply-side policy is derived from the law of sustainable forest management. According to the law, public subsidies can be applied for energy wood procurement from young stands. A stand must fulfill the requirements of law. The primary purpose of the law is to motivate a forest owner practice silvicultural, whose effects will be realized after several decades (Ovaskainen et al. 2004). However, subsidies increase the use of wood energy, because they evoke competitiveness in convenient stands of forest chip procurements from energy wood thinnings.

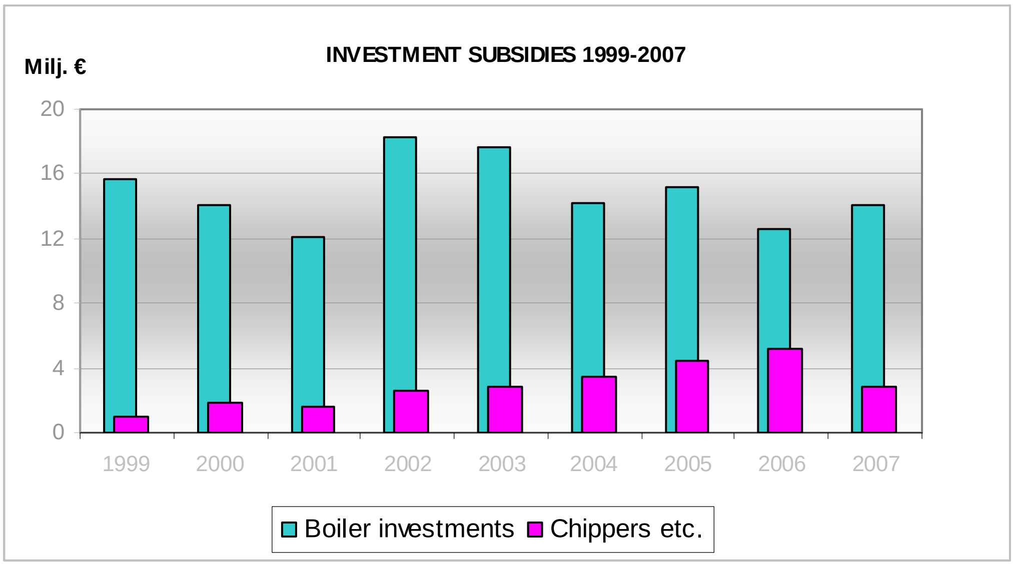


Figure 25. Investment subsidies in bioenergy in Finland during 1999-2007.

Subsidies consist of a silvicultural component and an energy wood procurement component. In the former, support for thinning work of young stand is given, despite that energy wood is not collected, but in practice it promotes energy wood supply. Finland is divided into three separate regions within the law and the subsidy levels of thinning work, of which young stands are dependent on. The exact figures of silvicultural support are collected in Table 7. Bunching, forwarding and chipping of energy wood are subsidised equally all over the country. In bunching subsidy is €3.5/m³, as well as in the forwarding activity (Pohjola and Uusivuori 2008). The chipping is subsidised by €1.7 per loose cubic meters, which is equivalent to €4.25/m³. There is also a support for planning work, which is €42 per hectare (ha).

Table 7. Amount of so called "Kemera" subsidies for young stand silviculture. [€/ha] (Finlex)

	NIPF`s own making	Bought service	Employment service
Southern Finland	135	210,5	60% of costs
Central Finland	162	252,6	70% of costs
Northern Finland	189	294,7	80% of costs

Figure 26 shows the value of electricity produced by wood in seven European countries. It is important to note that only the electricity subsidy for forest bioenergy using plant is seen in Finnish policy. However, it is worth mentioning that public support is stronger in many European countries and nation-wide policies are often in contrast to each other.

The Finnish forest industry is qualified about the mandatory increase of forest chip production for energy purposes by political interventions. The pulp and paper industry fears that mandatory policy could pose a threat to their competitiveness (Finnish Forest Industries 2008). This situation could occur if pulp wood was reallocated to energy production because of policy instruments. On the other hand, small and medium size wood product companies could benefit from forest-chips supporting policy (Hetemäki 2007). Ericsson et al (2004) remind that Swedish pulp and paper companies can earn and sell green certificates without obligation to buy them. This compensates the increased competition for wood.

The wood product or paper industry are not capable of utilizing energy wood in their main processes or in their products. Young trees with thin stems are not suitable for pulp wood, because stems are barked before upgrading and there is low ratio of wood to bark. The barking of stumps and branches is not even technically feasible with current barking technology. Thus, energy wood harvests do not threat the industrial wood procurements, if the increasing demand for wood-based fuels can be met with energy wood.

On the other hand, Gan and Smith (2006) noticed that development in technology might increase the share of the stem that the wood product industry can utilize in their processes. Therefore, the wood-product industry would accept lower quality raw material. Technology can be developed in the pulp and paper industry as well, when currently graded energy wood would be accepted as pulp wood.

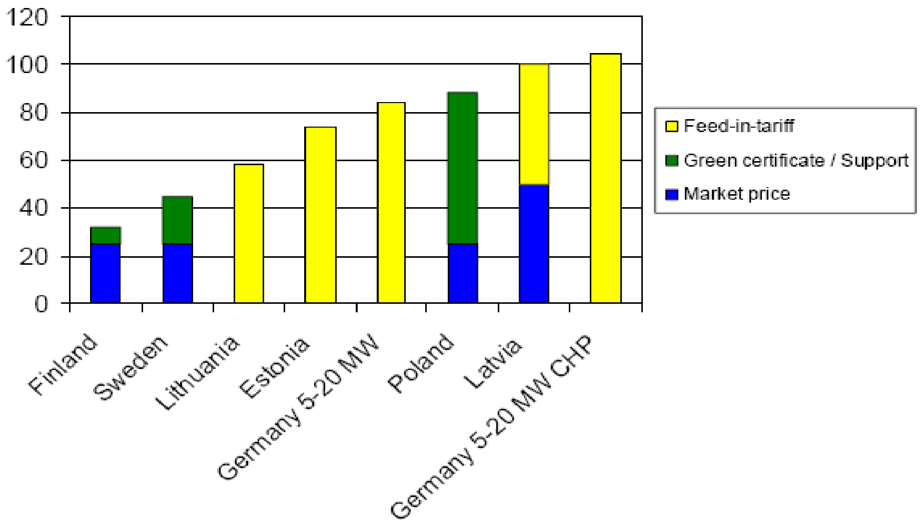


Figure 26. Value of electricity produced by wood in several European countries. [€/MWh] Modified from the source Metsäalan tulevaisuusfoorumi 2007.

6 CONCLUSIONS AND DISCUSSION

Wood-based fuels remain a significant energy source, with a share of approximately 20% of the total energy consumption in Finland. This study discusses only solid wood-based fuels that cover approximately 7% of total Finnish energy consumption. The depletion of conventional fossil fuels, political interference due to the global climate change, a surplus of forestry and economically exploitable energy wood resources are factors that continue to support the utilization of that energy source in the future.

Solid wood-based fuels form a heterogeneous energy source, where primary residues, such as different sources of forest chip, and secondary residues, such as bark and sawdust, are the most significant sources. The relative shares of different wood-based fuels will not stay stationary in Finland if the total utilization increases or remains at the current level. The share of primary residues will increase in the wood-based energy production, while the magnitude of secondary residues will diminish. Additionally, different forest chips, such as whole tree chips and stump chips, are notably distributed unevenly among different energy production facilities. This states that there is also heterogeneity among primary residues and forest chips can not considered as an one fuel.

Wood-based fuel utilization, as utilization of bioenergy in general, is often dependent on public policy. The dependence is from mainly the primary residue utilization in Finland, because by-products are a relatively inexpensive fuel. If bark was not utilized as fuel, it would be a cost as a waste for the forest industry. But because the growth potential of wood-based fuels is related to primary residues, the meaning of public policy is emphasized. There are many political incentives to support wood-based fuel utilization in Finland. Subsidies to sustainable forest management support the procurement chain of forest chips and emissions trading boost demand for wood-based fuels. Investment and electricity subsidies raise the energy producers` capability to pay for wood-based fuels.

Emissions trading is the most important policy instrument in Finland, which supports the demand for wood-based fuels. This study shows the empirical impacts of the emissions trading. This thesis discusses different wood-based fuels separately. It seems that excluding bark, the emission trading affects the utilization of wood-based fuels according to theory. The high price of credit increases the total utilization of forest chips, sawdust, industrial chips and recycled wood, but does not have a significant effect on the utilization of bark. If the competitiveness of forest chips in energy production is not sufficient, forest chip procurements are not profitable and energy wood are left in the forests. If sawdust or industrial chips are not competitive in energy production, they are allocated to the forest industry processes. Because bark does not have a competing use, the effects of the emissions trading on bark differs from those of other industrial by-products.

Another interesting finding is related to displacements in the wood-based fuel utilization between the emissions trading sector and smaller energy facilities. Decreasing credit price enhances the utilization of tradable biofuels in energy facilities under 20 MW, and vice versa. On the other hand, statistics show that the emissions trading has not reduced the utilization of wood-based fuels in energy facilities of less than 5 MW. The Finnish energy production is largely based on the centralized units. This means that the total consumption of biofuels grows while the price of allowance increases.

As the Hillring (2006) states, it seems that the interest of wood-based fuels is extended. The forest industry utilized 64% of wood-based fuels consumption in 2007. When small sawmills and other small energy facilities related to the wood product industry are also included, the share is 71%. The share has declined approximately 5% during 2003-2007, in which 4% occurred in 2005. This demonstrates a trend that is likely to continue; demand for wood-based fuels will grow among community energy facilities due to increased political incentives. When the significance of forest chips rises, the trend will be emphasized, unless biorefineries change the situation.

The credit price is predicted to stay above €20/t during the second round of emissions trading. It also appears that the demand for wood-based fuels is increasing. The supply constrains the growth in the wood-based fuel utilization in near future, but this factor is subject to much of uncertainty. The industrial by-product supply is predicted to reduce and the real potential of economically harvestable energy wood remains ambiguous in Finland. Different studies have produced diverse results. Additionally, the potential of economically harvestable energy wood does not correspond to the supply. This finding argues that the available methods for modelling the supply for forest chip are insufficient. Ignoring forest owners' forest management behaviour is the most crucial disadvantage in these methods. There are significant differences between the results of the resource focusing studies. In addition, the regional potentials and supplies vary remarkably. However, the results are suggestive.

Wood-based fuel procurement is strongly linked with the forest industry and its production. The Finnish forest industry faced the structural change after the millennium (Hetemäki 2006). This is mainly due to reduced growth of demand in the main market of the Finnish paper industry. Globalisation is the most important factor in the wood product industry. This has affected the production quantities in Finland, which are not predicted to grow anymore. The Finnish paper companies chose to focus especially on upgrading graphic and printing papers in the 80’s. The demand of these products has decreased more than for example the demand of packaging products in Europe and North America, for example.

Hetemäki (2006) predicts that the production of Finnish forest industries reduces dramatically after 2015. Along with the reduction of paper and pulp industry, the pulp-wood demand was reduces by 5-15 million m^3 compared with the demand in 2006. The same reduction is 2-3 million m^3 for the wood product industry. Thus, the overall wood demand for present forest industry products decreases 7-18 million m^3, which is equivalent to 8-20% of present wood demand. These changes strongly affect the market for wood-based fuels. The share of industrial by-products will decrease in energy production.

At the same time, the age structure of Finnish forests will evolve. There is increasing potential to harvest pulp wood sustainably (Korhonen et al. 2006). Even though energy wood procurement is still a supporting operation of industrial wood delivery, the structural change offers an opportunity from the energy wood point of view. The opportunity is formed because the more the demand of wood in traditional applications decreases, the more potential is available for new applications. An oversupply for pulpwood in the market is a possibility. Resources are allocated there, wherever the best price is paid. If the Finnish forest industries will not develop new products or applications and the timber supply will stay constant, a portion of pulp wood can be funneled to the energy production. Energy prices are supposed to rise in the future, in which case the stumpage price of energy wood can also raise.

There is also the possibility that the reduction in industrial wood demand reduces energy wood supply. Particularly, the reduction in the wood-product industry would reduce the demand for final felling and therefore reduce the availability of harvesting residues and stumps. Elands et al. (2005) say that there are a growing number of forest owners in Europe who are not economically dependent on their forests. Also, according to Favada et al. (2007), a disinterest in forest property is increasing among forest owners in Finland. When a forest owner is disinterested in his or her property, he or she is not necessarily aim at maximizing his or her objective function or profits. This can cause decrease in both production among the traditional forest industries as well as the supply of energy wood, leaving more timber potential untapped.

Because structural change of the forest industry has developed further in the USA, it is warranted to study how wood-based fuel utilisation has developed there. If Finnish and American circumstances for bioenergy utilisation were similar, the development of wood-based fuel utilisation could follow the American trend also in Finland. The structural change has not enhanced the use of wood-based fuel in the USA yet. According to the FAOSTAT, the level of use rather decreased in the late 1990’s. One reason can be that the political support of bioenergy has been relatively weak in the USA. Therefore, the competitiveness of bioenergy has not reached the competitiveness of fossil fuels extensively. The competitiveness can change in northeastern states in the beginning of 2009, when Connecticut, Delaware, Maine, Maryland, New Hampshire, New Jersey, New York and Vermont initiate their own emission trading scheme (RGGI 2008). Guo et al. (2007) say that forest biomass utilization has received more attention from public policies during last years. For example, the Advanced Biofuel Technologies Program allocates annual funding of $585 million from

2005 to 2009 for demonstrating alternative transportation fuels production and the Cellulose Biomass Program provides for loans up to $250 million per production facility for cellulose production. Figure 27 illustrates the development of the wood fuel use in the USA during 1990-2006. These preceding changes in public policy are not seen in fuel wood consumption yet.

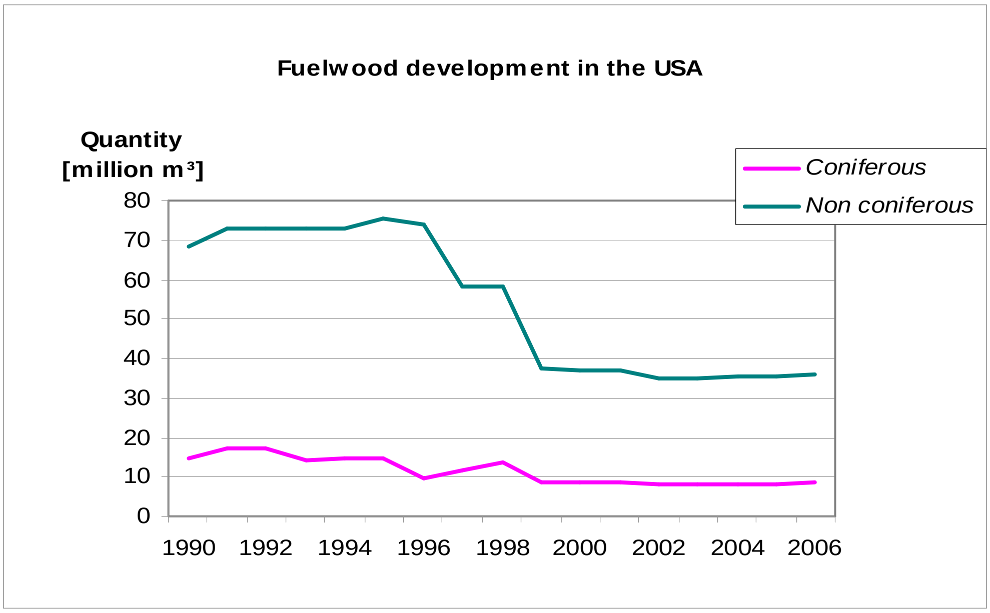


Figure 27. Fuel wood development in the USA. (FAOSTAT)

Hetemäki et al. (2006) say that increased and diverse use of forest energy is the most important opportunity of timber production in the present structural change of the forest industry. Co-production of bioenergy products and other processed bioproducts along with traditional forest industry products would also improve the profitability of traditional products. These new products could encourage the extension of production in Finland.

However, the entire bioenergy market is sensitive for changes in the operational environment. These changes can be related to, for example, political decisions or energy prices. This makes the direction of development in wood-based fuel is hard to predict. Additionally, the wood-based fuel scheme will change without new energy products from the forest industry in Finland.

Future studies of wood-based fuels are needed. The supply for energy wood could be modelled by using forest economic approach. Also, the demand for wood-based fuels involves many unsolved research subjects. Though this study offers empirical results on the impacts of the emission trading, it would be scientifically important to study these impacts by using an econometric approach. If data about fossil fuel consumption was available, the sign of the synergy parameter $Bx_i x_j$ on the theory introduced in Chapter 3, could be solved by using econometric approach. The data about fossil fuel consumption could also improve the econometric analysis about demand for wood-based fuels.

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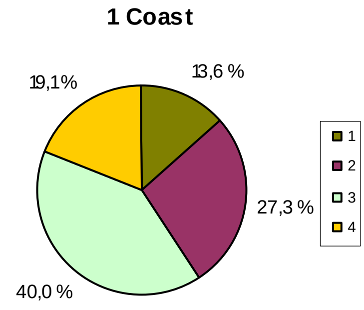
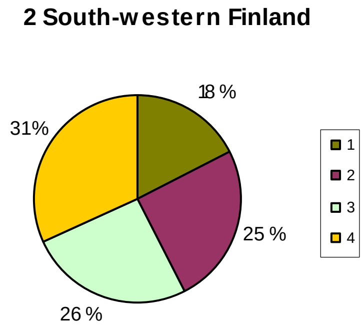
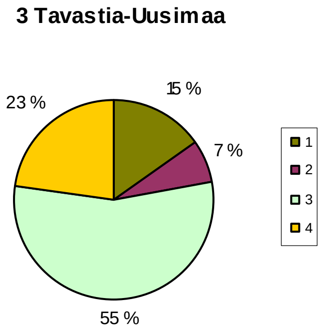
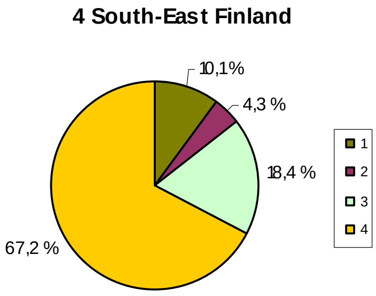
APPENDIXE 1

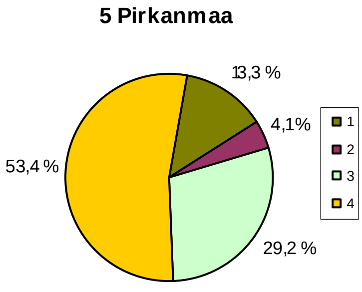
The shares of forest chip inputs among different categories of energy facilities

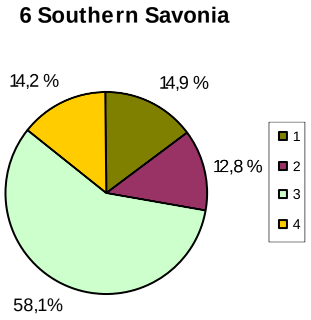


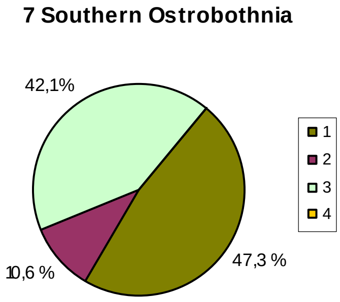


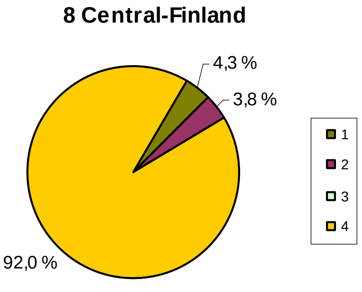


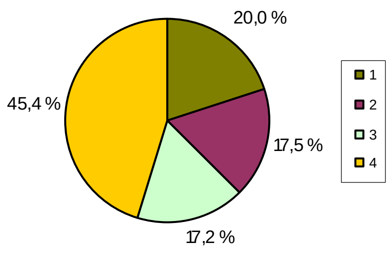




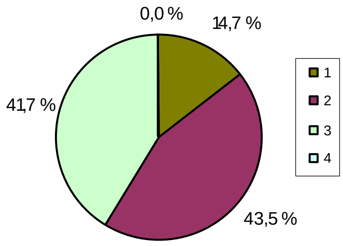








9 Northern-Savonia



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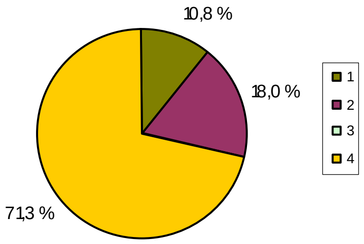
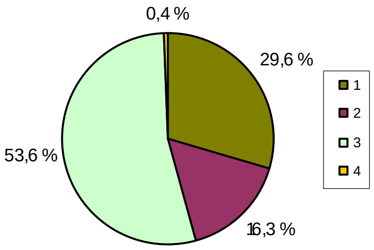


11 Kainuu



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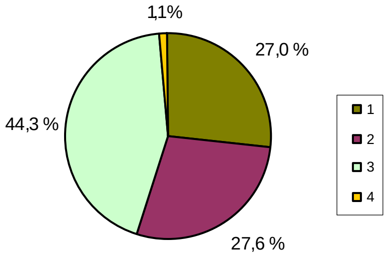
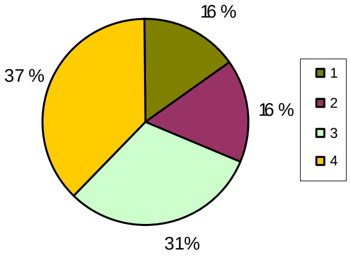


13 Lapland



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