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Modeling Energy and Climate Policy in the Finnish Forest Sector

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Abstract

The development and structural changes that the forest sector in Finland is going through emphasizes the need to modify the forest policies in Finland. A shift from a focus on timber production and traditional forestry products toward new products as well as new services is called for. New services include the climate and bioenergy potential services, landscape, travelling and recreation, and ecological services. This report describes the structural context and principles of an ongoing modeling work in Metla. This work is part of the research project The Future Development of the Finnish Forest Sector, which is sponsored by Metla and Metsämiesten Säätiö Foundation. The purpose of the modeling work is to build a policy simulation model to be able to analyze policies relevant for the Finnish forest sector.

Keywords

forest sector, energy sector, climate change, partial equilibrium, policy simulation model

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Foreword

This report is part of an ongoing project that examines the impacts of climate, energy and forest policies on the Finnish forest and energy sectors. One of the objectives of the project is to build a partial equilibrium simulation model, in order to run policy simulations and analyze the effectiveness and impacts of policy measures.

The purpose of the present paper is to provide the background for the model building process. It describes the main features of the Finnish forest and energy sectors. In doing that, it discusses the demand and supply structure for the various forest products, energy products, and roundwood and energy wood. In addition, the relevant simulation modeling literature, and the modeling of different climate, energy and forest policies are discussed. The study concludes by outlining the main features that the simulation model being built in the project will have.

The study is part of the research project “The Future Development of the Finnish Forest Sector” being carried out at the Finnish Forest Research Institute (Metla). This project was made possible by funding from Metsämiesten Säätiö Foundation.

This work is an outcome of joint effort by the authors. Of the particular chapters or sections the main responsibility is the following: Hetemäki & Uusivuori chapters 1 and 5; Hetemäki section 2.1.4; Kangas chapter 4; Laturi chapter 2.2 and 3.2; Lintunen chapter 2.1 and 3.1.

Vantaa, 25.9.2009
Jussi Uusivuori and Lauri Hetemäki

1 Introduction

National forest sectors around the globe are in the process of being reshaped dramatically. Forests and forest sectors with their products and services are one of the focuses in the national and international climate policies world wide. This is true also in terms of energy policies: in many countries forests provide substantial potentials for bioenergy and in building up renewable energy sectors.

Finland, as many other industrialized countries with sizable forest sectors, is undergoing a process where the traditional wood utilizing industries are cutting down their operations in the country and redirecting their new investments to mainly those markets where the product consumption is increasing the most and/or where the wood fiber supply is based on fast growing plantation forestry.

Along with the forest industrial changes, there are also public attitude changes toward forests and their use in developed countries. These changes are reflected in the land ownership behavior of nonindustrial private forest owners. The private forest owners, who own most of the forests in Finland, are being urbanized, and are becoming to some extent less production minded. This will influence the forest sector in the upcoming decades.

The development and structural changes that the forest sector in Finland is going through emphasizes the need to modify the forest policies in Finland. A shift from a focus on timber production and traditional forestry products toward new products as well as new services is called for. New services include the climate and bioenergy potential services, landscape, travelling and recreation, and ecological services.

The Government of Finland launched its National Forest Programme 2015 in spring 2008. The Finnish Forest Research Institute (Metla) was involved in providing background work for this programme. In particular, Metla helped the Ministry of the Agriculture and Forestry in preparing scenarios for the development of the forest sector. One aspect of this work was using available modeling tools to study possible scenarios and policy impacts within the forest sector. This work showed that there is a discrepancy between the demand side and supply side models describing forest sector in Finland. From the policy perspective, the description of the private forest owner behavior should be strengthened in the modeling work.

Metla was also involved in the National Climate and Energy Strategy work led by the Ministry of Employment and Economics during 2007–2008. This program outlines the policy responses that Finland will follow to meet the EU, Kyoto and IPCC commitments in climate mitigation and adaptation and in terms of bioenergy targets One lesson from that work has been that for policy purposes the forest and energy sectors in Finland should be viewed within a more integrated framework than currently is typical. Therefore also, simultaneous analysis and modelling of the forest and energy sectors is becoming a necessity, due to the increasing role of forest biomass based energy production. The models should also be more conducive to integrating policy tools in order to study their impacts.

These are some of the central issues that are addressed in this paper. In particular, the work analyses the links between the roundwood supply side and demand side by basing the supply side on the behavioral optimization of the nonindustrial private landowners. In addition, the energy sector and the role of energywood is discussed.

In summary, the modeling initiative described in this report has three main ‘drivers’ or objectives within which it tries to make a contribution to existing modeling work:

– Linking forest and energy sectors
– Linking forest industry and accurate nonindustrial private forest owners’ behavioural descriptions
– Enable improved integration of policy tools in the model, in order to analyze policy effectiveness and impacts.

The purpose of this report is to describe the background for building of a new partial equilibrium model for the Finnish forest and energy sectors, which incorporates the three features listed above. In doing this, we discuss e.g. the various approaches that have been adopted in the literature for building sectoral partial equilibrium models.

The outline of the report is as follows. First, the structure of wood demand and supply in Finland is described. This lays the background for what one needs to model, in order to capture the salient features of the Finnish forest sector and wood using energy sector. Next, the forest, climate and energy policies are discussed. That is, the content of the commonly used polices and their implications are presented. Next, the different approaches and more technical issues related in modelling demand and supply, as well as different policy measures are discussed. This discussion leads us to consider the essential question of this report, namely: What type of structure and features should a partial equilibrium model have, which would allow to study the effectiveness and implications of various forest, climate and energy policies to Finnish forest and energy sector?

2 Wood demand and supply in Finland

2.1 Structure of the demand

Wood is a versatile raw material which can be classified into several sub-categories. Here, we use a classification of wood based on tree species and suitable raw material uses. The demand for wood consists of the demands for these separate categories. There are three main users of the wood: forest industries, energy industries and households. The forest industries use wood as a raw material for various types of final goods. All the users, including forest industries, utilize wood in thermal energy and/or electricity production via different kinds of processes. In addition, there is a wood demand that does not involve harvesting, for example climate services.

In this section, we present the wood categories and the level of their demand and the industries that use them. A special emphasis is given to the forest bioenergy generation, where the forest biomass demand is expected to grow significantly due to the climate and energy policies.

2.1.1 Wood categories

The usage of the wood depends on its physical properties. These properties depend on species of the tree, types of forest site, silviculture etc. From the viewpoint of the consumer, the main characteristics of the wood are species of the tree and size and quality of the tree stem. We classify the timber by these attributes.

Due to the climate, coniferous forests are widespread in Finland, as approximately 80 % of the growing stock volumes consist of softwood (Metla 2007a, 67). The main softwood species are Scots pine and Norway spruce. The prevalent hardwood species is birch. These three species dominate the Finnish wood markets although there are some other species that are used in smaller scale. As their names suggest, the softwood is less dense (on average about 400 kg/m^3 basic) than hardwood (490 kg/m^3 basic). However, the effective heating values of the wood species are quite similar (dry matter: 19.2 MJ/kg) (Alakangas 2000). The fibers in softwood are longer than in hardwood which is reflected in the characteristics of various pulp and paper categories.

Trees of all species are divided into two timber grades. These grades are saw-timber trees and pulpwood. The grading is based on the size and quality of the yielded roundwood. The trees with large diameter, so that they yield at least one log, are considered to be saw-timber trees (abbreviated here as logs).[1] Trees with smaller diameter, poor quality large trees and top stems of the larger trees are pulpwood. There are also more rarely used timber grades that are more strictly related to the suitable raw material use (e.g. post, small-diameter log, veneer log etc.). However, here we focus on the two main timber grades.

The timber grades do not cover all the wood consumption. Firstly, a share of the trees cannot be categorized as logs nor pulpwood. These include mainly small-sized trees, whose diameter size is too small for pulpwood. Secondly, the logging residues and stumps and roots of all the harvested trees do not belong to any of the above-mentioned groups, yet they are utilized. These two groups can be burnt as such or after chipping into forest chips. Therefore, we call this category as forest chips. Thirdly, there is roundwood that is used in energy generation. This wood is mostly chopped fuelwood for the small-sized dwellings and some of it is utilized by heating and power plants. Since industry chips their otherwise unusable roundwood, we include its portion of energy roundwood

[1] Log is a straight stem with top end diameter at least 15 cm. ‘Small-diameter log’ is thinner.

into the forest chip category. We label the fuelwood of dwellings as fuelwood. The forest chips and fuelwood are jointly labeled as energy wood.

The wood types above (logs, pulpwood, fuelwood and forest chips) are harvested from the forests. In addition there are the wooden residues of forest industry processes. These industry residues contain bark, dusts and chips and they are utilized as raw material but also in energy generation.

2.1.2 Demand due to processing

Forest industries

Forest industries use wood as their main raw material. The industry is divided into wood-product and pulp industries. The four main sub-industries of the wood-product industry are sawmilling, plywood and veneer, particle board and fiberboard industries. The other intermediate level industries are manufacturing of builder’s carpentry and joinery, wooden containers and other wooden products. The pulp industry is divided in to mechanical, semi-chemical and chemical pulp industries.

Sawmilling industry has the largest roundwood input volumes of all the wood-product industries. It produces sawn and planed sawn timber and other machined wood. The second largest industry in volume is plywood and veneer industry. As the name suggests it produces veneer sheets and their upgrades. Cutting, barking, sawing and planeing of wood produces chips and dusts of various grain sizes in all the wood-product industries. These by-products are used by particle board and fiberboard industries which produce various wood based boards with or without adhesives.

The pulp industries produce several pulp types for different paper categories. There are two processes for making mechanical pulp: grinding and refining. In the grinding process small logs (bolts) of pulpwood are pressed against rotating stone. In the refining process chipped pulpwood is ground up in refiner plates. Of the two, the refining process consumes more electricity, but it is gentler to fibers. Spruce is the dominant raw material for mechanical pulp. When wood is pretreated with chemicals prior to refiner plates, the pulp is called chemi-thermomechanical pulp (abbreviated as semi-chemical pulp). In the chemical pulp process chemicals and heat separates the fibers of the wood from lignin. The yield is low since the lignin is separated from fibers, but the fibers remain longer than in mechanical pulp. Chemical pulp processes need thermal energy which is received from burning the lignin of the black liquor in a recovery boiler. The pulping processes that use chipped wood can also use the by-product chips of the forest industries.[2] A rough outline of forest industries’ inputs and outputs is presented in Table 2.1.1. (Finnish Forest Industries 2007).

Production of sawmilling industry is an order of scale larger than in other wood product industries. In 2008 the wood-product industries produced 9.9 million m^3 of sawn goods, 1.3 million m^3 of plywood and veneer sheets and 0.3 million m^3 of other wood-based boards in Finland (Metla 2009a). Production of sawn goods nearly doubled during the 1990’s but has leveled since that. Plywood industry is yet growing, even if its production levels are still small compared to the sawmilling. Production levels of chemical pulp are about one and a half times the levels of mechanical pulp, including semi-chemical pulp. In 2008 pulp industries produced total of 7.2 million tons of chemical pulp and 4.5 million tons mechanical and semi-chemical pulp. Production of chemical pulp increased quite steadily for thirty years and production doubled in twenty years from mid-eighties. Production of mechanical pulp grew at a similar rate. Since 2006 the production of pulp products has declined by 2.5 million tons (Finnish Forest Industries 2009).

[2]Chips are here defined as wooden residue that is or can be chipped to a size large enough to be used as a raw material for pulp industries. Dust contains finer residues.

Table 2.1.1. A rough outline of forest industries' inputs and outputs.

Industry	Main input	Main products	By-products/residues
Sawmilling	Logs: soft wood	Sawn and planed wood	Chips, sawdust, bark
Plywood & veneer	Logs: spruce & hardwood	Plywood and veneer	Chips, dusts, bark
Boards	Chips, sawdust	Particle & fiberboard	Cutting residues, dust
Other wood products	Logs: pine	Wooden products	Cutting residues, dust
Mechanical pulp	Pulpwood: spruce, chips	Mech. pulp	Heat, bark
Semi-chemical pulp	Pulpwood: hardwood, chips	Semi-chem. pulp	Bark
Chemical pulp	Pulpwood: pine & hardwood, chips	Chem. pulp	Waste liquors, bark

A large share of Finnish made pulp is also used in Finland (67 % in 2008). The volumes of paper production are large (2008 figures): magazine paper 5.9, fine paper 2.9, other papers 1.4 and cardboard 2.9 million tons (Finnish Forest Industries 2009). Production over time is shown in Figure 2.1.1. Growth was steady until the year 2000, after which it has stopped. In fact, in recent years there have been significant capacity cut-downs, due to which the paper and paperboard capacity has declined from the 15.5 mill. t in 2005 to 12.7 mill. t in 2009, and the pulp capacity from 14.9 mill. t in 2006 to 12.2 mill. t in 2009.

Since the forest industries in Finland are large compared to the size of the nation, a significant share of produced goods is exported. In 2008, the total value of forest industry product exports was 11500 million € (including wood products and pulp and paper). Wood products cover about a quarter of the export value while pulp and paper industry covers the rest of the value. The export volumes of forest industry products follow the same trends as production levels: exports of sawnwood increased rapidly in 1990s, but have levelled after that. However, exports of plywood have been increasing also in the last decade.

One-fifth of wood pulp is exported from Finland, mainly to the companies' own mills in Central and Western Europe. The exports consist mainly of sulphate pulp. In case of paper, about 90 % of

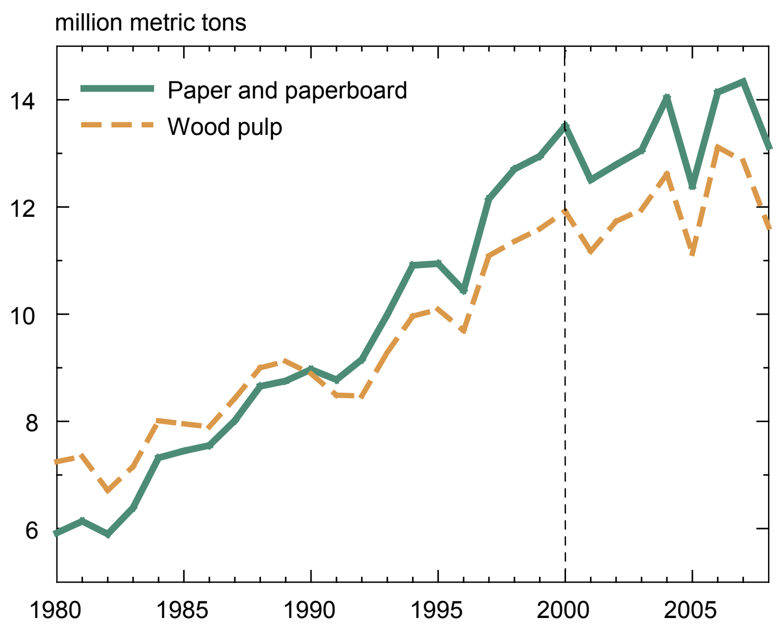


Figure 2.1.1. Pulp and Paper Production in Finland 1980–2008 (Finnish Forest Industries 2009).

Table 2.1.2. Wood products exports from Finland in 2008 (million euros) (Metla 2009d).

	Euro	Asia	North America	Africa	South America	Oseania	Total
Sawn goods	666	240	1	245	–	2	1154
Plywood	543	48	15	2	0	1	610
Veneer sheets	34	4	1	0	–	–	39
Particle board	22	0	0	–	0	–	22
Fiberboard	16	2	0	–	0	0	17
Wood pulp	837	217	2	14	5	–	1 076
Paper	4 120	433	455	78	264	157	5 507
Paperboard	1 333	250	90	47	33	25	1 778
Other wood products	972	119	68	6	11	10	1 187
Total	8 641	1 323	633	413	314	194	11 518

the production is exported. The paper and paperboard exports grew for thirty years almost hand in hand with pulp and paper production. The main export products are nowadays magazine and fine paper totalling over 8 million tons. Paperboard is also important export product with quantity of 2.6 million tons. Newsprint has lost its significance and the exports of kraft and other paper have been quite constant. Exports of these paper grades totalled in about 0.9 million tons. Wood products industry is less export orientated industry than paper industry, since about 40 % of the production is consumed in domestic markets. Finnish forest sector products are exported to all around the world, as can be seen from Table 2.1.2. In value, most important import countries of Finnish wood products are EU-countries, Japan, Russia and Egypt (Metla 2009d).

Roundwood demand

The consumption of wood in forest industries is presented in Table 2.1.3. The division by timber grades follows the industry classes: logs are mostly utilized in wood-product industries and pulpwood in pulp industries. In the sawmilling industry softwood is the main raw material and in the plywood and veneer industry spruce and hardwood. In the pulp industries the main raw material for mechanical pulp is spruce, for semi-chemical pulp hardwood and for chemical pulp, pine and hardwood. The board industries and pulp industries use also imported chips as well as chip and dust by-products from all branches of the forest industries.

Consumption of logs has been quite stable for a decade in Finland. Log consumption was almost at the same level in 2008 as it was in 1997. Pulpwood use, however, has been increasing, especially

Table 2.1.3. Consumption of wood in forest industries in Finland in 2008 (million m^3) (Metla 2009a).

		Wood-product industries				Pulp industries			Total
		Saw-milling	Plywood/ veneer	Boards	Other	Mech.	Semi-chem.	Chemical	
Logs	Pine	10.48	0.00	–	0.37	–	–	0.27	11.13
	Spruce	9.84	2.05	–	0.02	0.54	0.01	0.06	12.51
	Hardwood	0.17	1.45	–	–	–	0.00	0.01	1.63
Pulpwood	Pine	1.20	–	–	–	0.14	–	13.99	15.33
	Spruce	0.38	–	–	–	7.20	0.08	2.66	10.31
	Hardwood	0.00	0.00	–	–	0.89	0.94	10.91	12.75
Imported chips		–	–	0.06	–	0.17	0.00	2.38	2.61
Sawmill chips & dust		–	–	0.62	–	1.95	0.64	6.40	9.61
Total		22.08	3.50	0.68	0.38	10.88	1.67	36.68	75.87

in the case of hardwood. In the period 1996–2006, the total pulpwood use increased by 38 % and hardwood by 50 %. By 2008, the total pulpwood use has decreased 10 % and hardwood 15 % from peak rates of 2006. Some of the Finnish roundwood and wood residues are also exported. In 2008 exports were 1.1 and 0.37 million m^3 of roundwood and wood residues respectively. The joint value of these exports was 130 million €. Roundwood is mainly sold to Sweden (72 % in 2008) and wood residues to Sweden, Denmark and The Great Britain (Metla 2009d).

2.1.3 Demand due to energy generation

Wood-based energy generation

Demand for wood by the energy sector is generated by the use of the wood fuels. Wood fuels are mainly utilized by forest industries, energy industry and households. Fuels are used in order to produce heat and electricity (power). Heat is needed for industrial processes and heating of buildings. Therefore, heat production is divided into industrial steam and district heating segments. Heat and power can be produced separately or by combining heat and power production (CHP). Wood based industrial heat is mainly produced by the forest industries whereas energy industries produce separate power and most of the district heating. Households' wood fuel use is mostly heating of their dwellings.

In Finland 21 % of the consumed energy in 2008 was produced by wood-based fuels (Statistics Finland 2009a). The distribution of energy generation by wood fuels is presented in Table 2.1.4.[3] Most of the wood-based energy comes from industrial CHP, which practically means the forest industries. Also the heating of the small-sized dwellings has a large share. In fact, at the present moment energy industry generates quite a small share of wood-based energy.

Table 2.1.4. Wood fuel consumption in energy production in Finland in 2007 (PJ). Separate power production includes CHP power production with auxiliary condensers and separately recovered condensing power. DH refers to district heating (Statistics Finland 2009c).

Separate production				CHP		Total
Power	District heat	Industrial steam	Heating of dwellings	In DH	In industry	
10.5	5.0	10.7	48.6	18.8	191.1	285

The climate change sets increasing pressures on energy industries. The EU policies targeted to mitigate the change, expand the use of renewable energy sources (RES). For Finland, the target share of renewable energy in final energy consumption is 38 % by the year 2020 (EC 2008b). In 2006 the share was 28.9 % (Statistics Finland 2009a). Renewable energy is based on biomass, wind, hydro, solar and geothermal sources. In Finland, most promising renewable energy sources are forest biomass and wind power. Whatever the Finnish solution for reaching the renewable energy targets will be, it is clear that wood-based energy generation will increase.

Some remarks on wood-based energy generation technologies

In this section we present a rough outline of the energy generation technologies when wood fuels are utilized. Although the technology is highly evolving the basic guidelines can be given. This section draws on VTT (2004), Helynen et al. (2002) and Jalovaara et al. (2003).

Heat and power can be produced separately or they can be co-generated. Separate heat production of heat has high efficiency of 80-90 %, while power production has electricity efficiency of 30–55

[3]The figures of Table 2.1.4 are partly inaccurate since part of the small heating and industrial plants are not included. The total wood energy produced in Finland in 2007 was 295 PJ (Statistics Finland 2009c, 59).

% depending on technology used. While the total efficiency (thermal efficiency) of cogeneration (CHP) is typically high, nearly 90 % or more, the separate production is needed also, since the heat and power loads differ in size as well as in timing. In cogeneration the total efficiency is divided between electricity and heat production efficiencies determined by power-to-heat ratio of the plant. Typically, electricity efficiency cannot be made in cogeneration as high as in separate production.

Wood fuels can be used in direct combustion, in combustion after gasification or after further processing. The case of processed wood fuels is discussed separately in next section, here we focus on combustion and gasification.

There are four major types of combustion technologies used: pulverized fuel burners, grate firing, fluidized bed combustion and recovery boilers. Pulverized fuel burner is least suitable for wood fuels and it is in Finland mainly used with coal and peat. There are estimates that up to 5 % of input power could be wood in pulverized fuel burner, without any modifications in fuel injection processes (e.g. Helynen et al. 2002). This kind of cofiring has been experimented in Finland. Grate firing is typical in households and small-scale heat production. With traveling grate the technology is suitable for peat use and also for cofiring of peat and wood.

More large scale combustion of wood fuels is done in fluidized bed and recovery boilers. There are different kinds of fluidized bed technologies and more is under development. Typical models utilized are atmospheric bubbling and circulating fluidized bed combustion, BFBC and CFBC respectively. FBC technologies have some favorable properties. Firstly, combustion is done in low temperature and the process mixes the fuel with air which reduces emissions. Secondly, the process is suitable for multi-fuel use. In Finland these fuels are typically peat and wood. The other large scale combustion technology is the recovery boiler. These boilers are used in chemical pulp processes for recovering the process chemicals. While the recovery takes a part of the heat produced, the rest is used in paper processes or as district heating.

Gasification is another way to produce energy from wood fuels. These technologies are developing rapidly and only some main principles are presented here. In gasification fuel is heated in low oxygen environment, which doesn't allow proper burning. While some of the energy in fuel is consumed in the heating process, most of it is separated in various gases which constitute syngas (synthesis gas, also product gas). After cleaning, the syngas can be used in similar processes as natural gas, even though syngas has lower heating value. Typical direct uses of syngas are combustion in gas engine or in gas turbine. Syngas is also easily incorporated in cofiring in existing plants. The gas engines are suitable for small scale power production and they have good total efficiencies. Gas turbines have been used as source of peak power, but this has changed due to the development of combined cycle technologies. In combined cycle exhaust gases of gas turbine are reheated and they power a set of steam turbines. This combination raises the electricity efficiency over 50 % and it can also be utilized in CHP. The technology for integrated gasification and gas turbines with combined cycle (IGCC) is under rapid development. It is good to notice that combined cycle technology for boilers (pulverized fuel and fluidized bed) needs pressurized combustion and it is one line of research also.

Processed wood fuels

Wood fuels can be refined. Instead of burning the wood and syngas, both of them can be processed to have higher energy density and additional uses, e.g. liquid transport fuels. There are multitude of processing technologies and they are under intense research. Therefore the field is evolving rapidly. We illustrate here some of the prominent current and future technologies. Good introduction to the topic in Finnish can be found in (VTT 2004).

The pellets and briquettes are compressed wood dust and chips. The raw materials are typically by-products of sawmills and other mechanical forest industries. This way the humidity of the dusts is low enough (10-15 %) for direct processing. In the case of moist raw materials they need to be dried first, which consumes energy and raises production costs. Since pellets have high energy density and uniform quality they are a usable fuel for many applications. In Finland the production of pellets has grown in recent years (see Figure 2.1.2). Most of the pellets are exported (60 % in 2008) but domestic use has been increasing.

Also the other by-products can be processed. For example bark can be powdered to be used in cofiring with fossil fuels in a burner. The abundant by-product in chemical pulp industry is lignin of black liquor and it can be utilized in several ways. The usual burning in recovery boiler can be replaced by gasification and the product gas is usable for further processing. It is also possible to extract the lignin and utilize it in energy production or as a raw material. Raw soap and tall oil are also raw materials for fuel products.

Wood fuel can be processed to liquid fuel. Ethanol is received via hydrolysis and following fermentation of sugars. The hydrolysis of wood is more difficult than that of starch containing biomass and lignin cannot be utilized in the process. Ethanol can be used as such or further upgraded. Another way to liquidify wood is via pyrolysis. The yield of the product called pyrolysis oil is high and it is suitable for replacing fuel oil.

Syngas received from gasification of wood biomass opens new ways to upgrade wood fuels. These methods are numerous (e.g. Spath and Dayton 2003). Most promising technologies from pulp and

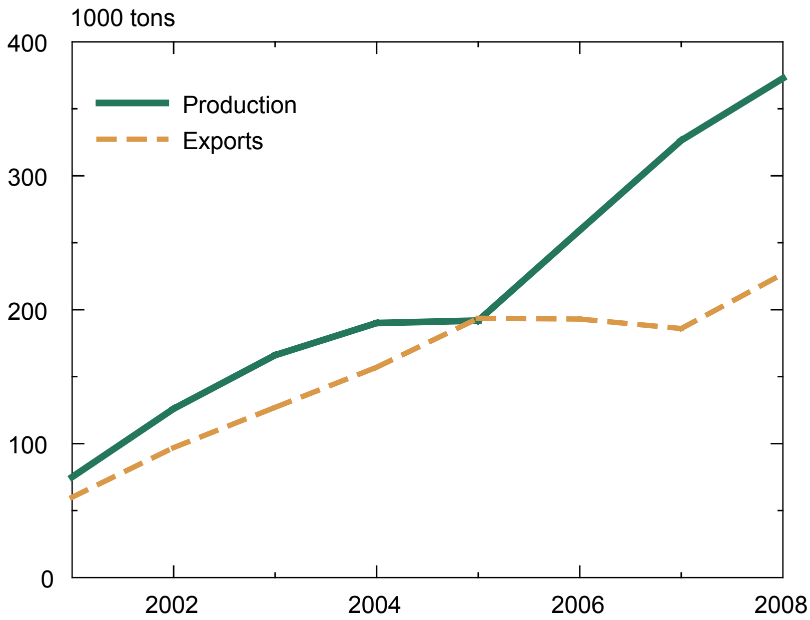


Figure 2.1.2. Production and exports of pellets in Finland (Metla 2009b).

paper industries are Fischer-Tropsch (FT) fuels, dimethyl ether (DME) and alcohol fuels (Larson et al. 2006). FT synthesis of natural gas and gasified coal to liquid fuel is quite mature but growing industry and FT synthesis of biomass-based syngas has received wide interest. The product of FT synthesis are hydrocarbons that can be refined to diesel type fuels. DME is also usable in diesel-engines but it needs pressurized fuel and refueling systems in order to be in liquid state. Since its burning is more clean than normal diesel oil it has received interest as a fuel for centrally refueled urban fleet vehicles. Increasing use of ethanol as a transport fuel makes also the syngas-to-alcohol processes interesting. The methods studied are catalytic synthesis and fermentation. Through gasification also the lignin can be utilized in alcohol production (Larson et al. 2006).

Wood fuel demand

In Finland, a significant share of the consumed wood ends up in energy generation. The total consumption of wood is presented in Table 2.1.5. Fuelwood and forest chips account for some 13 % of the direct consumption of harvested trees. More than half of the solid by-products and residues are utilized in energy generation and roughly half of the barked raw material of chemical pulp is burnt as black liquor in recovery boilers. Wood spent for energy generation totals 21.6 million m^3 of which forest chips have a share of 21 %. If the volume of black liquor is added, approximately 40 million m^3 of wood was used in energy production in 2009, which is about one half of the total roundwood consumption.

In order to analyze the energy use of wood in more detail, we study the segments of the wood fuels. In Table 2.1.6 these segments with their possible uses and tradability are shown. Although they are both forest chips, small-sized trees and logging residues are separated, since their collection costs are different and there are differences in their usability. Fuelwood for small-sized dwellings is typically traded in a small scale or not traded at all but used directly by the forest owner. Markets are, however, emerging. Industrial chips are suitable raw material for pulp and boards industries

Table 2.1.5. Total consumption of different wood types in Finland in 2009 (million m^3) classified by supply type and final user. Waste liquors are not included. Forest chips use by small-sized dwellings is estimated to be 0.6 million m^3. (Metla 2009a).

Harvesting and imports				By-products and residues	
Forest industries		Energy generation		Forest industries	Energy generation
Logs	Pulpwood[1)]	Fuelwood	Forest chips		
25.27	40.99	5.40	4.63	9.61	11.60

[1)] Includes imported chips (2.61 million m^3)

Table 2.1.6. The main segments of wood fuels, their main use and tradability. Logging residues include stumps and roots.

Source	Segment	Use	Trading
Harvesting & thinning	Small-sized trees	Energy	Market (forest chips)
	Logging residues	Energy	Market (forest chips)
	Fuelwood	energy	Partly non-market
By-products and industrial residues	Industrial chips	Multiple	Market
	Sawdust	multiple	Market
	Bark	Energy	Mainly non-market
	Liquors	Energy	Mainly non-market

and sawdust is suitable for board industries only. Chips and dusts can also be used in pellet production. Bark and black liquor are typically burned at the production site. Other waste liquors can be processed and they are traded. Even though boards industry is quite small in comparison with the sawmilling and plywood industries, the fact that it uses dusts and chips as raw material, makes it important in wood fuel considerations.

Most important wood fuel in Finland are waste liquors of pulp industry, especially black liquor. It covers half of the total wood fuel consumption. Other significant segments are fuelwood of small-sized dwellings and forest industries' bark residue. They cover jointly 28 % of the wood fuel consumption. Forest chips cover 11 % and its share is bound to increase. Wooden by-products other than bark have small shares since they are mostly spent as raw material. The consumption of wood fuels is presented in Table 2.1.7.

In recent years the amount of forests chips used has been rising rapidly. The utilization of forest chips in is presented in Figure 2.1.3. The forest chips consumption by the households is based on a study in 2000/2001 and 2007/2008 heating seasons but statistics on industrial use are compiled every year. The growth of use in CHP has risen strongly. The increase has been almost 25 % a year.

Table 2.1.7. The consumption of wood fuels in Finland in 2008 measured in volumes and energy content. Waste liquors are mainly black liquor and other by-products include e.g. tall and birch oil and methanol. Other contains recovered wood, pellets and briquettes and other residues. Energy distribution between fuelwood and other wood fuels is partly estimated. Value of small-scale forest chips use is based on study on 2007/2008 heating season (Metla 2009a; Metla 2009b; Metla 2009c).

Forest chips		Wooden by-products			Other by-products		Fuelwood	Other	Total
Industry	Small-scale	Chips	Dusts	Bark	Waste liquors	Other			
Million m^3									
4.03	0.60	0.76	1.61	7.09	–	–	5.40	2.15	21.6
PJ									
28.9	4.3	5.5	11.9	45.8	144.0	4.0	38.9	15.5	299

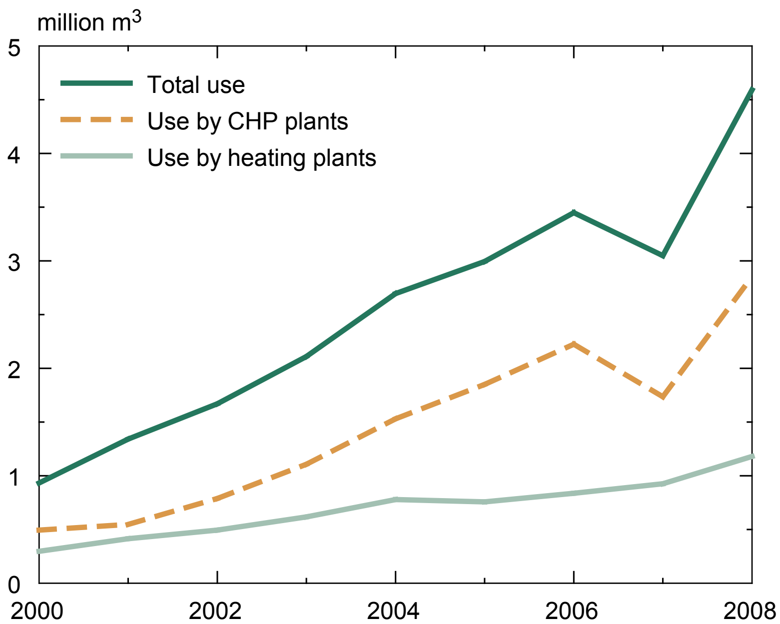


Figure 2.1.3. The consumption of forest chips. Total use includes households and CHP and heating plants (Metla 2009b).

The use in heating plants has been also rapid (almost 19 % a year), but the use is in smaller scale. In year 2007 forest chip use in CHP plants decreased notably due to the reduction in emissions credit prices. Heating plants are not included in the emissions trade and there the growth has been more steady.

The wood fuel prices are site dependent since the markets are local and evolving. There are, however, average estimates for the prices paid by heating and power plants. In 2006 the average price of forest chips was 11.95 euro/MWh. The industrial residues were cheaper, with price of 9.7 euro/MWh for industrial chips and dusts and 9.2 euro/MWh for bark (Metla 2007a). The prices have been increasing for several years and the rise is expected to continue as increased demand leads into the utilization of high cost wood sources. In 2009 forest chips price was 16.8 euro/MWh (Statistics Finland 2009b).

2.1.4 Conclusions and future outlook

The discussion in chapter 2.1 has shown that woodfiber consumption and production structures in Finland are heterogeneous. There are many users of wood, and the supply of woodfiber originates from a number of different sources. However, the relative importance of different actors in the wood market varies considerably. The forest industry is the dominant user of wood. In 2007, out of the total wood consumption, 93% was due to forest industry demand, 6% due to small-sized dwellings, and 1 % by heating and power plants.

Given that the share of exports in the Finland's total production of paper is around 90 %, and for sawnwood about 60%, the Finnish forest products and roundwood markets are heavily dependent on EU and global forest products markets. The business cycles and structural changes in global forest products markets will directly influence the harvesting activity and roundwood production in Finland.

The overall picture of wood consumption pattern obscures the fact that a significant part of the wood consumed by forest industry ends up in combustion. Figure 2.1.4 shows that almost half of the woodfiber consumed annually in Finland is used for combustion. A significant part of this combustion is related to forest industry processes. In chemical pulp production, the bark and the black liquor, or about 45% of the woodfiber coming to the pulp mill, is used for energy generation. In sawnwood industry, the bark and roughly a third of the sawdust ends into energy production. In mechanical pulp process, basically only the bark is used for energy generation.

As a result of this close interconnection of forest industry output and woodfiber based energy generation, the level of forest products output is a significant determinant of woodfiber energy use. Therefore business cycles and the long term structural changes in the forest industry markets, have direct implications to the short-term and long-term consumption of woodfiber for energy purposes in Finland. This is one important feature indicating the need to analyze the forest and energy sectors simultaneously.

The links between forest products outputs and woodfiber based energy production take place at many different levels, and at least from the policy analysis point of view, are also complex. First, in the demand side, there are large number of processes and users which consume woodfiber for energy generations. For example, industry process heat and power, municipal district heating plants, smaller scale heating and power industry, pellet industry, households, as well as exports of woodfiber for energy purposes. Similarly, the sources (supply) of woodfiber for energy purposes

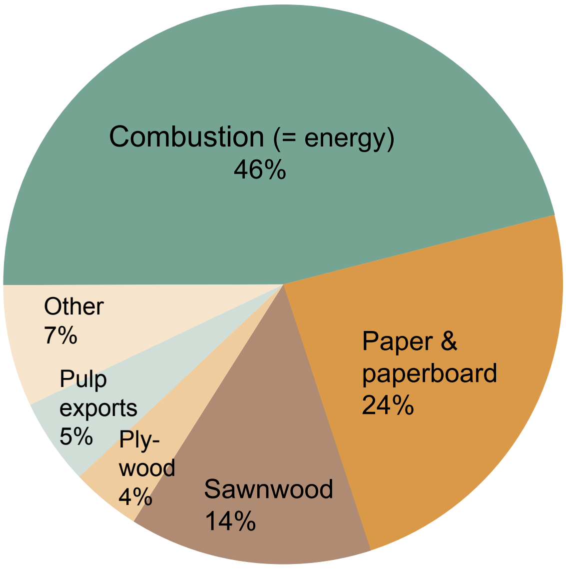


Figure 2.1.4. The wood consumption in Finland in 2004 (Data Source: Statistics Finland).

are manifold. It may originate e.g. as forest chips and stumps from clear-cutting sites, bark, wood products industry logging chips or sawdust, black liquor, thinnings, or pulpwood harvests. What complicates the picture even more, is the fact that some of these woodfibers can be substitutes or complements to other raw materials in energy generation, such as for oil, coal, natural gas, or peat. Indeed, the co-firing of woodfiber and peat is of significant importance in Finland.

If policy or markets affect any of the woodfiber demand or supply side factors, this is likely to have feed-back impacts on the other components. For example, a feed-in-tariff for wood energy is, ceteris paribus, likely to have impact on roundwood prices, as well as the price of and demand for peat. On the other hand, a demand shock to the paper or sawnwood markets would have direct implications to the level of forest products output, and therefore, also to the amount of woodfiber consumed in Finland. This would in turn affect the roundwood markets, as well as the possibilities in generating woodfiber based energy in Finland. Therefore, in order, to be able to fully assess the policy or market impacts, one would need to model all the possible linkages between the different factors and sectors.

Modeling the different feed-back linkages between forest and energy sector is a very demanding task, which however, appears to be coming ever more important. For example, the need to regulate CO_2 emissions and the objective to increase renewable energy production will increase the importance of this in the coming decades. Also, the concerns related to oil prices and energy security, drive the development towards increasing the role of forest biomass energy. Evidently, also new polices which enhance the forest and energy sector linkages will be put in place in the coming years.

In order to illustrate what type of implications could result to Finnish forest and energy sectors, we take up few possible examples of the foreseeable development. This will also help to point out some of the key features that a policy relevant simulation model of the Finnish forest and energy sector needs to incorporate.

Future outlook

Finland's forest sector is currently undergoing a structural change. The largest impacts of the structural change are probably still to be seen in the coming decade or so. Some of the essential features of this structural change are the following:

– Forest industry is cutting its capacity in Finland, and redirecting its investments mainly to those markets where the product consumption is still increasing, or where the wood fiber supply is based on fast growing plantation forestry. Basically, the industry is continuously looking at the most competitive investment cites globally, and less so in Finland. As a result, the pulp and paper and sawnwood output level is most likely to decline in Finland in the coming decades.

– Forest industry, energy industry and investment companies are developing new forest based energy and chemical products, some of which may be available at commercial scale in the coming 3-5 years. For example, pulp and paper industry and sawnwood industry are likely to increase significantly their energy related operations in the coming decade. However, the commercialization of some new products may take a considerably longer time.

– Energy companies are increasing district heating and electricity production based on forest biomass.

– The wood consumption allocation for different purposes, shown in Figure 2.1.4, is likely to change significantly due to the above developments. In particular, the importance of combustion is increasing, while that of pulp and paper and sawnwood is declining.

– The attempts to cut back CO_2 emissions will most probably lead to forest playing more important role in climate policy. For example, forest owners may earn monetary benefits for providing climate services through their forests.

– Attitudes and values related to forests are evolving. For example, the private forest owners that own most of the forests in Finland, are being urbanized, and to some extent may become less production minded.

– All of the above changes will most likely affect e.g. forest, energy, environmental and economic policies. For those planning the new polices, there is a great need for information about the likely impacts of the different polices that could be put in place.

It is the last point, which is one of the major motivations for the current work.

2.2 Timber supply

2.2.1 Forests in Finland

Forestry land covers about 68% of the total land area, i.e. 26.3 million ha, including all land which is not classified as agricultural land or built-up areas. Finland's forests are almost entirely in the boreal coniferous forest zone. The most common species in Finnish forests are Scots pine (*Pinus sylvestris L.*), Norway Spruce (*Picea abies*) and birch (*Betula* spp.)(Metla 2007a).

Forestry land is divided into four categories upon the growth conditions of trees. The forest land is the most important category covering 20.1 million ha. The scrub lands cover 2.8 million ha. Bald or near bald areas are categorized as waste lands (3.2 million ha) and to the other forestry land (0.2 million ha) which consist of for example forest roads. 17,1 million ha of the total forestry area in the three first categories are on the mineral soil sites and 9 million on the mires. Forestry land also includes forestry lands which are out of wood production as nature conservation areas.

For the purposes of this report and the modeling work, we will focus mostly on the forestry land which is available for wood production (FAWP) and is classifield to the forest land (19.1 million ha) or to the scrub lands (2.0 million ha). The forestry area available for wood production in total is 21.0 million ha.

The total size of the Finnish forestry land has been almost invariant since Word War II. However, between the 1950s and 1980s the forest land increased by about 15% and both scrub and waste land areas decreased by about 30 %. Since the 1980s the forestry land measured as forest land has been almost invariant and the changes in scrub and waste lands have been small.

The FAWP area is mainly owned by nonindustrial private forest (NIPF) owners (59 %). The state owned area covers 26 % of FAWP, the remaining area belongs to companies and institutions such as local communities and parishes. The state owned forestry areas are typically in the northern Finland especially the nature conservation and wilderness areas. Therefore the state owned forestry areas have on the average smaller growing stock volume and the yearly increment of the growing stock is also below the forestry land owned by others.

The growing stock on forest land and scrub lands is in total 2189 million m^3 and the growing stock on FAWP lands is 2054 million m^3. The average growing stock in Finland is nowadays 105 m^3/ha, and it varies between 160 m^3/ha in the South-coast to 64 m^3/ha in Lapland. The average stock typically decreases when going from South to North in Finland.

The annual addition to the of growing stock has been increasing strongly since 1970s. In the latest National forest inventory the annual growth of the stock has been estimated as 99 million m^3, of which the annual increment on FAWP lands part was 96 million m^3. The average annual growth of trees in Finland on the forest land is 4.8 m^3/ha and 4.3 m^3/ha if the scrub lands are also included. On the forest land the difference on the annual increment of growing stock is minor between mineral soils and mires 4.9 m^3/ha and 4.6 m^3/ha respectively. Taking into account also scrub lands the average annual growth of trees in the mineral soils is 4.6 m^3/ha /a and in the mires 3.5 m^3/ha /a. The regional differences on the annual increment of growing stock in forest land differ between the Häme-Uusimaa region’s 7.4 m^3/ha/a and Lapland’s 2.3 m^3/ha/a.

The total drain of growing stock in Finland have been 65–70 million m^3/a in recent years which is about 70% of the annual increment of the growing stock. The total drain consists of roundwood harvests, logging residues and the naturally drained trees in the forests. In recent years, the growing stock in the Finnish forests has been incresing about 30 million m^3/a (Korhonen et al., 2007).

National forest inventories (NFI) have been carried out in Finland since 1920s to collect national and regional data of forest resources; for example volumes, growth, health, mean diameter of trees, and the of ownerships of forestry lands in Finland. The field measurements of the latest NFI10 started in 2004. Recent inventories are based on systematic cluster sampling and field measurements. Since the NFI9 (1996–2003) persistent sample plots have also been used and will be measured again in the coming inventory. About 80 000 sample plots were measured in the NFI9. One fourth of those plots is stated as permanent. The results of NFI give reliable estimates for areas over 200 000 hectares, as the size of Finnish Forestry Centres (Korhonen et al. 2007, Metla 2007b).

2.2.2 The ownership of forests and timber supply in Finland

The forestry land area in Finland is maily owned by non industrial private owners and the state, as shown in the Figure 2.2.1. The role of NIPF owner's is even higher in the timber supply while they owns 59 % of the forestry land area available for wood production. Also their round wood harvest covers over 80 % of the total roundwood removals in Finland in last 10 year, as presented in Figure 2.2.2. The significance of state forest is opposite in the timber supply because state forest's are mainly in the Northen Finland and due the conservation areas.

In the Appendix Table A.2.2.1 is presented ownership of forestry land at regionally at Forestry Center level. The Finnish Forestry Centres are regional administration organisations, which are controlled by the Finnish Ministry of Agriculture and Forestry. The function of the 13 Forestry Centres is to provide forest owners with information about forestry practices and their environmental impacts. The Forestry Centres also carry out administrative regulation based on the Forest Law. The statistics of Finnish forestry are usually collected and published at Forestry Centre level. The regional timber supply is presented in the Table A.2.2.5.

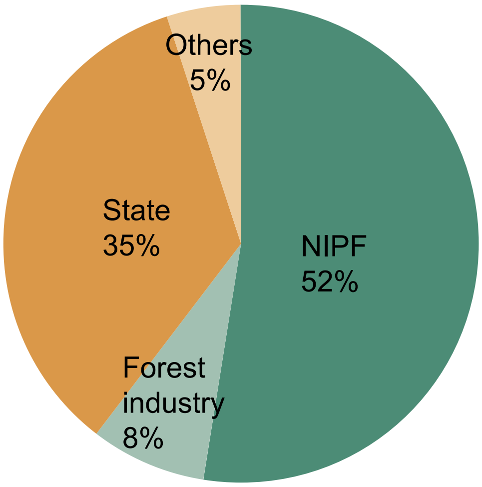


Figure 2.2.1. The ownership of forestry land in Finland at in NFI9 (Metla 2005).

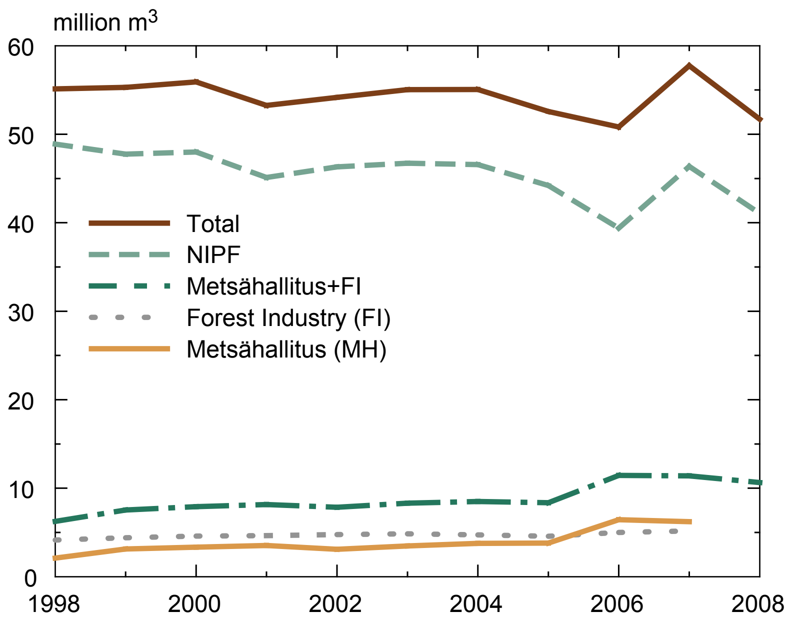


Figure 2.2.2. Roundwood removals by forest owner in Finland 1998-2008 (Metsähallitus has been included to forest industy since 2008) (Metla 2009a).

Non industrial private forest owners

The non industrial private forest owners' area is 13.8 million ha covering 52 % of the forestry land area and 59 % of the forestry land area available for wood production. The roundwood removals from those forest has been between 45 to 55 millions m^3 during the last 10 years. As presented in Figure 2.2.3 total removals has been slightly declining due the decrease of log removals. Pulp wood removals have been quite stable. the fuel wood removals have been increasing and the share of that have increased from 9 % to 13 % of the total harvesting volume.

Studying the NIPF owners' objectives in forestry, Kuuluvainen et al. (1996) found four categories among the Finnish NIPF owners. According to that study, over half of the private forest land is owned by multiobjective owners and recreationists gaining non-monetary benefits and values from their forests. The other categories, the investors and self-employers were considered to receive mainly monetary values from their forests. Table 2.2.1 presents the share of land area and the shares of forest owners in each category. Favada et al. (2007) found five categories to classify NIPF owners' objectives. Four of them correspond to Kuuluvainen et. al. study. The fifth group, called indifferent owners, was formed by forest owners who could not specify any specific objectives in forestry.

Table 2.2.1. The distribution of Finnish forest area and amount of owners by the objective of forestry (Kuuluvainen et al. 1996).

	Multiobjective owners (%)	Recreationists (%)	Self-employed owners (%)	Investors (%)
Share of forest land area	33	21	31	14
Share of owners	26	31	30	13

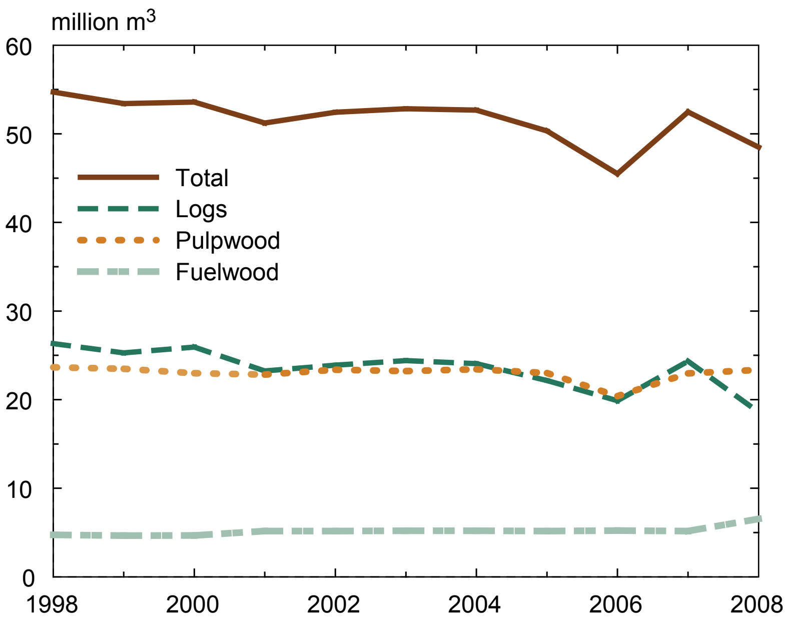


Figure 2.2.3. Roundwood removals from non industrial private forests in Finland 1998–2008 (Metla 2009a).

The Forest and Park Service, Metsähallitus

Metsähallitus is a state-owned enterprise that controls about 9 million ha of land area and 3.5 million ha of water area in Finland. For the wood production Metsähallitus has about 3.5 million ha of forest land and 1.5 million ha of waste- and scrub lands. The rest, about 4 million ha land area consists of e.g. conservation areas and wilderness areas. In the statistics of Finnish forestry Metsähallitus have been included to group industry since 2008 (Metla 2009a). Regionally forests owned by Metsähallitus are emphased strongly to Northen Finland. Regional roundwood removals from Metsähallitus forests in 2007 are shown in the Table A.2.2.3. The Northen-Finland Forest Centers Kainuu, Pohjois-Pohjanmaa and Lappi have the main role in the Metsähallitus timber removals covering about 70 % of the total Metsähallitus harvests. The harvests from Metsähallitus forests consist mostly of pulpwood which cover over 60 % of total their harvests, and in Lappi Forest Centre the share is even 76 %.

Forest industries

The forest industries' forests account for about 8 % of the forestry land area in Finland. The largest forestry areas owned by forest industries are in the Keski-Suomi, Pohjois-Savo, Pohjois-Karjala and Kainuu regions. Table A.2.2.4 presents commercial roundwood removals from forest industries' forests by Forestry Centres in 2007. The share of log removals was about 43 % and pulpwood removals about 57 % of the total forest industries removals in 2007. In the Rannikko, Pohjois-Pohjanmaa and Lappi Forestry Centres the share of log removals are lowest, covering about 29 %, 28 % , 25 % of the total removals in those areas respectively, but the total harvests in those areas covers only 4 % of the removals from forest industry forests. The most important regions for the forest industries harvests are Keski-Suomi, Pohjois-Savo and Pohjois-Karjala, whose total share is about 50 % of the total harvests in the industry owned forests in 2007.

Other owners

The other forest owners consists on e.g. municipalities, parishes, Finnish Forest Research Institute and jointly owned forests, various communities and other companies than forest industry. Municipalities, parishes and common forests are the most important owners in this owner class, owning 425 000, 168 600, 520 000 ha forestry area respectively (Kirkkohallitus, 2007; Metla 2007a; Metsätalouden kehittämiskeskus Tapio, 2006).

Altought the recreation and outdoor activities are an important use of the municipality forests, more than half of the municipality forests were classified as timber producing forests in a study, which covered 390 of the 432 Finnish municipalities (Monimuotoisuuden turvaaminen..., 2006). In the parish-owned forests, the total income from forestry was 16,6 million € in 2006.

In the statics of timber supply in Finland are municipality, parishes, other societies owned forest and those state owned forest which are not owned by Metsähallitus included in the non industrial private owned forest statistics.

Wood imports

Finland used about 20 million m^3 of imported roundwood in 2008 (see Table 2.2.2). In 2005 Finland was world's third biggest roundwood importer after China and Japan. Roundwood is imported mainly for Eastern Finland's pulp industry. The amounts of imported softwood and hardwood are in the same magnitude. Birch, spruce and pine are the major imported wood species.

Russia is by far the biggest roundwood exporter in the world. Between 2005 and 2008 Over 70 % of the Finnish roundwood imports come from Russia. The imported amounts of roundwood from Russia declined in 2008 and they are expected to decline more, because of the uncertainties

Table 2.2.2. Imports of roundwood and wood residues in 2008 in million m^3 (Metla 2009a).

Roundwood imports	
Softwood	6.6
Pine	3.4
Spruce	3.2
Hardwood	8.7
Birch	8.2
Other	0.6
Fuelwood	0.3
Chips	4.1
Wood residues	0.5
Total	20.2

concerning the export duty increases by the Russian authorities. As a WTO member Russia could perhaps become a less risky source of wood imports into Finland.

Besides Russia, the other imported wood into Finland (2005-2008) originated from Latvia, Sweden and Estonia, with shares of 8 %, 6 % and 6 % respectively (Metla 2009a).

Energywood supply

An overall objective exists to increase the use of bioenergy in Finland, to mitigate climate change and to increase the self-sufficiency of energy production. The main raw material of used wood based bioenergy in Finland is the proseccing residuals from forest industry. The roundwood supply to energywood use was about 10,9 million m^3in 2008 of which about 60 % was firewood and the share of forest chips was about 40 % (Metinfo 2009, Mäkelä 2009). Table 2.2.3 presents the shares of sources of energywood in Finland at 2006.

In the tending of seedling stands and the first thinning the share of energywood potential of the total wood supply of forest is notably higher than in the later thinnings and final fellings. Kiema et al. (2005) estimated energywood potential in some central Finland communities. According to them, the energywood potential from the final fellings was about 60 m^3/ha to 80 m^3/ha and from the logging residues and stumps about 50 m^3/ha.

Table 2.2.3. The energywood (roundwood) consumption shares in Finland (%).

	Firewood (2000–2001)	Forest chips (2006)			Total
	Total	Heat and power plants	Small properties	Total	
Final fellings					
Logging residues**	0–50	*64*	25	57	25–55
Stump	0	*14*	0	12	*5*
Thinnings					
Logs size trees	0–50	–	–	–	0–30
Small size trees	*50*	*20*	*75*	*26*	40
Import	*0*	*3*	0	*3*	

* Small properties uses also about 1 million m^3 of waste wood as firewood
** Including harvested roundwood which are not used as market roundwood
(Sevola et. al. 2003, Ylitalo 2006, Ylitalo 2007, Laitila et al.2008)

Table 2.2.4. An example potential of forests energywood (roundwood) supply in Southern Finland based on Hakkila (2004) study.

Fellings	Age of forest	Industrial wood (m^3/ha)	Energywood (m^3/ha)	Share of energywood (%) Min, Min-Max, Max	Totally
Maintenance of seedlings	10–20	–	15–50	100	100
1. thinning	25–40	30–80	30–50	50–38	28–63
2. thinning	40–60	50–90	20–40	29–31	18–44
3. thinning	50–70	60–100	20–40	25–29	17–40
Final felling	70–100	220–330	70–130	24–28	18–37
Total		*360–600*	*155–310*	*28–34*	*19–46*

Hakkila (2004) presents the energywood potential of pine and spruce logging residues in the first and second thinnings and final fellings. The energy wood potential is typically higher (or the share of energywood potential to industrial roundwood is higher) in the spruce forests than in the pine forests. In the table 2.2.4 is an example of the energywood supply from thinnings and final felling in Southern Finland.

The share of residual roundwood in pine and spuce forests is about 25 % of the roundwood removals in the first thinnings. In the second thinning the share is about 15 % and in the final felling only about 5 % of the total removals are residual roundwood. The dry mass of crown residuals consists mainly of living branches. The total volume of crown residuals is about 20 % of roundwood removals in final fellings and second thinning in pine forests. In the first thinning of pine forest the crown residuals make about 35 % of the total volume of round wood. In the spruce forest this share is about 50 %. The relation of dry weight and energy content of pine and spruce stumps increases with the dimension of stump. For example when the dimension of spruce stump increases from 20 cm to 40 cm, the energy content increases about 300 % (Hakkila 2004).

Several studies have estimated the future use and and supply potentials of energywood at the local or at the state level in Finland. Pöyry (2007) evaluates that the theorethical potential of the energywood supply in Finland in 2020 is 26.3 million m^3. The shares of stumps and small size trees are notable higher in the theoretic potential than in the energywood consumption shares in Finland at 2006 (see Table 2.2.3 and 2.2.5).

Hakkila (2004) estimated that the annual supply potential in the Finnish forest is 15 million m^3 energywood. The main potential of energywood orginates from the final fellings, which consist of logging residues and stumps 8 mill. m^3 and 2 mill. m^3 respectively. The potential of energywood from young forest felling was 5 mill. m^3. The potential of energywood from the later thinning is observed to the zero, because it is assumed that energywood inflict the growth of forests so that it is not economical to collect residues. The total energywood harvesting potential is supposed to be 33 % from the total energywood potential of forests fellings.

Table 2.2.5 presents the theoretical potential of energywood supply in Finland in 2020. The techno-economic potential is lower than the theoretical potential, due to the transportation costs and higher costs to collect energy wood from smaller diameter forests . Pöyry (2007) calculated techno-economic potential of energy wood supply in Finland, which is presented in Table 2.2.6. The techno-economic potential is totally only 38 % of the theoretical potential.

Table 2.2.5. The theoretical potential of energywood supply by categories in Finland in 2020 (Pöyry 2007).*

	Felling residuals	Stumps	Small size tree	Total
Volume (million m^3)	8.4	9.3	8.6	26.3
Share (%)	32	35	33	100

* Assumed that energy content of energywood is 2 MWh/ m^3

Table 2.2.6. The techno-economic potential of energywood supply in forestry centers in 2020 (Pöyry 2007).*

	Felling residuals	Stumps	Small size tree	Total
Volume (million m^3)	3 905	2 670	3 515	10 090
Share (%)	39	26	35	100
Of theoretical potential (%)	47	29	40	38

* Assumed that energy content of energywood is 2 MWh/ m^3

Total wood supply

The total supply of wood was 83.3 million m^3 in 2008 of which domestic supply covered 63.2 million m^3 and imported wood 20.2 million m^3 as shown in Table 2.2.7. In Appendix Table A.2.2.5 is presented total wood supply by forestry centres.

Multiple-use forestry

The most significant economic values of Finnish forest orginates from wood production. Forests provide also possibility to carry out other commercial or recreational activities such as hiking, camping, hunting, or picking of berries and lichen. The valuation of those activities are estimated at a coarse level and the values are not always commeasurable (Metla 2007a).

Energywood harvesting and collecting logging residues decreases the amount of decayed wood in the forests. The increased drive on foresry machines due the energy wood harvesting and collecting logging residues affects negatively to habitat of saproxylic species (Siitonen 2008).

Table 2.2.7. Total wood supply in 2008 in Finland (million m^3) (Metla 2009a, Mäkelä 2009).

	Domestic	Import	Total
Logs	*22.3*	*1.8*	*24.2*
Pine	10.2	0.6	10.8
Spruce	11.0	0.7	11.7
Hardwood	1.2	0.6	1.8
Pulpwood	*30.2*	*13.5*	*43.7*
Pine	14.6	2.9	17.5
Spruce	8.2	2.5	10.7
Hardwood	7.3	8.0	15.4
Fuelwood	*6.6*		*6.6*
Pine	1.6		1.6
Spruce	1.4		1.4
Hardwood	3.6		3.6
Other		*4.6*	*4.6*
Energywood	4.0	*2.8**	*4.3*
Total	*63.2*	*20.2*	*83.3*

* Imported fuelwood

3 Models of the forest sector

3.1 Demand models

The demand of wood consists of two primary uses, namely raw material use in forest industries, and fuel use in various energy producing industries. Therefore, the modelling of wood demand needs representations of wood product, pulp and paper and energy industries and their markets. This has been done in various ways, and various approaches have been used in previous models. In this section, we present some basic features in sectoral modelling, and how the issues analyzed are addressed in sectoral models.

3.1.1 Objectives of the demand models

There exists a large number of models that describe forest and energy industries. These models vary widely with their modelling philosophy, but the objectives are typically the same. The main objective of these models is to give an estimate of how industries will adjust to policy and other economic shocks. In the short run, the adjustments are changes in input uses as the composition of inputs is changed and activity levels are adjusted for the new situation. In the long run the adjustments are done by altering the production technology by adaptation of new technologies. All these changes are costly and the models are used to assess the levels of these costs.

During the recent years the climate change mitigation has been the driving force of energy policies. These policies target to the reduction of greenhouse gases (especially CO_2), by decreasing the use of fossil fuels and encouraging the use of renewable energy and energy saving. The rising interest in renewable energy has increased its importance in energy sector models. Although forest industry has always been important factor in energy markets in Finland, the connection of forest and energy sectors is expected to tighten even more. This raises the need for joint modelling of energy and forest sectors with significant weight on wood-based energy issues. The objective of such a model is to present the effects of climate policies on forest and energy sectors: how the demand for wood changes, which industries benefit and which suffer and what are the costs of these adjustments.

3.1.2 Dichotomy of the models

The objective of the modelling is to analyze adjustments originating from policy and other shocks. Therefore, it is of utmost importance to model the adjustment mechanisms of the studied industries as correctly as possible. In the short-run, the physical capital of the industry is invariant and the adjustments occur through other, variable, inputs. In the long-run, it is possible to invest in new technology (and disinvest old). This technological change represents an alteration of physical capital and allows for better adjustment to policies as the production possibilities change.

There are two prominent methods for modelling the long-run technological change. The first is a traditional economic approach which uses abstract production functions that define the limits of production, given a set of input variables such as labour and capital. Technological change is modelled via substitution between inputs and a change of productivity parameters. The second method is an engineering approach of activity analysis. The production functions are a set of Leontief production technologies with constant coefficients that relate inputs to output. Technological change is modelled as mobilization of new production technologies through investments (Löschel 2002). These two modelling methods are called top-down (TD) and bottom-up (BU), respectively (e.g. Wene 1996, Hourcade et al. 2006).

The two approaches are very different and it is no wonder that the results of the models vary significantly (Grubb et al. 1993). Bataille (2005) and Hourcade et al. (2006) analyze the problem by defining three properties that a good policy model should have. The properties are technological explicitness, macroeconomic realism and microeconomic realism. Technological explicitness is self-explanatory and means proper description of production technologies. Macroeconomic realism consists of feedbacks between sectors and economy as a whole including growth and trade aspects. Microeconomic realism means realistic assumptions of production and investment behaviour. Conventional TD models have been strong in macro and micro realism while BU models have focused on technologies.

Both methods have their pros and cons, but they are both currently in use. However, there has been a clear convergence of two modeling traditions and attempts have been made to combine the good properties of the two approaches. To differentiate these new models from conventional TD and BU models they are called hybrid models. In the rest of the section we illustrate pros and cons of the two modelling traditions and represent some of the hybrid models. Our presentation draws much on the useful discussions of these modelling traditions written by Bataille (2005) and Hourcade et al. (2006).

Top-Down models

Conventional TD models are economy-oriented and they are typically computational general equilibrium (CGE) models, yet some non-equilibrium models exist (Löschel 2002, Hourcade et al. 2006). In general, the focus is on economic relations instead of technological accuracy. Production technologies are aggregated into production functions, which are often assumed to be in constant elasticity of substitution (CES) form. As the name suggests, in CES production function the substitution of inputs is modelled via constant and exogenous elasticity of substitution parameters (ESUB). These parameters control the possibilities of input substitution as price-ratios change.

Technical change is mostly assumed to be exogenous. The change is modelled through changes of an exogenously changing productivity parameter. For example in energy models this parameter is autonomous energy efficiency index (AEEI). ESUB parameters and the time trends of AEEI are estimated econometrically from past data or they are 'guesstimated' based on expert opinion. Therefore, their use in future projections can be unsound. This is partly because the estimation of AEEI is difficult as it includes only autonomous technological change (it is separated from changes due to the price-ratios variation) and because this kind of analysis does not take into account the induced technological change issues (e.g. Goulder and Schneider 1999, Goulder 2004).

Policies affect price-ratios of the inputs. Adjustments are done by substitution between inputs, including capital. This is adjustment under given technological constraints, i.e. existing production technologies. Since in the CGE models the economy is efficient, there is no possibilities for Pareto improvements. Therefore, adjustments cause improvements in one sector but impairment in another. This causes costs and there are no "no-regrets" efficiencies available (Battaille 2005). Technological change of increasing efficiency parameters alleviates these costs. The results depend heavily on assumptions about technical change.

Most of the TD models have exogenous technical change but there are numerous possibilities how to model it. For example, increases in efficiency parameters can be augmented by capital vintaging where different vintages of capital have different substitutability properties (e.g. Jacoby and Sue Wing 1999, Babiker et al. 2001). There are also TD models with endogenous technical change (see

Gillingham et al. 2008). Models with endogenous technological change are more complicated than the models with exogenous technological change they replace (Edmonds et al. 2000).

Bottom-up models

BU models are activity analysis models typically based on linear programming (e.g. Nyboer 1997). The models have a set of industry or sector level Leontief production technologies which are used in demand satisfying production. Demand can be inelastic or price dependent. In the former case the technologies are chosen by cost minimization criteria and in the latter by surplus maximizing criteria. The economic use of these methods is based on the papers by Hotelling (1938) and Samuelson (1952).

Since the technologies are specified separately they can be presented rather realistically. Production possibilities are defined via technology snapshots that evolve through time. Technological change is based on these changes of snapshots when a new technology replaces an old one (Löschel 2002). Main criteria for the investing decision are the life-cycle costs and the performance characteristics of the technology. Technological change is quite rapid in BU models compared to the TD models. Grubb et al. (1995) see that technological change is fast in BU models because the engineering data includes future technologies, which causes optimistic implementation of new technologies. Note also that the guesstimation of parameters of future technologies is prone to an error so the long-run predictions may be unsound in BU modelling.

While the description of the current technologies is accurate, there lies problems in BU models also. The models are technologically focused and the markets under study lack proper connection and feedback to the rest of the economy (e.g. Battaille 2005). Jacoby (1998) states three pitfalls of BU modelling: Confusion of market failures with other market barriers; Lack of attention to market structure; Failure to account for inter-market adjustments. These pitfalls, if ignored, may lead to a too fast technology adaptation and the lack of inter-market adjustments may cause faulty predictions if the policy changes are significant. The first two issues are related to the problems in microeconomic and the third in macroeconomic realism.

Hybrid models

Researchers have developed a new line of so called hybrid models that try to combine the good properties of the two modelling traditions. Hourcade et al. (2006) define hybrids as models that have at least one clear modification that removes them from traditional classifications. So the hybrids are TD-based models with more accurate technology description or BU-based models with increases in micro and macro realism.

In Yatchew (2006) there is a good presentation of some of the recent hybrid models with various approaches. Böhringer and Rutherford (2008) see that there are three alternative routes to construct a hybrid model: (a) Combining existing top-down and bottom-up models with a recent example by Schäfer and Jacoby (2006); (b) Modeling thoroughly the other aspect and using a reduced form of the other (e.g. Manne et al. 1995); (c) Use of an integrated model and using mixed complementarity formulation for the CGE model (Böhringer 1998). The details of these approaches vary and technological explicitness, macroeconomic and microeconomic realism have been combined in various ways. In the examples subsection we present some of the hybrid models in more detail.

3.1.3 Policy cost analysis

In the short-run, new physical capital cannot be built. Instead, adjustments are done through substitution of variable inputs. Utilization rates are also altered between sectors and technologies as some plants are shut down and others are put into operation. In the medium-term perspective the capital can also adjust to the changing price-ratios. New capital investments allow for increasing the substitutability of the inputs as well as increase efficiency. In medium-term perspective it is possible to name the technologies that can come to commercial use in that period. This allows the modeller to assume a set of BU technologies that are relevant for the time-period or to guesstimate the effects of these incoming technologies on elasticities of substitution as well as on efficiency factors. Also the use of history based econometric estimates can be justified.

In the long-run, however, the technological change cannot be predicted very accurately. In fact many of technologies used in the distant future cannot be predicted at all. The costs and other properties of the future technologies are only very inaccurately, if at all predictable. There may also be some backstop technologies whose properties are developed beyond our imagination. Therefore, explicit technologies of BU models are not accurate in long-term calculations. Similarly, econometric methods cannot foretell the future advances of production technologies. Some kind of abstraction and projections are needed and in this respect the models of endogenous technical change are valued (e.g. Romer 1990, Löschel 2002).

The assessment of the costs associated to above-mentioned adjustments is a major question of sectoral economic modeling. Adjustment costs are calculated comparing policy scenarios with a baseline scenario. For BU models these costs are mainly financial costs of production or total surplus changes in every market. TD models capture better the intangible costs such as option value and utility changes (see e.g. Jaccard et al. 2003). General equilibrium models also present all the costs in the economy while in partial equilibrium the costs are related on markets under study. Based on these observations Hourcade and Robinson (1996) have grouped the costs in four broad categories: engineering and financial costs, sectoral costs and macroeconomic costs (see also Edmods et al. 2000). The first two costs are observed in assessing technologies whereas the sectoral costs aggregate these costs taking into account the costs occurring within the whole sector. When inter-sectoral adjustments are taken into account one ends up with macroeconomic costs.

3.1.4 Examples of energy sector models

Many of the recent energy sector models are coupled with environmental issues. Therefore, some of the models presented here might be called as energy-environment models. In this section we present examples of models belonging to the different modelling categories.

MIT-EPPA (MIT – Emissions Prediction and Policy Analysis) is a top-down energy-economy model that is a component of Integrated Global Simulation Model (IGSM).[4] It is based on earlier OECD GREEN model (Burniaux et al. 1992). MIT-EPPA presents a good example of computational general equilibrium model that utilizes concepts presented in previous sections. The firms have mixed nested CES and Leontief production technologies that exhibit constant returns to scale. Technology mix differs between production sectors. The consumer utility is also represented by nested CES function. Therefore adjustments to shocks depend heavily on elasticity of substitution parameters. Inter-temporal decisions are made recursively period by period based on current values

[4]IGSM is a model used for climate change assessment, see Prinn et al. (1999). Discussion here covers version 3.0 of EPPA.

of variables (recursive dynamics). Therefore MIT-EPPA differs from truly dynamic forward-looking inter-temporal optimization models. Growth is based on accumulation of capital and technological change of which energy efficiency improvements are modelled via AEEI index. Accumulation of capital is divided into malleable and non-malleable parts meaning that new investments are malleable in a sense that they can be adjusted to current price ratios using CES structure. Older capital is non-malleable and has to be used in Leontief production with input shares determined by the period it became frozen. Therefore, there are several vintages of capital whose properties depend on previous periods' economic setting (Babiker et al. 2002, Jacoby and Sue Wing 1999, Jacoby et al. 2004).

A particularly good example of a bottom-up model is ETSAP-TIAM (ETSAP – Times Integrated Assesment Model). It is a global incarnation of TIMES model, which is a descendant of MARKAL and EFOM models. TIMES model is a partial equilibrium model with an extensive description of energy forms and process technologies covering both current and future technologies. The model solves equilibria of different markets by matching supply and demand. Endogenous supply is modelled via cost minimization while demand for a good is either endogenous or exogenous with constant elasticity structure. Under perfect competition and sufficient market independence this corresponds to the maximization of the joint consumer and producer surplus. The model contains multiple time periods ranging over 100 years. In basic setup inter-temporal decisions are made with perfect foresight as the agents observe future values perfectly at the decision time-period. However, it is possible to relax this assumption by modelling the decision making under uncertainities about the future by stochastic programming. Since the structure of the model is large there is a need for linearization. This allows the use of powerful linear programming tools. However, for example the production functions are typically non-linear but they are modelled in piecewise linear manner. While TIMES is a BU model, some of the macroeconomic effects are captured with demand relations that depend on macroeconomic parameters such as the GDP and the size of population. Technological change is represented by introduction of novel technologies and cost decreases due to the learning-by-doing (Loulou and Labriet 2008, Loulou 2008, Loulou and Lehtilä, 2007).

As said, there are several ways to hybridize a model. Here we introduce briefly couple of models based on different approaches. CIMS (originally Canadian integrated modelling system) presents an example of a bottom-up model that has been augmented to better comply with the micro and macroeconomic realism. Especially the microeconomic realism of investment decisions is improved. This is done by simulating technological competition via logistic function. Also the life-cycle-costs of investments have been formulated with addition of non-financial costs and non-financial discounting. Both capital costs and intangible costs decline endogenously as the market share of given technology rises. Macroeconomic realism is added by adding demand modules that have feedbacks including foreign trade and disposable income effects of changing value-added of manufacturing. Iteration is used to even out supply and demand. The model is based on earlier ISTUM model which is technologically accurate bottom-up model (Jaccard et al. 2003, Bataille 2005 and Bataille et al. 2006)

In the Second Generation Model (SGM) technological detail is inserted into a large top-down model by nesting the Leontief production functions via logit-function (e.g. Brenkert et al. 2004). Schumacher and Sands (2007) demonstrate the effect of nested Leontief production function in the case of steel industry compared to the usual CES-specification. It is, however, debatable whether SGM is a TD model or a proper hybrid model. The other approach is to include bottom-up technological detail for sectors of interest in a CGE model without any nesting. The technique is based on mixed complementarity problem (MCP) formulation of the general equilibrium problem.

This line of research has been promoted by Böhringer (1998) and Böhringer and Rutherford (2008). The method is demonstrated in an empirical application by Böhringer and Löschel (2006).

3.1.5 Examples of forest sector models

Buongiorno (1996) classifies the forest sector models according to their general principles. The oldest class of models is based on econometric estimation of relevant market and production relations. This method faces many difficulties, including estimation and data problems as well as issues with technical change. Another method is linear programming approach where the optimal set of activities is calculated. The method is the same as in many of the bottom-up energy sector models. The difficulties of this approach are problems with getting good enough technological data and dynamic behavior that is unrealistically fast to mobilize new technologies. The third principle is to use system dynamics approach, where dynamics are presented with differential equations. The difficulties here are that models are loosely related to the data and differential equations may be invalid. The analysis is done without equilibrium which is problematic in the perspective of economic science. The more novel models try to capture the best parts of these principles.

In general, forest sector models are bottom-up models that concentrate on accurate presentation of forest industry processes and giving less emphasis on wood supply considerations. A prominent line of modelling tradition is based on Global Trade Model (GTM) which was developed at IIASA (Kallio et al. 1987). It utilizes all the three principles described earlier. The model has been successful and there are a lot of descendants of GTM globally of which two more modern are EFI-GTM and NTM II (Kallio et al. 2004, Bolkesjø et al. 2006).[5] Kallio et al. (2004) gives a good description of the GTM modelling structure and our summary is based on that paper. In the model the joint surplus of consumers and producers is maximized in every market in every region with inter-regional trade. Markets for goods are separate and consumer behavior in every market is based on constant elasticities. Production side, however, is presented with constant input-output coefficient Leontief technologies. Wood supply is in constant elasticity form with data-based growth functions. Optimization in wood supply and investments is myopic as the solution method is recursive programming. Bolkesjø et al. (2006) have included forest based bioenergy products into NTM II model.

There are several models that represent Swedish forest sector which is relatively similar to the case of Finland. Nyström (e.g. 2000) has created a model of energy and material flows in the forest industry. The model is based on MARKAL structure with linear programming methods. The model consists of eight paper groups, six pulp mill types and four wood working product groups. Processes have been described in engineering accuracy. Lönnstedt's (1986) model has a very different approach. The model is a set of equations that govern the relations between economic factors in a way that does not fully have microfoundations. The relations are plausible but functional forms used are partly unmotivated. The structure of the model resembles of system dynamic approach (e.g. Buongiorno 1996). However, it gives a good review of issues a forest sector model should represent.

Summary

There are several models that describe energy and forest industries with considerable precision. Yet models do not exist that include economically and biologically precise description of forest owner behavior. Hence the study of wood markets is flawed in a sense that supply side of markets

[5]Kallio et al. (2004) gives a more thorough list of the descendants as well as other forest sector models.

is not modelled properly. A model with modeling of forest owner behavior would allow study of policies that affect wood supply decisions and wood markets in general.

The properties of existing models give insights on the properties needed for an adequate sector model. It seems that BU modeling of technologies is needed for accurate description of industries. Model with projections up to 30 years into future can be seen in forest and energy sector as a medium-term model. The expected lifetime of technologies is several decades and technologies that are commercially used in 30 years are already under development. Therefore, BU technology sets needed for modeling of technological change are already known and their properties can be predicted with reasonable accuracy. In a model based on inter-temporal decision making the use of BU technologies introduces a risk of unrealistically rapid technological change. This problem needs to be solved in a good model.

3.2 Forest management and forestry models

The optimal management of forest, which can be seen as decision making over the alternative management activities, maximizes the benefits of a decision-maker. For comparing forest managements one needs to know the state of the forest and the estimates for the effects of different management activities (Pukkala, 1994).

3.2.1 The optimal management of forest

The Faustmann model was the first forest model where the optimal rotation age of an even-aged forest was determined by using the assumption that a forest owner maximizes the net present values of forest. Hartmann (1976) presents a model based on the Faustmann model, where the forest owner benefits consist of both monetary and amenity values from forestry. The optimal management of forest is more complex if thinnings are included in the decision analysis.

3.2.2 The forest simulation and forestry models

The forest simulation and forestry models can be divided into two categories based on the description of the forest trees or growth.

1. Forests are measured at stand level as a biomass
2. Forests are measured at an individual-tree level

If forests are measured as a stand level biomass, all trees are simulated to have similar behaviour. When forest management and timber supply are simulated in large regions usually the description of forest is measured at the stand level. The input data of stand level models are given as mean annual growth of trees. The forest management activities cannot be directed to some special type of trees. The models that measure the forest as individual trees, are based on more detailed information of the state and the growth of the trees in forests. Therefore these models can be used to simulate and direct management activities even at the tree level.

Some excamples of forestry models are presented next. The European Forest Information Scenario Model (EFISCEN) and The Forest and Agricultural Sector Optimization Model (FASOM) are stand level models and the MELA model is an individual tree model.

The European Forest Information Scenario Model

The European Forest Information Scenario Model (EFISCEN) is a forest resource projection model for large forest areas. The EFISCEN model is based on Sallnäs core work, which was developed for the Swedish conditions in late 1980's (Sallnäs 1990). The first European level application was done by International Institute for Applied Systems Analysis (IIASA) to study the dieback of forests due to the acidification. In 1996 European Forest Institute presented the first version of EFISCEN. EFISCEN model has been used to estimate e.g. wood production possibilities and climate change impacts on European forests.

The regional forests area in the EFISCEN model can be described with different forest types. The division of regional forests into different types of forest is done in the input data of the model, where for example forest ownership or species can be used as the sorting criteria. Each forest type is described by a two-dimensional matrix (age classes, growing stock) presented in the Figure 3.2.1.

The aging of a forest type moves the area to an older age class. The growth of the forest moves the forest area to higher volume of growing stock. Thinning and natural mortality moves the forest area to a lower volume of growing stock. The final harvest moves the forest area to non stocked area. Regeneration moves non stocked areas to the first age class and lowest volume of growing stock. Natural mortality is a user defined function, which gives the share of an area which will move to the lower volume class. The growth and initial state of forest types and age classes are given as exogenous variables to the model.

Forest and Agricultural Sector Optimization Model

The Forest and Agricultural Sector Optimization Model (FASOM) was developed for the U.S. Environmental Protection Agency (EPA) to analyze welfare and market impacts of forests carbon sequestering policies. Since then, it has been used to analyze also other policy impacts on the agricultural and forestry sector (Adams et al., 1996).

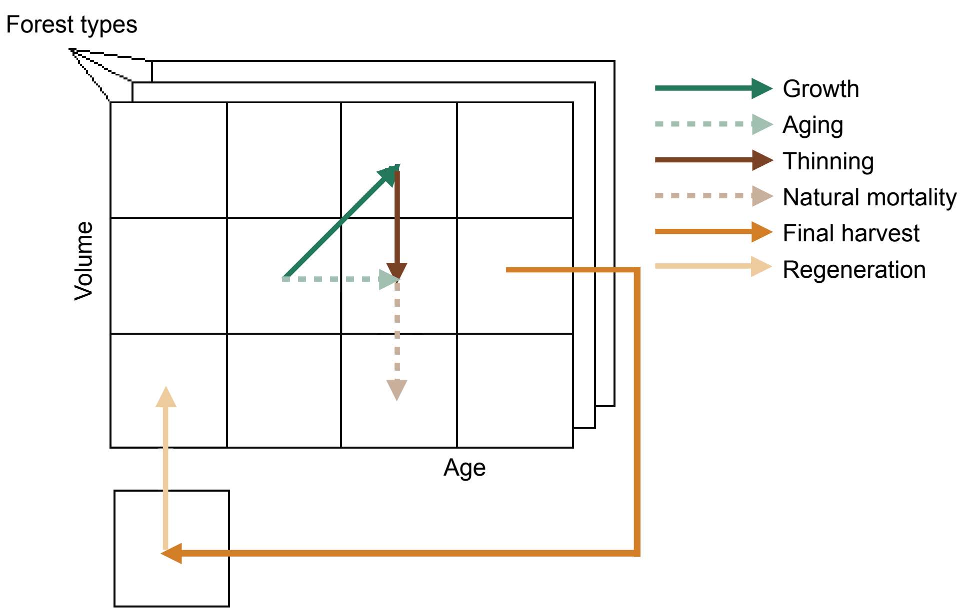


Figure 3.2.1. The forest type state matrix in the EFISCEN model (EFISCEN 2008).

Fasom is a spatial equilibrium model that maximizes the sum of net present values of agricultural and forest sector consumer's and producer's surpluses. It is a regional level model having 11 supply side regions, and one national demand region. The prices of commondities in both sectors and land area are endogenous. The landowners have "perfect foresight" on future prices, so the excepted and realised future prices are identical. The forest management intensity is determined endogenously in the model. The land allocation between sectors and the determination of planting tree species are endogenous.

The markets are modelled for logs, pulpwood and fuelwood. The supply side elasticities for forest sector products are estimated from historical data. The supply of public forest is an exogenous variable.

The forest land is structured by age class, region, growing conditions, ownership, cover type and management regime. Also the suitability of forest land to agricultural use is one criterion, due to the land allocation changes between sectors. There are four categories for tree species, two owner classes (industrial and non-industrial) and three different growing conditions for forests. Also the forest management intensity has four categories. The forests are structured with ten year age classes.

There are fixed shares for logs, pulpwood and fuelwood in all structured forestland age classes. The logs can be substituted for pulpwood and pulpwood can be a subsitute for fuelwood e.g. if pulp wood price is low enough it is a competitive substitute for fuelwood.

The estimation of carbon sequestering into forests in the model consists of changes in the carbon reservoirs in trees, soils, forest floor, understory, wood products and woody debris.

MELA model

The first computerised operational research method for cuttings in Finland was published by Kilkki et. al. (1968). The first fully operational version of MELA (Metsälaskelma) model was released in 1983. MELA is a linear programming model with numerical simulation. The model is widely used also in policy applications (Korpilahti 2006; Redsven et al. 2007).

MELA is based on simulations of forest growth with endogenous forest management. The simulation of the growth of forest is computed by modelling individual tree growth. The management of forest is optimized by using JLP package (Lappi 1992). The optimizing process maximizes the net present value of forests. Limits and predestined management activities can be set for the optimizing process.

4 Climate, energy and forest policies

Forest sector is influenced by many policies. We have divided forest policies into three major groups. *(1) Climate policies* that either create disincentives for fossil fuel usage and thereby increase the competitiveness of forest bioenergy, or create incentive for carbon sink maintenance in forests. *(2) Renewable energy promoting policies*, that seek to increase the use of renewable energy sources, such as forest biomass in electricity production. *(3) Forestry polices* that mainly provides subsidies for felling, harvesting and chipping of energy wood. Forest policies also include e.g. subsidies to R&D, but we will not cover them in this paper.

One of the main reasons for promoting forest bioenergy are the European Union's climate and renewable energy targets: at least 20 % reduction in greenhouse gases and 20 % share of renewable energy sources in energy consumption by 2020 (EC 2008a). In order to reach these targets, the Finnish government sees it particularly important to increase the utilization of forest biomass in energy production. This objective will be supported by various policy measures.

On the other hand, forests and forest products influence climate change and its mitigation in many ways. Forestbiomass can substitute for fossil fuels, and forest products can substitute for products whose production processes generates more greenhouse gases. Forest products also hold up carbon during their lifetime, which for some products, such as lumber, can be up to hundred years. Forests are also important carbon sinks and reservoirs, i.e., forestry can both maintain present carbon reservoirs as well as create new sinks.

The purpose of this chapter is to discuss the various climate, energy and forest policy measures. First, the main principles of the various policy measures are presented. Secondly, the practical experiences of these policies in various countries are discussed. After that, we summarize the strengths and weaknesses related to each policy measure. Finally, we present and interpret the policy measures from the economic theory perspective. That is, what is the basic economic theory behind the policy measures, and what are the economic implications.

4.1 Climate policies

Kyoto Protocol was the first major international climate agreement. It was agreed in Kyoto in 1997 and it concerns years 2008–2012. Altogether 174 states have signed and ratified Kyoto Protocol. European Union has agreed on more long-term emission reductions than what was agreed in Kyoto Protocol. European Union's target for greenhouse gases reduction is 20 % by 2020 if the reduction is unilaterally made by EU and 30 % if other developed countries and more advanced developing countries also commit themselves to the emission reductions (EC 2008a).

The main climate policy instruments are emission trading and carbon taxes. Existing climate policies affect the Finnish forest sector in many ways, of which we point out two main ones. Firstly, forest bioenergy is basically CO_2-neutral. Therefore, with emission trading or carbon tax, forest bioenergy becomes more competitive than without these policies. Secondly, many forest industry production processes cause CO_2 emissions, and therefore emission trading or carbon tax would directly impact the production costs.

Subsidies to carbon sequestration is one possible new climate policy that would also affect forest sector. If forest owners gained subsidies for carbon sequestration, that could affect their decision making.

4.1.1 Energy and emission taxes

Emission tax is a basic environmental policy instrument first introduced by Pigou in 1932, therefore it is known as *Pigouvian tax*. Pigouvian tax is a per unit emission tax: the polluter must pay a predetermined tax for every unit of its emissions. If the Pigouvian tax is set optimally, it equals the marginal social damage due to pollution. Many energy taxes that are set for fossil fuels are actually emission taxes, namely carbon taxes. In Finland energy taxes have been one of the key policy measures to control CO_2 emissions (Ministry of Trade and Industry 2006). Energy taxes can also have other than climate change mitigation goals, such as security of energy supply and promoting of domestic energy production, increasing energy efficiency, and increasing employment and incomes especially in rural areas.

According to Finnish Ministry of Trade and Industry (2006), in the present situation, in which EU's main climate policy tool is emission trading, energy taxes are no longer important climate policy tools in Finland. Therefore, the other above-mentioned reasons are more valid for introducing energy taxation. Indeed, the Finnish energy taxation is presently under development. In the sectors outside emission trading, carbon taxes are still valid.

In Finland, the energy taxes are currently levied on electricity, coal, natural gas and some liquid fuels such as gasoline and diesel. Forest biomass fuels are exempted from taxation, but all electricity is taxed in Finland. The following energy tax rates are examples of current Finnish taxes (Parliament of Finland 2007b, 2007c):

- electricity tax is 2.63 €/ MWh_e for industrial users,
- electricity tax is 8.83 €/ MWh_e for other users (e.g. households),
- coal tax is about 6 €/ MWh and,
- fuel tax is about 70 €/ MWh.

4.1.2 Emission trading

Emission trading is a policy instrument, which can be used to reach emission reduction targets in a cost efficient way. In emission trading, regulators first decide the optimal amount of the emissions. The emission credits are then allocated between firms through free allocation or auction. If a firm is short of credits, it can reduce its emissions to comply its credits or it can buy more permits. If a firm can reduce its emission efficiently relative to the other firms, it may have extra credits, which it can sell in the emission trading markets. Thus, an opportunity for trading and a market for emission credits is built. Therefore emission trading is also called as ”cap and trade” -system. A market clearing-price per one unit of emissions emerges in emission credit markets. The market clearing price indicates the opportunity cost of emissions. If the end-product and emission credit markets are both perfect, then the credit price is at the same level with Pigouvian per-unit pollution tax (Baumol and Oates 1988, 177).

Emission trading is a cost-efficient tool to reduce emissions, because emissions are reduced where it's cheapest, no matter what the original allocation was. However, the original allocation affects firms' profits. In emission trading, the emissions do not exceed the target level set down by the regulators, so the desired reduction in emissions is always reached.

European Union initiated emission trading scheme (EU ETS) in the beginning of 2005. The objective of EU ETS is to meet the CO_2 emission reduction targets requested in the Kyoto Protocol. The first period 2005–2007 was the implementation and trial period and the second period 2008–2012 is the Kyoto commitment period. EU ETS covers nowadays only CO_2 emissions and one emission credit represents the right to emit one ton of CO_2. EU ETS allows emitters to use credits also from Kyoto's project-based mechanisms: joint implementation (JI) and the clean development mechanism (CDM).

All 27 EU members are enclosed in the EU ETS and Norway joined in the beginning of 2008. EU ETS covers around 45 % of EU's total CO_2 emissions, including about 12 000 installations in 28 countries. About 500 Finnish installations are included in emission trading. EU ETS accompanies large emitters in the power and heat generation and in addition iron, steel and pulp and paper industries. Power sector is the biggest and most active actor in EU's emission trading (Point Carbon 2008). The power plants that have smaller output capacity than 20 MW are not included in EU ETS. From 2013 forward EU ETS will cover new sectors such as transport, buildings, services, smaller industrial installations, agriculture and waste (EC 2008a).

In EU's emission trading, EU policymakers first decide the amount of emissions for each period. This amount of credits is then allocated to member countries. Next the individual countries' regulators decide both how much credits each sector gets and the allocation of credits inside each sector. In 2008 European Commission (EC 2008a) decided that before 2020 EU will finish the free allocation of emission credits and will gradually shift to auctioning of credits. Energy sector shifts to full auctioning from the year 2013. Auctioning of credits can reduce the windfall profits of energy sector. Member States handle the auctioning and also receive extra revenues from it. At least a portion of these revenues must be spent to R&D of climate change mitigation, adjustment to low carbon economy etc.

In the beginning of 2005, the price of EU-ETS's emission credit was around 8 €/tCO_2. Subsequently, the price remained volatile from 2005 until the end of April 2006, reaching the highest point at around 30 €/tCO_2 and the lowest point at around 7 €/tCO_2. In the end of April 2006 the first information of the true emissions was published and the markets realized an excess of credits existed. The new information decreased the credit price rapidly and by the end of 2007 the price had reached the level of only 0.03 €/tCO_2. In the beginning, the emission credit price of the first trade period also followed the price development of fossil fuels and electricity, in particular German prices (Aatola, Ollikka and Ollikainen, 2008). In the beginning of 2008, the second period of EU ETS started and the allocation of credits was scarcer than in the first period. The price for emission credit was around 14 €/tCO_2 in July 2009 (Point Carbon 2009).

United States has some unconnected emission trading schemes. Northeast States have decided on Regional Greenhouse Gas Initiative (RGGI). The participating states are Connecticut, Delaware, Maine, Maryland, New Hampshire, New Jersey, New York and Vermont. In addition, the District of Columbia, Massachusetts, Pennsylvania, Rhode Island, the Eastern Canadian Provinces and New Brunswick are observers in the scheme. RGGI was initiated in January 1, 2009. In the beginning RGGI will include only CO_2 emissions from power plants, but it may expand to cover more GHG gases and polluters. The RGGI price for emission credit was around 3 \$/tCO_2 in June 2009 (RGGI 2009). Also Chicago and the State of California have emission trading schemes.

Emission credit price has an effect on the actors in the energy sector. For example, emission trading increases electricity price and it makes coal fired electricity production less profitable compared to natural gas. When considering emission trading and forest bioenergy in Finland, it is important to remember that the most important substitute for peat in electricity and heat production is forest chips. Peat and forest chips can be cofired in the same boilers when producing electricity and heat. Peat is involved in emission trading, but forest chips are not, because they are classified to be CO_2-neutral in EU ETS. Therefore, the higher the emission credit price is, the more competitive forest chips use is in comparison with peat use.

Paper and pulp industry's costs rise as a consequence of EU-ETS. Lund (2007) made an assessment of EU-ETS on energy intensive industry under auctioning of credits. Lund calculated that the direct emission costs of EU-ETS to paper and pulp industry are 0.54 % of production value and that the indirect costs that derive from the probable increase in the electricity prices are 1.1–3.3 % of production value (emission credit price is assumed to be 40 €/tCO_2). Indirect costs differ between the mills, because they use different amounts of self produced energy. The more the mill uses self produced energy, the lower the indirect EU-ETS costs are. PTT (2008) calculated that that for the pulp and paper industries, the direct costs, indirect costs plus the additional costs of wood raw material price increase are 5.1 % of total turnover, if the emission credit price is 40 €/tCO_2. Although the two studies are not perfectly comparable, it can be noticed that PTT gives a lot of weight on emission trading's effect on raw material prices and Lund neglects these effects. Finnish paper and pulp industry has criticized the full auctioning, because they trade in global markets and allegedly it is hard for them to add the extra costs of auctioning to their end-product prices (Finnish Forest Industries 2008). For the previous reasons, industry is relieved from auctioning if for example its exports are more than 30 % of its net revenues (Confederation of Finnish Industries 2009).

4.1.3 Carbon sequestration policies

Forests are important carbon reservoirs, so in order to mitigate the climate change, it is important to maintain or increase these reservoirs. Forestry provides many different ways for carbon sequestration (Richards and Stokes 2004):

1) Afforestation of agricultural land,
2) Reforestation of harvested or burned timberland,
3) Modification of forestry management practices to emphasize carbon storage,
4) Adoption of low impact harvesting methods to decrease carbon release,
5) Lengthening forest rotation cycles,
6) Preservation of forestland from conversion,
7) Adoption of agroforestry practices,
8) Establishment of short-rotation woody biomass plantations and
9) Urban forestry practices.

In principle, carbon sequestration policies could be used to compensate forest and landowners for the above-mentioned forestry works. Typically, carbon sequestration policy could be for example a subsidy from the government to the forest owner. Finnish forest lands accounted for an equivalent amount of 41 million tons CO_2 net carbon sink in 2006 (see Table 4.1.1). From a biological point of view, Finnish forests could contain more carbon than nowadays. Wood products and wooden buildings remain as carbon reservoirs for a long time, and additionally they are substitutes for other raw materials that are often more energy intensive. In 2006, wood products accounted for 0.4 million tons CO_2-equivalent amount of net carbon sink. Climate policies could also subsidize the production of wood products and help to increase the amount of sequestrated carbon (Valsta et al. 2005; Statistics Finland 2008a).

Table 4.1.1. The net carbon stores (in million tons CO_2 equivalent) of Finnish forests and wood products (Statistics Finland 2008a).

	Forestland	Wood products
1990	-23	-0.9
1995	-23	-0.9
2000	-27	-1.3
2005	-38	-0.3
2006	-41	-0.4

Carbon sequestration policies could also be used to lengthen the rotation age of forests and increase the amount of carbon sinks. In the long run, carbon sequestration policies could increase the total supply of wood. On the other hand, the supply of wood could decrease in the short run. As an influence of carbon sequestration policies, the proportion of logs could increase and the proportion of pulpwood could decrease in the wood supply (Valsta et al. 2005).

Through increased tree growth, climate change can increase carbon sinks in forests. However, climate change can also pose a threat to the carbon balance of forestland. When climate warms up, the plant remains decomponsate faster and CO_2 emissions from soil increase. Decomposition processes are very sensitive to climate change particularly in countries with cold climate, like Finland (Vanhala et al. 2007).

According to the Kyoto Protocol's article 3.3 the signed and ratified states can credit the net carbon sinks when reducing greenhouse gas emissions. The credited net carbon sinks must occur from silvicultural works (afforestation, reforestation and deforestation) that are done since 1990 (UN 1998). Because also deforestation is involved in the article 3.3, the carbon sink can also turn into a source of emission. Kyoto Protocol's article 3.4 states that signed and ratified countries can choose if they want to compensate their CO_2 emission's by for example forest management. Each state has their own maximum limit for compensation. The compensation limit is 0.6 million CO_2/a equivalent tons for Finland (EM 2003).

4.2 Renewable electricity promoting policies

European Union has set Finland a 38 % target of renewables of gross final energy consumption in 2020. This means that Finland must increase the use of renewables almost 10 %-units from the 2005 level (EU 2008b). To achieve this goal, Finland must develop its renewable electricity promoting policies. Forest bioenergy promoting policies are in a key position in this progress: the target for 2020 for forest chips use is very ambitious, 21 TWh, whet compared to the use in 2006, 6 TWh (Finnish Government 2008). Forest bioenergy based electricity is at the moment promoted with investment and electricity subsidies in Finland. If Finland wants to increase the forest bioenergy based electricity production, some changes are needed in the policy legislation. Finnish Ministry of Trade and Industry (2006) proposed two alternative ways to make forest bioenergy policy more effective. First option is to increase the levels of current subsidies and the second option is to introduce new types of policies, namely feed-in laws or green certificates. The major difference between the used subsidies and the new policies is the fact that the current policies are funded by the government and feed-in laws and green certificates are funded by electricity users. Finnish Ministry of Trade and Industry points out that it is hard to increase the present subsidies for numerous reasons such as government's scarce budget setting.

4.2.1 Investment and electricity subsidies

The current Finnish policy options to increase the production of electricity that is produced from renewable energy source (RES-E) are investment subsidy and electricity subsidy. Both subsidies are paid by the government. Investment subsidy is a certain percentage of initial investments. Investment subsidy is allocated to the producer before the investment, but the producer receives the subsidy when the true costs of the investment are known. It means that the initial investment must be paid by the producer. Investment subsidy for forest bioenergy using power plant can be up to 40 % of the eligible costs. Finnish RES-E producers can receive investment subsidy for an investment that

- increases the use or production of RES-E
- promotes energy conservation
- improves energy efficiency
- reduces the environmental damages of energy production/use or
- otherwise promotes the security and versatility of energy management (Council of State 2002).

According to the Ministry of Trade and Industry (2006) the investment subsidy is still valid in the emission trading situation and it is especially needed to commercialize new RES-E technologies and to reduce the CO_2-emissions in the sectors that are not included in EU ETS.

The other present RES-E policy instrument in Finland is electricity subsidy. The level of electricity subsidy is 6.9 €/MWh_e when the electricity is produced from forest chips (Parliament of Finland 2006). If a RES-E producer receives production subsidy, it is still affected by the electricity price, because the subsidy is only an extra price that is paid on top of the electricity price (Finnish Energy Industries 2007). According to Ministry of Trade and Industry (2006), the overall effect of investment and electricity subsidy is 7–11 €/MWh_e in large power plants that use forest bioenergy.

4.2.2 Feed-in laws

Feed-in laws are used to increase the consumption of renewable energy in electricity production. Basically they create a RES-E demand that otherwise would not exist at least at the same level and they make RES-E production more profitable. The most common feed-in law is a guaranteed long-term minimum price (€/MWh_e), for generating electricity with renewable resource. The guaranteed price is called feed-in tariff (FIT). Electric utilities are obligated to purchase RES-E at a tariff price that is determined by the regulators. The idea of FIT is that when electricity producers face a certain long-term minimum price, they are encouraged to invest on immature renewable energy technologies. FITs also provide long-term financial stability to electricity producers and smoothen the volatility and seasonal differences of energy markets. One important feature of FITs is that they can be designed individually for each renewable energy source or technology. That increases the flexibility of FITs, but it can also increase the control costs of a FIT scheme (Lesser and Su 2008; Menanteu et al. 2003).

The determination of a long-term minimum price is difficult for the regulators. Too high FIT increases energy prices and reduces economic welfare. On the other hand too low FIT does not increase the use of renewable energy to the social optimum, so the policy goals will not be met (Lesser and Su 2008). Feed-in tariffs are usually designed to decline over time. After an investment RES-E producer receives high tariff, but the tariff price falls with time.

Feed-in tariff is a certain above market price. Another feed-in policy tool is price premium. Feed-in premium (FIP) is a price that the RES-E producer receives on top of the market price. In this sense, FIP is a more market based tool than FIT (Muñoz et al. 2007, 3105).

Lesser and Su (2008) bring out the fact that different feed-in policies have some similarities. First, feed-in laws guarantee an electricity price that is above market price. Second, it is inefficient to assure minimum price forever, so feed-in laws usually have a time limit. Third, the feed-in policies normally have some technological improvement incentives, which make investments profitable. Fourth, feed-in laws are usually different for each renewable source or technology. Feed-in tariffs and feed-in premiums are usually paid by electricity utilities. Electricity utilities add the extra price to consumer prices, so the real income transfer is from consumers to RES-E producers.

21 EU countries have feed-in laws for renewable energy (Fouquet and Johansson 2008). At the moment there is no feed-in law for renewable electricity in Finland, but the government has already decided on feed-in law for biogas. However, Finland has a FIP for peat. GreenStream Network (GSN) has estimated the possible costs of RES-E FITs in Finland. In their scenarios FITs were set for wind power, biomass, biogas, hydro power and smaller energy sources such as solar power. They calculated that the extra cost that feed-in tariffs cause to consumers would be 0.4–1.7 €/MWh_e in 2010 and 2.3–9.7 €/MWh_e in 2020 depending on the assumptions behind the calculations. In their calculations the Finnish electricity price was assumed to be 45 €/MWh_e (GSN 2007, 59). The Finnish Ministry of Employment and Economy (2009) prepares a feed-in tariff for wind energy. The planned tariff is 83.5 €/MWh_e for new wind power plants.

German and Spanish feed-in laws are commonly considered to be successful. Germany has a feed-in tariff scheme and Spain has both a feed-in tariff and a feed-in premium scheme. Germany introduced its tariff in 1991 by the Electricity Feed-in Law. Energy utilities were obligated to buy RES-E at 90 % of the electricity consumer price. The first law focused on wind energy. As a consequence of the law the amount of installed wind energy grew rapidly in Germany during the 1990’s (Lesser and Su 2008). In 2000 Germany passed the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) and it was reconstructed in 2004. EEG guarantees electricity grid access, priority of renewable electricity, tariff and nation-wide equalization. EEG has different fixed tariffs (€/MWh_e) for different renewable energy sources and technologies. For example, biomass has 37 different tariffs in EEG. German tariffs are guaranteed for 15–30 years. Tariffs decline over time at a certain percentage that is also different for each technology. EEG has increased the production of RES-E strongly in Germany (GSN 2007; Muños et al. 2007).

Spain’s feed-in law was introduced in 1998 and it was modified in 2004. Spanish feed-in law assures electricity grid access, priority of renewable energy, security and predictability to RES-E producers and nation-wide equalization. The Spanish feed-in law offers two options for RES-E producers: a fixed tariff and a price premium. Producers can choose each year which alternative they want to use as their support scheme. According to Muños et al. (2007) the Spanish electricity price is typically quite high, and most of the producers choose the price premium. Tariffs and premiums are calculated as a percentage of average electricity consumer prices. Spanish tariff system has served wind energy best (Rio and Gual 2007).

European Union wide feed-in law harmonization is a widely discussed idea in the European energy policy literature. European Commission (EC 2005) points out some benefits and drawbacks of feed-in law harmonization. According to EC the biggest benefit of harmonization would be static and dynamic efficiency. Harmonization could reduce both the costs of renewable energy technologies and the administrative costs related to feed-in laws. Harmonization would also reduce market distortions in EU's electricity markets. One major drawback of harmonization is possible over-pricing, which would occur from the fact that it is difficult to establish an EU-wide feed-in tariff. Muños et al. (2007) propose a feed-in law harmonization that is based on modular and transparent feed-in premium. Their suggestion takes into account technology, politics, national priorities and some grid services.

Feed-in tariffs are a widely used policy instrument in Europe. Finland could use FITs to increase its forest bioenergy based electricity production, but FITs also have some weak points. The major benefits and drawbacks of implementing FIT for forest bioenergy are summarized in Table 4.1.2. Forest bioenergy based electricity promoting feed-in premium has many of the same advantages and weaknesses as feed-in tariff. However, since FIP is a more market-based tool than FIT, it can adjust better to electricity price changes and suit better to open electricity markets. The advantages and weak points of FIPs for forest bioenergy based electricity are shown in Table 4.1.3.

Table 4.1.2. Pros and cons of implementing FIT for forest bioenergy based electricity (FBE-E).

PROs	CONs
+ Increases RES-E economically.	– Too high FIT might channel pulp wood to FBE-E production.
+ Good policy tool in the long-run.	
+ Can be set to correspond with FBE-E's costs.	– Difficult for the regulator to set FIT right.
+ Lowers the investor's risk.	– Relatively high control costs.
+ Supports technological innovations.	– FBE-E cofiring technology is already quite mature.
+ FBE could be used in domestic electricity production.	– FIT suites badly to open electricity markets, because the price is fixed.
+ FIT is not bounded to government budget.	– FIT is eventually paid by consumers.
+ FIT is usually fixed, so it does dot need adjustment	– FBE-E might not need subsidies, if the emission credit price is high.
	– Might hike up forest raw material prices.

Table 4.1.3. Pros and cons of implementing FIP for forest bioenergy based electricity (FBE-E).

PROs	CONs
+ More market-based than FIT.	– More uncertain than FIT.
+ Suits better to open electricity markets than FIT.	– Risk of over-compensation when electricity price is high.
+ FBE could be used in domestic electricity production.	
+ Increases RES-E economically.	– Too high FIP might channel pulp wood to FBE-E production.
+ Good policy tool in the long-run.	
+ Can be set to correspond with FBE-E's extra costs.	– Difficult for the regulator to set FIP right.
+ Lowers the investor's risk.	– Investment risks are higher than with FIT.
+ Supports technological innovations.	– FBE-E technology is already quite mature.
+ FIP is not bounded to government budget.	– FIP is eventually paid by consumers.
+ Could be set to compensate the price of emission credit.	– FBE-E might not need subsidies, if the emission credit price is high.
	– Might hike up forest raw material prices.
	– Relatively high control costs.

4.2.3 Tradable green certificates

Tradable green certificates are relatively new policy option to promote the use of RESs in electricity production. In tradable green certificate (TGC) scheme, the regulators decide a fixed quota of RES-E. When electricity producer produces RES-E, it creates two separate products: electricity and green certificates. RES-E producer gets one certificate for each pre-defined unit of RES-E it produces. Electricity market actors, usually energy utilities are obligated to buy a fixed amount of TGCs that equals with the RES-E target set down by regulators. Energy utilities are usually obligated to buy a certain percentage of their electricity as RES-E. To show that they have reached their target, they have to hand over predetermined amount of TGCs at a given point of time. Regulators can also allocate the RES-E requirement to electricity consumers or producers instead of electricity incentives. If the electricity market actor, who faces the RES-E requirement, does not meet its target, it has to pay a pre-determined penalty.

Energy utilities can buy and sell TGCs. The price of TGC is determined in the markets, where demand is fixed. If TGC demand is high compared to its supply, the TGC price will be high and it will act as an incentive for new producers to produce RES-E. In theory the producers who can produce RES-E with the lowest costs, sell TGCs and RES-E will be produced cost-efficiently. Energy utilities compensate the costs of TGC in consumer electricity prices, thus the income transfer is from consumers to RES-E producers.

The RES-E target is usually common for all RESs. It is then important to decide, which energy sources are regarded as renewable. Usually large hydro plants are ruled out from TGC scheme, because they have much lower production costs than the other renewable energy technologies. Also the cofiring of renewable and non-renewable energy source in electricity production can be restricted in TGC scheme (Menanteu et al. 2003; Schaeffer et al. 1999).

Tradable green certificate scheme has been introduced in 8 EU countries (Global Renewable Energy Database 2008). Finland has no TGC scheme, but if emission trading and present policies do not promote the use of renewables efficiently enough, TGCs will be considered (Ministry of Trade and industry 2005). In Finland hydro power and forest chips have the lowest costs of renewable energy sources, so if they were included in the green certificate systems, they would be the first renewable sources that benefit from it. That is because green certificate prices are the same for all renewable energy sources. Electrowatt-Ekono (2005) has estimated the suitability of green certificates in Finland. Electrowatt-Ekono reminds that if forest bioenergy is strongly subsidized, there is a danger that pulp wood is used in electricity production rather than in paper and pulp industry. In their opinion green certificates could be applied for forest bioenergy only in small power plants that are excluded from emission trading. The interest group of Finnish energy producers Finnish Energy Industries opposes green certificate scheme. This resistance is based on the view of green certificates overlapping with EU ETS. On the other hand some of the Finnish Energy Industries' important members such as Fortum and Vapo support green certificates (Haukkasalo 2007).

GSN (2007, 62) has estimated the costs of green certificate system in Finland. The costs to consumers were 0.0–0.5 €/MWh_e in 2010 and 7.0–23.8 €/ MWh_e in 2020 depending on the assumptions behind the calculations. EU bioenergy targets tighten towards the year 2020, and more expensive technologies are introduced and the costs of green certificate scheme rise notably. Finnish electricity price was assumed to be 45 €/ MWh_e. Finnish Ministry of Trade and Industry (2006, 106) did not recommend green certificate scheme to Finland, but they point out to some considerations that should particularly be taken into account, if TGCs are introduced in Finland:

- time limit of TGC scheme (at least 15 years)
- the quota of RES-E
- what RESs and RES-E techniques would be justified to green certificates
- do existing producers receive certificates
- are some electricity consumers relieved from certificate buying obligation and
- should certificate prices have some minimum and maximum levels set by authorities?

All the green certificate schemes in place are quite new, and there is not much experience considering them. The green certificate scheme of United Kingdom (UK) follows the theory of green certificates, and this scheme is illustrated here. UK's green certificate scheme started in 2002. The scheme is technology neutral with one certificate representing 1 MWh_e of RES-E. The scheme includes multiple RES technologies such as hydro, wind, biomass and biogas (Global Renewable Energy Database 2008). In the scheme the co-firing of biomass and coal has been restricted to only 10 % of the total amount of green certificates. The production of RES-E has not met its targets in UK, thus a significant portion of green certificates have been compensated with penalties. Nevertheless, the use of RES-E has increased in UK after 2002 more than before. The mature and relatively inexpensive RES-E technologies such as biomass, biogas, and wind power on land have developed the most in UK (GSN 2007).

Sweden introduced certificate scheme in May 2003. Swedish certificate system covers RES-E such as wind power, solar energy, biomass and small hydro plants. The scheme also covers peat, when it is burnt in a CHP plant. The electricity that is produced by peat is not calculated to renewable energy targets that the certificate system has. According to Swedish Energy Agency peat is involved because they want to assure that the peat that is used in CHP plants is not replaced by coal. The objective of the scheme is to increase the RES-E production from the renewable sources that are justified for certificates from 6.5 TWh_e in 2002 to 17 TWh_e in 2016. The corresponding production in 2006 was 11.6 TWh_e, an increase of 5.1 TWh_e since 2002. The growth is mainly due to the increased biomass use in existing power plants. Most new plants (73 %) that started up between May 2003 and December 2006 are wind power plants (Swedish Energy Agency 2007)

The possibility of EU-wide TGC harmonization has generated some interest. European Commission (EC 2005, 19–20) states that overall costs of attaining the EU's RES-E target could be lower with the harmonization of TGC than with separate national policies. EC also points out that EU-wide TGC scheme could also lead to more stable certificate prices than national level policies. According to Rio (2005) both importing and exporting countries could benefit from harmonization. Importing countries would save costs and exporting countries would gain extra revenues. Rio however reminds that Member States might have other national goals apart from RES-E cost efficiency. National goals could include domestic RES-E production and sosio-economic and environmental issues that are met better if the TGC schemes are not harmonized.

If Finland introduced tradable green certificate scheme, it probably would include many different RESs and technologies, because the certificate markets would be quite small for only one RES. TGC scheme has some benefits and weak points, when considering forest bioenergy based electricity. They are illustrated in Table 4.2.1. Forest bioenergy based electricity has relatively low production costs, so it would benefit from TGC scheme. One drawback of TGC scheme is that with high certificate prices, it might be possible that pulpwood is used in electricity production. In Sweden the prices of forest chips are higher, and the prices of pulp wood are generally lower than in Finland. Even so, pulpwood has not been used in electricity production in Sweden (BioEnergia 2008).

Table 4.2.1. Pros and cons of implementing TGC for forest bioenergy based electricity (FBE-E).

PROs	CONs
+ The produced amount of RES-E is certain (with high enough penalties).	– Might be hard to set the penalties right.
+ Increases competition between RES-E producers.	– Might hike up forest raw material prices.
+ Increases FBE-E strongly relative to other RES-E, because of comparatively low costs.	– Might channel pulpwood to FBE-E production.
+ Could raise the competitiveness of small power plants.	– If big and small power plants are in the scheme, the big ones benefit.
+ Cheap policy for consumers in the short-run, because the RES-E producers with the lowest costs increase their production first.	– Might be expensive for the consumers in the long-run, because it does not promote particularly investments.
+ TGCs are not bounded to government budget	– TGCs are eventually paid by consumers
+ FBE could be used in domestic electricity production.	– Finnish certificate markets would be quite small
+ Control costs are relatively low.	

4.3 Finnish forestry subsidies

Finnish forestry promoting policies are set down in the Law for financing sustainable forestry (Kestävän metsätalouden rahoituslaki, KEMERA). The latest version of the law (544/2007) was introduced during the year 2008. The purpose of KEMERA is to promote wood production and the use of energywood. The implementation of the law is mainly done by subsidies, but some forestry works can also be financed by loans.

KEMERA-subsidies can be applied for forestry works that secure or promote the sustainability of wood production, maintain forest biodiversity or nurture forest. Most of the Finnish forestry promoting subsidies are geared toward to private forest owners. The works that are subsidized by KEMERA need to fulfill some general requirements:

- economically viable
- suitable for forest biodiversity conserving
- designed to be carried out with minimum possible costs and
- meet with forestry's best practice principle.

The forestry works that can receive KEMERA-subsidies can be made by the forest owner or the works can be contracted to an outside actor. To receive the subsidy, the forest owner must have a plan or report the work by implementation report. The plan is done before the work and the implementation report after the work is done. The forestry works (of which three first are covered in this chapter), that can receive subsidies are

1) tending of seedling stands and improvement of young stands,
2) energywood harvesting,
3) energywood chipping,
4) forest regeneration,
5) forest fertilization,
6) peatland forest care,
7) forest road construction,
8) forest non-financial use and biodiversity maintenance,
9) forest nature care and
10) other enhancement actions.

The pre-conditions set for the subsidies are fairly complicated. Pöyry (2006) has suggested some ideas to simplify the KEMERA-law. For example Pöyry suggests clarification to the terms of KEMERA-subsidies to minimize the uncertainty relating to receiving the subsidies.

Tending of seedling stands and improvement of young stands

This group includes for example the following works: tending of seedling stands and thinning of young stands. Our focus is on thinning of young forests, since it yields small sized trees that are good quality raw material for forest chips. Those forest chips can be used even in demanding small-scale heating plants as inputs. The harvesting and chipping of the energywood part of the wood material that has been harvested under young forest management subsidy can receive energywood harvesting and chipping subsidy.

The minimum size of young-forest management area that is subsidized is 1 ha. Forest owner can receive young-forest management subsidy only once in rotation for one area. If forest owner carries out subsidized thinning, the amount of cut trees must be over 1000 stems/ha. The amount of young-forest management subsidy is 84.5-294.7 €/ha.

Energywood harvesting

Forest owner or harvesting contractor can apply subsidy for energywood harvesting. Energywood means here wood that is harvested within improvement of young stands and has been delivered to energy use. Subsidy can be allocated to energywood bunching and forest transport. The amount of harvested wood must be at least 20 m^3 to receive the subsidy. Forest owner can receive energywood harvesting subsidy only once per rotation for one forest area. The amount of energywood harvesting subsidy is 7 €/m3, from where 3.5 €/m3 is for bunching and 3.5 €/m3 is for transport.

Energywood chipping

The chipping of energywood can be subsidized, if the energywood is felled under subsidy for improvement of young stands or harvested under energywood harvesting subsidy. Subsidy can be applied by private forest owner, heat company, chipping contractor or other forestry professional. The energywood chipping subsidy is 1.7 €/chipped loose-m3 (Parliament of Finland 2007; Pöyry 2006, 13; Tapio 2007).

Harvesting residue collection

Because there is scarcity of energywood chips in energy production, we present a possibility for harvest residue collection subsidy. If the energywood harvesting and chipping subsidy would include also sustainably harvested residue collection after final felling, the energywood supply could increase.

4.4 Climate, energy and forest policy modeling

The principles of the economic modelling of the policy instruments are presented in this chapter. Bioenergy and forestry models that also take into account policy instruments are presented in Chapters 3.1 and 3.2. The presentation related to emission tax and emission trading is mostly based on the classic environmental economics literature. However, the literature considering carbon sequestration policies, renewable electricity promoting policies and forestry policies is relatively new.

4.4.1 Climate policy economics

Fossil fuel use causes negative externality in the form of carbon dioxide emissions that foster the climate change. To correct the negative externality, regulators can impose climate policy instruments. Climate policy instruments give a price for the negative externality, CO_2. The economics of three climate policy instruments: emission tax, emission trading and carbon sequestration policies are presented in this chapter.

Emission tax

If a policy regulator decides to impose an emission tax, the externality of polluting is internalized into the decision making of polluting firms. Per unit emission tax was first proposed by Pigou in 1932, and it is known as Pigouvian tax (e.g. Hanley, Sjogren andWhite 1997 and Xepapadeas 1997). If there is no environmental regulation, emitting firms' total emissions are Q_e^0, because the aggregate marginal abatement costs (MAC) of reducing emissions are zero in that point. If regulators decide to impose an emission tax p_{tax}, the emissions reduce from Q_e^0 to Q_e^{tax} (Figure 4.4.1).

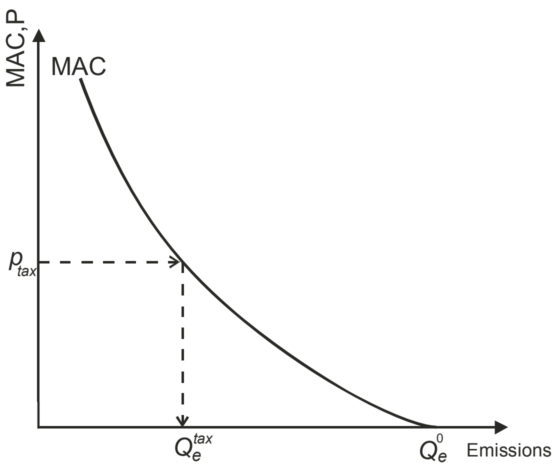


Figure 4.4.1. Emission tax.

When the firm i faces an emission tax p_{tax} and has emissions $e_i = \varepsilon_i x_i$, where ε_i is the emission factor of production x_i, it solves the problem

(1) $$\Pi_i = px_i - c_i(x_i) - p_{tax}e_i ,$$

where p is the price of the output product, x_i is the output and the production costs are $c_i(x_i)$. The following first order condition is $p = c_i'(x_i) + p_{tax}\varepsilon_i$. From the first order condition it can be observed that emission tax raises the costs of production and therefore it reduces the production of the pollutiong firm i. The effect of an emission tax on the firm's output is illustrated in Figure 4.4.2.

Emission trading

In the late 1950s both policymakers and economists were looking for tools to reduce pollution. In principle, policymakers supported quantity-based policies while economists supported price-based policies. Policymakers wanted to use a series of legal regulations, but economists promoted the use of a Piqouvian per-unit pollution tax for emissions.

Coase (1960) showed that if property rights were defined on the right way, pollution policies are not needed. Coase also argued that property rights could be explicit and transferable. That

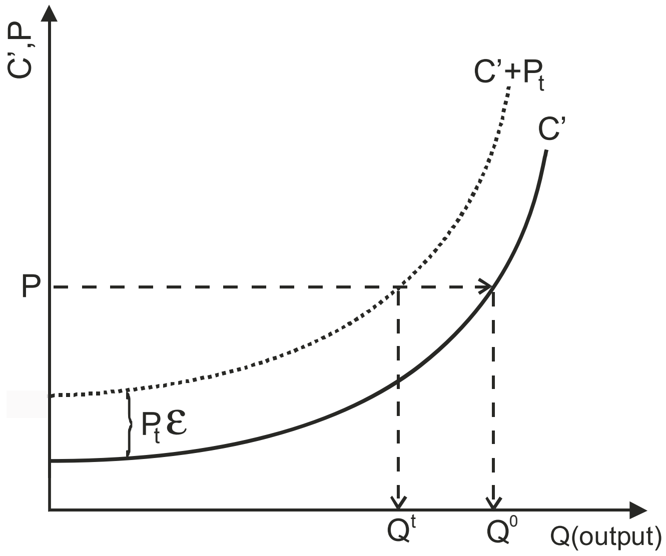


Figure 4.4.2. The effect of an emission tax on a firm's output.

way markets could play a crucial role in pollution policy. Coase's new approach opened doors to emission trading, which was first proposed by Dales in 1968 (Tietenberg 2006). Since then, emission trading has raised a lot of interest among economists and by now emission trading literature is wide-ranging. An extensive review of emission trading literature can be found on Tietenberg's website (Tietenberg 2008).

A conventional way of covering emission trading is represented in this chapter (e.g. Baumol and Oates 1988, Hanley, Shogren and White 1997 and Xepapadeas 1997). In emission trading regulators determine the optimal amount of emissions $\hat{Q}_e$ that equal the amount of emission credits. In the absence of climate policy, the marginal abatement costs (MAC) are zero and thus the total emissions are Q_e^0. If $\hat{Q}_e$ is the optimal amount of emissions, the emission credit price is p_{ec} (Figure 4.4.3).

In the initial allocation (grandfathering of credits) producer i gets $\overline{e}_i$ amount of emission credits. The sum of allocated emission credits to n firms is equal with the socially optimal amount of emission ($\hat{Q}_e$)

(2) $$\sum_{i=1}^{n} \overline{e}_i = \hat{Q}_e \, .$$

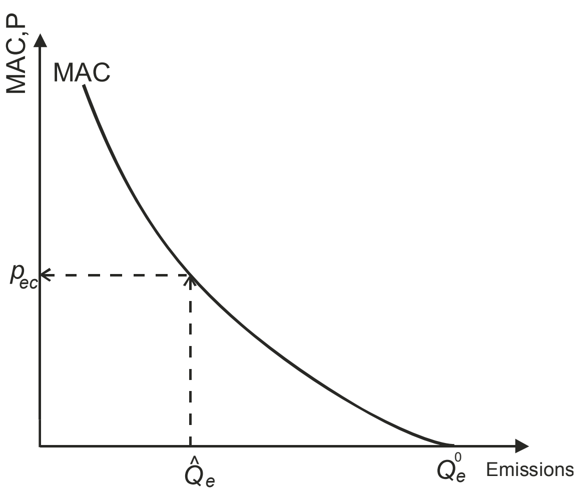


Figure 4.4.3. Emission credit price.

The emissions of firm *i* are $e_i = \varepsilon_i x_i$, where ε_i is production's emission factor and x_i is production. The price of the final product is *p* and the production costs are $c_i(x_i)$. The price of an emission credit is p_{ec}. Firm *i*'s profit function under emission trading can be defined as

(3) $$\Pi_i = px_i - c_i(x_i) - p_{ec}\left[e_i - \bar{e}_i\right]$$

and the necessary first order condition is $p - c_i'(x_i) = p_{ec}\varepsilon_i$. If the initial allocation is carried out by auction, firm *i* has to buy credits for all of its emissions and the profit function is

(4) $$\Pi_i = px_i - c_i(x_i) - p_{ec}e_i$$

and the following first order condition $p - c_i'(x_i) = p_{ec}\varepsilon_i$ is equivalent with the grandfathering situation. Figure 4.4.4 shows how emission trading affects a firm's output.

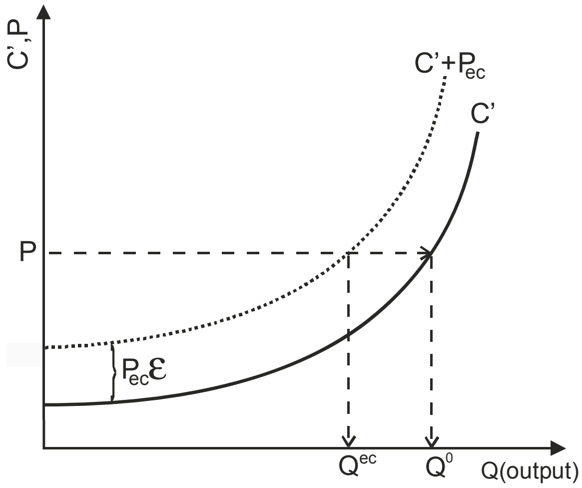


Figure 4.4.4. Emission trading.

The first order condition is similar with the situation of an emission tax. In a case of perfect information, emission tax leads to the same environmental improvement as emission trading. However, environmental regulation often faces the problem of imperfect information, while emission trading is a way to ensure the desired reductions in polluting.

Emission credit price represents an opportunity cost for a polluting firm, because the firm has to decide whether it produces (and pollutes) or sells emission credits at the market price. The opportunity costs exists both in grandfathering and auctioning situation. Therefore firms add the costs of emission credits to their marginal costs, even when the credits are allocated for free, as we saw earlier.

One recent interesting and important research area relating to emission trading is the emission trading's effect on electricity price. Emission trading raises the costs of electricity producing and the electricity producers pass at least part of the raised costs to electricity prices. The impact of emission trading on the price of electricity arises from three major factors (Sijm et al. 2005):

1) The price of emission credit P_{ec} (€/tCO_2),
2) The carbon intensity of marginal power production *I* (tCO_2/MWh) and
3) The level of passing through carbon costs *L* (%)

Thus, the change in the price of electricity, ΔP_e is

(5) $$\Delta P_e = \frac{P_{ec} IL}{100}.$$

The level of passing through carbon costs is determined by many factors. One major factor is the market structure of electricity markets. Theoretically, the more competitive the markets are, the bigger is the pass-through. Other important factors that influence the level of pass-through are the allocation mode, the elasticity of demand, outside competition and regulatory intervention (Sijm et al. 2005; Reinard 2007). The price of electricity is also influenced by many other factors than emission trading, so it is not easy to track down the effects of emission trading on it. Honkatukia, Mälkönen and Perrels (2006) made an econometric analysis of emission trading's effect on Finnish electricity prices. In their results the pass-trough rate was on average about 75-95 %. Sijm, Neuhoff and Chen (2006) estimated that the pass-through of EU ETS in the Member States is 60-100 %.

Carbon sequestration policies

The possibility of offsetting CO_2 emissions by expanding world's forest area was first proposed by Sedjo and Solomon in 1989. Carbon sequestration has been a popular research area in the last decades. Many studies have focused on the cost-effectiveness of carbon sequestration relative to other climate policies. An extensive review of carbon sequestration cost studies was made by Richards and Stokes (2004).

In principle, carbon sequestration policies could create a price for the stored carbon. The carbon price would create incentives for forest owners for maintaining or increasing the size of timber stock in their forests. The relevant policy instruments are subsidies to private forest owners and including carbon sequestration into emission trading. A subsidy could be seen as a carbon allowance, rental payment or periodic purchase of the incremental carbon sink by the government. If carbon sequestration entered emission trading, participating countries could use carbon sinks to partially compensate their CO_2 emissions. Forest owners could, for example, receive emission credits for a forest that is mature for felling. Subsequently, the forest owner could decide how much longer he wants to grow that forest. When a forest owner performs the final felling, he has to hand over an equal amount of credits that he received in the first phase (Uusivuori 2008).

When studying the costs and benefits of carbon sequestration policies one needs to calculate the value of the forest land. That can be done at least in three different ways: *(1) use of forest economics model framework (e.g. Faustmann), (2) a bottom-up engineering study* or *(3) econometric study.* We focus on the first method. The studies that have used forest economics models for land value and carbon sequestration are for example Englin and Callaway (1993), van Kooten, Binkley and Delcourt (1995), Murray (2000), Stainback and Alavalapati (2002) and Uusivuori and Laturi (2007). The preceding studies have found out that subsidies to carbon sequestration can lengthen the rotation age of forests and that the rotation age is positively correlated with the price of carbon. Many past studies have also proved that carbon sequestration is a cost-efficient policy instrument in comparison with other climate policy tools.

Land value (or utility) maximizing forest owner faces the costs of carbon sequestration. For example the forest owner might lengthen the rotation age of his stand, when the revenues from the wood sales are delayed, compared to the situation without carbon sequestration policies. Figure 4.4.5 illustrates that the additional aggregate marginal costs (MC) the carbon sequestration policies create to forest owners and the level of the carbon sequestration subsidy (P_{CS}) define the additional

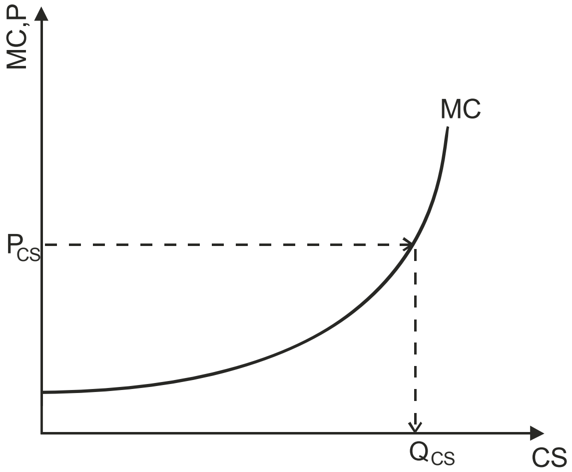


Figure 4.4.5. Carbon sequestration policy.

amount of sequestrated carbon (Q_{CS}) in CO_2-equivalent amount. If the forest owners are included in emission trading, the carbon sequestration subsidy (P_{CS}) is equivalent with emission credit price. In summary, in the optimum the marginal costs and the marginal benefits of carbon sequestration policies are equal.

When integrating the carbon sequestration into the Faustmann model, the sequestration policies add additional terms to the land value function, depending on how the policy is realized. The most simple way (e.g. van Kooten et al. 1995) is to add an extra term of net present value of carbon benefits (PVc) to Faustmann model

(6) $$PV = \frac{PV_F + PV_C}{1 - e^{-rT}},$$

where PV is the land value, PV_F is the net present value of timber benefits, r is the discount rate and T is the rotation age. If the net present value of carbon benefits is zero, equation (6) reduces to Faustmann model.

4.4.2 The economics of RES-E policies

In contrast with fossil fuel use, renewable energy use contributes to the preservation of public goods, namely clean air and climate stability. Because these public goods are non-excludable and non-rival, private actors do not have incentives to invest in them. Therefore government intervention in the form of RES-E promoting policies is needed to foster renewable energy. Another reason for RES-E policies is that renewable energy is in unfavorable position in comparison with fossil fuels and nuclear power, because the technology is still in many ways immature. RES-E policies are needed to help bringing renewable energy to the markets, because once a new technology has been adopted, it becomes more efficient (Menanteu, Finon and Lamy 2003, 801) The RES-E policies that are covered in this chapter are feed-in tariff, feed-in premium and tradable green certificates. The economics of electricity subsidy is to a large extent similar to that of feed-in premium.

The economics of feed-in laws

Feed-in laws are widely used policy instruments in RES-E promotion. Most literature considering feed-in laws is not analytical, but for example Menanteu, Finon and Lamy (2003), Rio and Gual (2007) and Fisher and Newell (2008) have considered feed-in laws in economical context.

Feed-in tariff

In the case of feed-in tariff the RES-E producer receives feed-in tariff price p_{fit} for every unit of electricity it produces. Feed-in tariff price is quaranteed to be higher than electricity price ($p_{fit} > p_e$). The profit maximization problem of RES-E producer is thus

(10) $$\Pi = p_{fit} x - c(x) .$$

The following first order condition is $p_{fit} = c'(x)$ and the obvious interpretation of the first order conditions is that FIT increases the marginal profits of RES-E production and the production of RES-E (Figure 4.4.6 left side). RES-E policies are often imposed together with climate policies, so the examination of their interaction is also important. For example, emission trading raises the price of electricity, as we saw previously. But in the case of feed-in tariff the electricity producer does not receive a higher RES-E price, when emission credit price goes up, because the tariff price is fixed (Figure 4.4.6 right side).

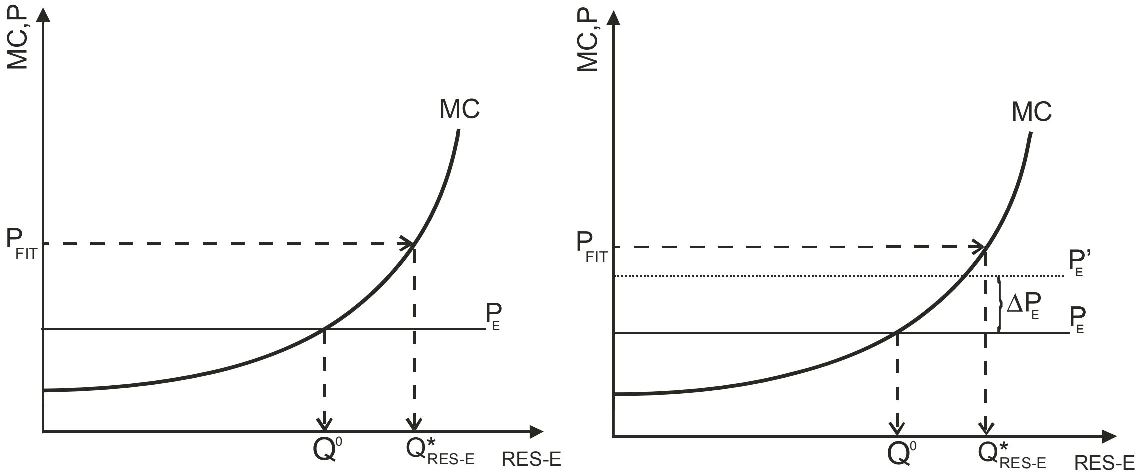


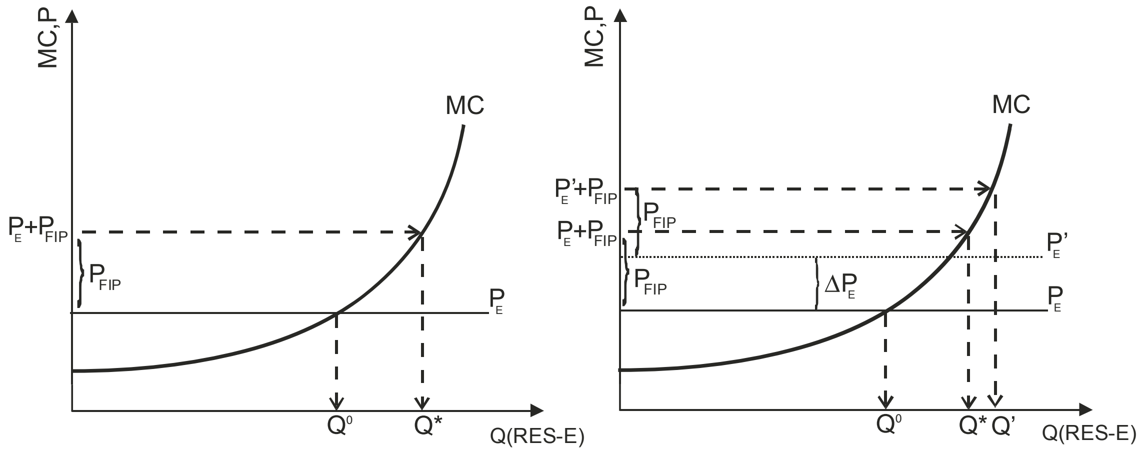
Figure 4.4.6. Feed-in tariff and emission trading's effect on electricity price.

Feed-in premium

Feed-in premium is equivalent with a production subsidy in a producer's problem. Subsidies have been analyzed for example by Hanley, Shogren and White (1997), Baumol and Oates (1988) and Xepapadeas (1997). The producer receives premium price p_{fip} (€/MWh) and electricity price p_e (€/MWh) for every unit of RES-E it produces. The profit maximization problem is thus

(11) $$\Pi = (p_e + p_{fip})x - c(x)$$

and the necessary first order condition is $p_e + p_{fip} = c'(x)$. The interpretation of the first order conditions is the same as in the case of feed-in tariff: FIP increases the marginal profits of RES-E production and the production of RES-E (Figure 4.4.7 left side). When feed-in premium is in use simultaneously with emission trading, they can be overlapping policy instruments, because the increase in emission credit price raises the RES-E price (Figure 4.4.7 right side).



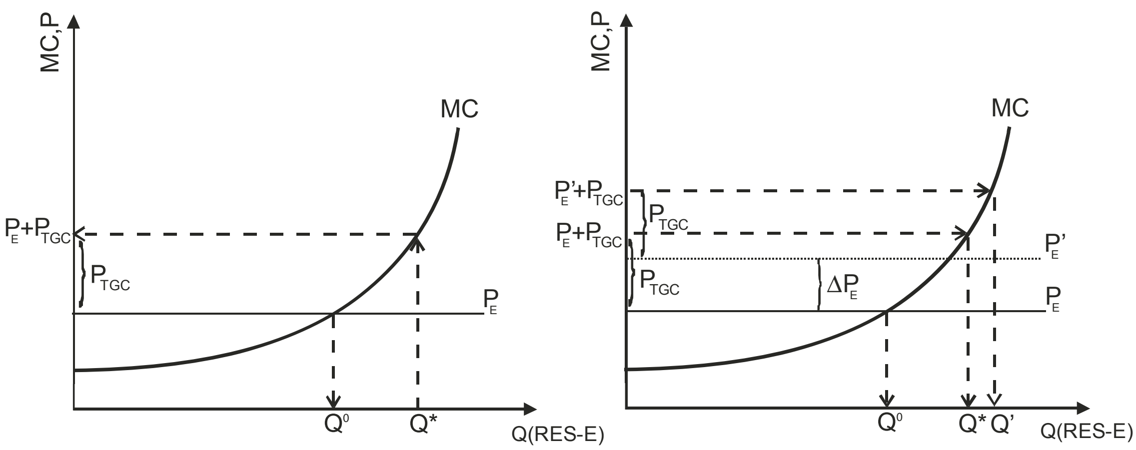
Figures 4.4.7. Feed-in premium and emission trading's effect on electricity price.

The economics of tradable green certificates

The economic literature of tradable green certificates include Amundsen and Mortensen (2001) and Menanteu, Finon and Lamy (2003). Some literature such as Marchenko (2008) study the green certificate market modeling, but we focus in this chapter on TGC effects on RES-E producers profit maximization. We follow the approach by Amundsen and Mortensen (2001). The producer receives certificate price p_{tgc} (€/MWh) and electricity price p_e (€/MWh) for every unit of RES-E it produces. The profit maximization problem is thus

$$\Pi = (p_e + p_{tgc})x - c(x) \tag{12}$$

and the following first order condition is $p_e + p_{tgc} = c'(x)$. The profit maximization problem is similar with FIP, so the interpretation of the first order conditions is the same as in the case of feed-in premium. Green certificates increase the marginal profits of RES-E production and the production of RES-E (Figure 4.4.8 left side). Also tradable green certificate scheme can be an overlapping policy with emission trading (Figure 4.4.8 right side).



Figures 4.4.8. Tradable green certificates and emission trading's effect on electricity price.

4.4.3 The economics of forestry subsidies

The economic literature focusing on forestry subsidies is narrow. The Finnish economic literature that has covered forestry subsidies consist mainly of econometric studies (e.g. Hänninen et al. 2001 and Linden and Leppänen 2003). Linden and Leppänen generated utility-maximizing framework for private forest owners and Ovaskainen et al. (2006) used a quasi-linear utility function to model forest owners' problem under forestry subsidy. The global literature of forestry subsidies is also mainly econometric studies (e.g. Romm et al. 1987), but for example Boyd (1984) did model forestry subsidies on utility maximizing forest owner's framework. The forestry subsidies that are covered in this chapter are subsidies for improvement of young stands, that can be seen as forestry investments and energy wood harvesting and chipping subsidies.

The young forest improvement subsidies are aimed to forestry management works and investments that improve the output of forest in the long-run. A forest owner might not have incentives to invest on forest, because the benefits of the investment are realized only after many years. Also, the forest capital has a relatively low return making other investments perhaps more interesting for private forest owners. On the other hand, forests do grow at their natural rate when left unmanaged, whereby the forest owners might not consider forestry investments necessary (Linden and Leppänen 2003). Therefore subsidies are needed to make the forestry management works and investments that increase the wood supply in the long run favourable.

Approaches used earlier are not relevant for our purposes, because all the past studies have modelled forestry subsidies combined. We want to model the subsidies of improvement of young stands and the subsidies of energy wood harvesting and chipping subsidies separately. We also want to take thinnings into consideration. Therefore we need to develop a way to model improvement of young stands subsidies for our model framework. There are many problems related to modelling the subsidies of the improvement of young stands:

1) model should include thinning decisions
2) forest owners don't have perfect information about the subsidies (Hänninen et al. 2001)
3) the bureaucratic problems related to applying the subsidies may cause additional costs for forest owners
4) the subsidy receiving conditions have limited the amount of trees per hectare that have to be cut, the amount of trees that should be left on the site and the minimum area in hectares that needs to be thinned and
5) the thinning subsidy can be received only for one thinning per rotation.

It is usually the forest owner who receives the energywood harvesting subsidy – as in some cases also the chipping subsidy. There is no earlier framework to be used in our model for the forest owner and there are also some problems related to modeling energywood harvesting and chipping subsidies:

1) the subsidies can only be received if the energywood is felled under the subsidies of the improvement of young stands,
2) the subsidy can only be received if the amount of harvested energy wood exceeds the predetermined minimum,
3) a forest owner can receive the energywood harvesting subsidy only once per rotation for one forest area,
4) the bureaucratic problems related to applying the subsidies may cause additional costs for the actor, who applies for the subsidy and
5) the receivers of the harvesting and the chipping subsidy can be separate actors.

4.5 Conclusions

Climate, energy and forest policies cover a wide-ranging set of instruments that aim at increasing the use and production of bioenergy or at reducing CO_2 emissions. A summary of the policy instruments and their main features is shown in Table 4.5.1. The focus of the Table is in the effects related to bioenergy and only the most important additional effects are mentioned. For example, many policies have also effects on employment, but these policies are not collected into the table. The Table shows that most policies affect both CO_2 emissions and bioenergy promotion. The policies are mainly directed to impact power companies or forest owners. The cost impacts of the policies usually fall on the government or consumers. It should be noticed that power companies can also include pulp and paper producers as well as sawmills, since they may produce electricity and heat as by-products.

All of the above mentioned policies are relevant for a policy simulation model. The current policies must be accounted for, but in order to meet the goals set by European Union for Finland some additional policies are also needed. The bioenergy promoting policies and forest subsidies (KEMERA) are probably in a key position when future forest policies are planned. The current policies, especially KEMERA subsidies, should also have new and innovative features when planning policies and building a simulation model.

Forest policies can change the operation of the companies that are affected by them. This has already happened is Sweden. For example, the pulp producer Södra has created a new focus for its strategy due to EU ETS and Swedish green certificate scheme. Power and heat production is becoming more and more important for Södra and they have even invested on wind turbines. As a consequence of this new focus, Södra was a net energy seller for the first time in 2008 (Roberts 2008). Recently, also the Finnish pulp and paper company UPM-Kymmene refocused its strategy, which emphasis much more in the energy production. The possible reforms, changes and possibilities that the policies can create in the forest sector should also be taken into account in the model.

Table 4.5.1. Summary of policies and their main features.

Policy	Primary target	Additional target	Policy directed to	Financier
Energy tax	CO_2 reduction	Bioenergy promotion	Power company	Government
Emission trading	CO_2 reduction	Bioenergy promotion	Varies	Consumers, companies
CO_2 sequestration	CO_2 reduction	Rotation age, wood supply	Forest owner	Varies
Investment subsidy	Bioenergy promotion	CO^2 reduction	Power company	Government
Electricity subsidy	Bioenergy promotion	CO_2 reduction	Power company	Government
Feed-in laws	Bioenergy promotion	CO_2 reduction	Power company	Consumers
Green certificates	Bioenergy promotion	CO_2 reduction	Power company	Consumers
Forestry subsidies	Roundwood production, bioenergy promotion	CO_2 reduction, forest management	Forest owner, other actors	Government

5 Framework of the model

5.1 Introduction

The global, EU and national policies related to energy and climate change will have important implications to the Finnish forest sector in the coming decades. The hierarchy of the policy framework is the following. At the global and EU level, the general targets and guidelines for policies are set. After these, the national governments set the more detailed policy measures in order to reach the given targets, and streamline the policies to be in line with the multinational guidelines. In practice, this approach still leaves the national governments a large flexibility to design the actual policy measures.

Given the global and EU policy objectives to control greenhouse gases, and to increase the share of renewable energy, the role of forests can be significant in achieving these objectives. Forests and forest products are a potential means to control CO_2 emissions, and a source of energy. Therefore, it is also of significant national interest to analyze the potential impacts of climate and energy policies to forest sector. In addition to expert views and various ad hoc analyzes, there is a need for more formal modeling work for this purpose. In Finland, there are already models, which are used for climate and energy policy simulations (e.g. POLA in the Technical Research Centre of Finland (VTT) and VATTAGE in the Government Institute for Economic Research (VATT)). However, none of the existing models contain a detailed description of the forest sector, e.g. the wood markets. They are also typically unable to link climate and energy policies with other policy measures relevant in the forest sector. Neither is there a model that combines in detail the forestry sector to the forest biomass utilizing energy sector. Still, in order to analyze the effectiveness of policies, and policy implications, e.g. to forest industry, the forest owners, and roundwood and energywood demand and supply, one needs to explicitly model also these actors and markets. The purpose of the current modeling work is to contribute to this purpose.

In particular, our objective is to build an energy and climate policy simulation model for the Finnish forest and energy sectors. The model will have a number of purposes. First, it is to provide a tool to better understand the forest sector and energy sector market behavior and interactions. Secondly, the objective is to undertake economic impact studies, especially as they relate to energy and climate policy efficiency, and the policy impacts to forest and energy sectors in Finland. For that purpose, the model is used to run sensitivity analyses and alternative scenarios. For example, the model could be used to explore the impacts of energy prices, taxes, subsidies, green certificates, carbon dioxide emission trade, or feed-in tariffs and premiums. The impacts range from changed investment and consumption patterns, employment, income distribution, wood supply, reduced CO_2 emissions, forest-based energy production, or sawnwood and pulp and paper production. The objective is also to model technologies in a way that the new energy efficient and CO_2-efficient technologies can be introduced and analyzed. In essence, the main object of the model work is to provide a supportive tool for designing forest, energy and climate policies, and in assessing their impacts.

The model will be primarily used for mid-term period analyzes, by which we mean simulations to next 5−20 years. Projections are made periodically from the base year through about 2030 (the dates are periodically updated). Within this time period, the technology, demographics, and economic conditions are sufficiently understood, in order to allow reasonable analyses using simulation models, such as the one we are building. However, often longer time horizons are also relevant for policy making, especially for analyzing climate policies. Consequently, the model should be flexible enough to be able to be informative for this type of simulations.

In Chapters 1−4, the main features of the Finnish forest sector, and the parts of the energy sector relevant for the utilization of forest biomass were described. Also, the forest and energy sector modeling literature, as well as the policy modelling approaches were presented. These chapters form a background that helps us in focusing our ongoing work of building a policy simulation model for the Finnish forest and energy sectors. In particular, they help us to answer the following questions relevant for the model building:

- Should the model be based on general equilibrium or partial equilibrium approach?
- What are the end-users (production and services demand), suppliers (industries, forest-owner groups) that should be included in the model?
- What is the appropriate geographical level of the analysis, i.e. national or regional, and on what level of aggregation the supply and demand are modelled?
- How are the dynamics of investments, demand and supply modelled?
- What policy measures should be included in the model?

These are some of the basic questions that a model builder faces when focusing the work and defining the model features. It is these questions that we now turn to analyze. Moreover, they are looked at from the perspective of the objective of our model work. That is, the model seeks to answer the "what if" –type of policy questions, and to be realistic enough, that the policy maker finds it useful in helping to answer these questions.

5.2 Defining the structure of the model

In building the model, a number of choices must be made in terms of the approach, scope, and level of detail. Various possibilities exist, as e.g. the literature survey in Chapter 3 has indicated. The purpose here is to discuss some of the essential choices that need to be taken, and to explain the approaches chosen for the Finnish forest and energy sector model that we are building.

5.2.1 Partial vs. general equilibrium model

The most complete approach of modelling the Finnish forest and energy sectors would be to analyze them as a part of the whole economy. That is, the model would explain the behavior of supply, demand and prices in the entire economy, of which the forest and energy sectors would be a part. This is in essence the general equilibrium model (GEM) approach. On the other hand, in a partial equilibrium model (PEM) approach, the equilibrium of the forest and energy sector markets are solved independently from the rest of the economy. The two model types, and the benefits and costs of building them, and having them operational, have to be compared against the purposes of the model: how the model is going to be used; which questions are to be addressed?

A choice between PEM vs. GEM approach is partly a trade-off between simplicity, and level of detail vs. theoretical robustness, and in incorporating the full impacts of the policy changes. Partial equilibrium models tend to be less demanding in terms of modelling work, updating, and running. Therefore, the resources put in the modelling work can be directed to provide a more detailed and realistic description of those sectors that the modeller is particularly interested. In the present case, the main purpose of the model is to assess the impacts and effectiveness of policy instruments, specifically the climate and energy policies, to Finnish forest and energy sectors, not the economy wide impacts and effectiveness. For the latter purposes there already exist models in Finland (e.g. VATTAGE).

However, a GEM model would be appealing because forest sector will generate cross-sectoral impacts in Finland. One of these features is naturally bioenergy, which links the forest sector to other sectors. In additon, the substitution between wood material and other materials, such as steel, plastics, concrete or glass, links forest sector to other sectors. Yet, it is possible, that partial equilibrium model is more usable than GEM, if it provides a more detailed and accurate description of those sectors where the primary interest of the analysis is. Thus, the choice between the modelling approaches is also an accuracy vs. validity issue.

Also, in a PEM approach, the modelling could be focused more intensively in the details and integration of the wood supply markets to the forest and energy sectors. In particular, it would be desirable to derive the wood supply from the utility maximizing consumer-forestowner behaviour, rather than use ad hoc approaches that are common in the general equilibrium models. This would allow a richer supply side description, and added microeconomic realism as compared to installing forestry as a simple production or activity component into the model.

In a utility maximizing framework, the model could have two types of assets, forest resources and other assets. The assets develop endogenously, the financial assets due to investments and depreciation. Investments develop due to consumption-saving decisions by the consumer-forestowners. The dynamic calibration of the convergence path to a steady-state would, however, be difficult in a two-asset model.

Given the limited amounts of modelling resources, the PEM approach would allow to concentrate the work in those markets and actors that are of particular interest to the researcher and policy maker. Also, it does not necessarily rule out the possibility of analyzing the economy wide general equilibrium impacts. Given the existence of economy wide GEM models for Finland, it may be possible to link the partial equilibrium analysis and results to such a model. Moreover, given time and resources, there is always the possibility to enlarge the partial equilibrium framework to general equilibrium framework.

In summary, the approach chosen here is a partial equilibrium. That is, the links and interaction between forest and energy sector to the rest of the Finnish economy are determined exogenously.

5.2.2 The scope of the sectors in the model

The model will incorporate three major sectors: forest industry (pulp and paper and wood products industry), forestry (roundwood markets), and energy sector. The type of modelling and the level of detail are different for each sector.

The level of industry and sector aggregation is mainly determined by two factors: the objective to describe the industry technologies as realistically as feasible, and the data availability. The industry data are based on the Statistics of Finland national accounts and industrial classification (TOL2002). However, in contrast to the TOL2002 classification, and in order to keep the model realistic, we also want to separate the chemical (kraft) pulp and mechanical pulp production, rather than group them together to pulp industry. This is important due to the very different energy utilization and energy generation in the two processes.

The forestry sector and roundwood markets are incorporated through the supply of roundwood and energy wood by the private non-industrial forest owners (NIPF), industry and state forests, and the imported roundwood. NIPFs supply almost 80% of the domestic roundwood, the forest industry companies typically around 12%, and the state forests (Metsähallitus) around 8%.

According to the TOL2002 classification, the most important industry sector using forest biomass for energy production (besides forest industry itself), is the sector aggregated under the name of "co-generation of electricity and district heating (TOL 40113). Under this category there are plants using both biomass (forest and peat) and fossil fuels (coal, oil, gas) as raw material. Thus, it is important to be able to model the combined heat and power (CHP) generation technology also based on *co-firing* different kinds of raw material. Indeed, from the climate policy perspective, the possibility of co-firing renewable biomass with fossil fuels promises to be an important channel through which the greenhouse gases can be reduced.

Also, in the analysis it is important to incorporate separately the peat raw material, since a significant amount of the forest biomass used for energy production is based on co-firing peat. In addition, due to the feed-back and substitution effects between the energy industries using biomass as raw material, the other renewable energy industries, and the fossil energy based industries, it is important to model also the latter industries.

In practice, as the modelling work progresses, the availability and quality of the data, and the practical needs and problems, will in the end determine the final aggregation level of the industries. For example, a possible structure is one, in which the integrated pulp and paper plants are modelled individually, as well as large sawmills, while the smaller units, such as small-sized sawnwood producers are lumped together according to the regional basis. An analogous structure can be applied with the power and heat sector, so that larger units (>20 MW) are modeled separately, and the smaller units in appropriate size classes (<5 MW and 5−20 MW). Also, a regional disaggregation of the power and heat units is possible. The power and heat sector categorization can be based on other characteristics also, such as technology types, or separation of the units operated by the pulp and paper industries.

The base year for the data is 2007. However, it is possible that during the modeling work this is updated depending on the availability of more recent data.

The forest products demand in Finland is largely based on exports, and the demand functions in the model will describe the exogenously determined demand. These functions define the forest-industry product prices which are treated as given for the producers in Finland. In the energy sector, the prices may be determined endogenously by the supply-demand equations in the energy market modules. Together with output prices, wood prices enter the output level decisions of forest-industries and the heat and power sector. Simultaneous modeling of the roundwood demand and supply allows the endogenous determination of roundwood prices.

As the modelling work progresses, it is to be decided which other markets will be endogenously described, i.e., in terms of supply and demand. For example, for energy policy purposes, it would be useful to have the peat price endogenously determined.

The input demands are derived from the profit or cost functions − at least when the top-down approach is used, and in some cases also in the activity analysis based models. The input substitution between wood and other inputs is an important area of study, for example in the heat and power production. However, the model should also be able to address the decision-making context of multiple output production (beyond a fixed coefficient technology). This is relevant in the forest sector, for example, when assessing future production of pulp producers between pulp and energy, or in determining sawmills production of woodchips for pulp industry vs. energy industry. Thus, the multiple output decisions should also be endogenously determined within the model.

The forestry sector will include the description of equilibrium in the following markets:

- Energy wood market (i): whole-tree chips from young forests, and (ii): logging residues from clearcut sites
- Logwood market (i): spruce; (ii): pine and (iii): hardwood
- Pulpwood market (i): spruce; (ii): pine and (iii): hardwood

For other input markets, such as, labor and capital, a straight-forward approach would be to use a fixed coefficient model. Also, CO2 emissions and other pollutants would be easiest to model based on fixed coefficients. Figure 5.2.2.1 provides a schmatic description of the different primary and intermediate product flows we want to incorporate in the model.

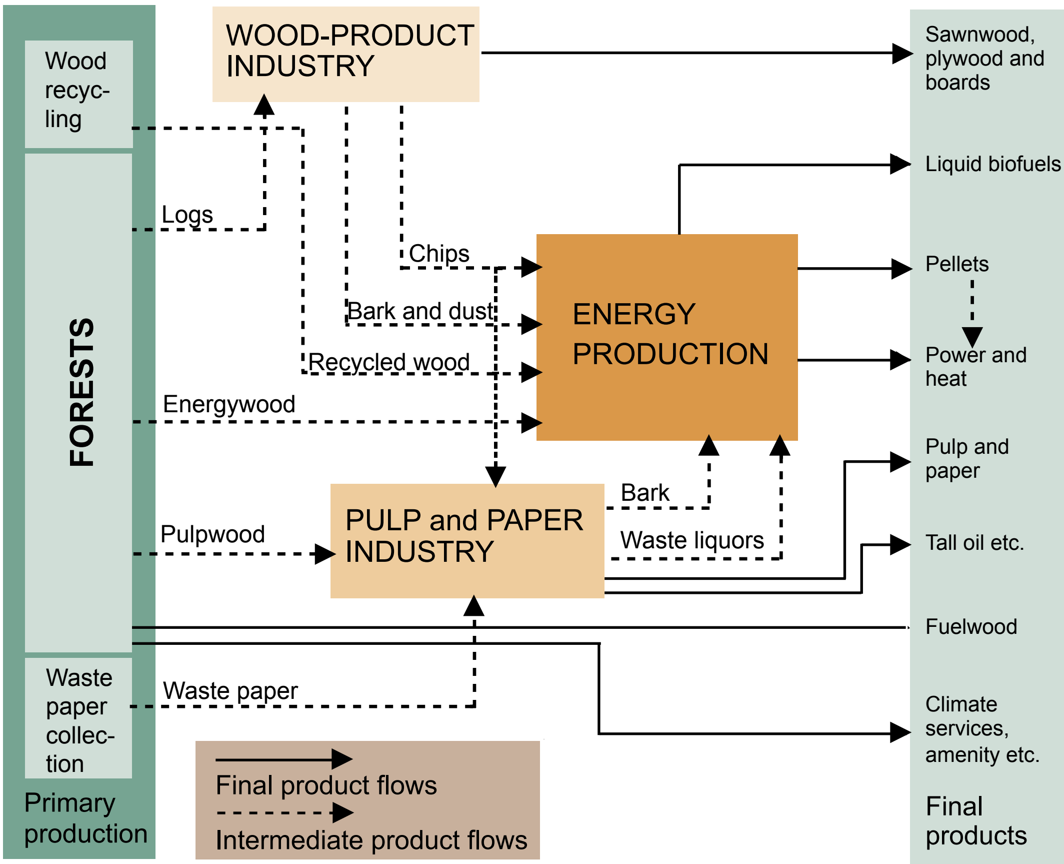


Figure 5.2.2.1. The structure of primary and itermediate product and service flows in the model.

5.2.3 Structure of the demand side

The demand module of the model includes descriptions of the forest industries (pulp and paper, sawn wood, panel industries), and the power and heat industries utilizing forest biomass, as well as fossil fuels, and wind power. The nuclear and geothermal energy suppliers are excluded from the model.

The energy and forest products demand can be modelled as a combination of "bottom up" characterizations of technology and "top down" economic behaviour. For example, it may be possible that the technological details of existing power and heat generation be incorporated into the top down characterization, while using activity analysis and input-output coefficients for the forest products. The market behaviour enters via the existing econometric estimates, or estimates that are generated within the present modelling work. The possibilities for technology and energy efficiency improvements over time will also be incorporated, but the exact method is still open. Indeed, the choices depend, among other things, as to how much flexibility the model should have in the different sectors in terms of describing technological development, or in experimenting with so far unknown technologies.

Natural regional basis for the demand for roundwood and energywood would be provinces. The fact that the wood supply side regions (forestry centers) are not completely consistent with those of the demand side, should not be a problem. Roundwood demands and supplies can be aggregated to the national level, and consistent larger regional units can be formed.

One open question is how to treat the energy wood demand for heating in domestic households in Finland. Most of the roundwood going for this purpose does not enter the markets, since it is collected from forests owned by the household. Also, data do not exist for the part exchanged in the markets. Yet, the amount of this type of wood is substantial enough to affect the roundwood markets.

In the future, there could be excessive supply of wood to meet domestic industrial and energy sector demand. Also, the fast developing and un-harmonized bioenergy policies in European countries may also create incentives to export energy wood from Finland in larger amounts. This, in turn, could imply that exports of roundwood and energywood become to play significant role in roundwood markets (currently, they are of minor significance). If this was the case, wood export demand should be one of the demand elements included in the model.

Another interesting question is, whether the forestry demand side should be extended to include also the demand for forest protection. In this case, the demand can be also for land units, rather than only for volumes of wood. In the utility maximizing consumer-forestowner optimization problem, the non-timber amenity preferences are parameterized, and the parameters can be thought to reflect the general public's preferences over recreational values and other amenities linked to standing protected forests. Thus, the societal changes in preferences that are related to forests, could be included in the supply side of the model.

In addition, there is also the demand for standing forest due to the forest related tourism, hunting associations, or the planned landscape rental schemes. A natural operational monetary unit of the protected forest markets' would be the rental value of standing forest. It would be over this rental value that the possible equilibrium of these markets should be solved for. These markets are likely to be highly local.

5.2.4 Structure of the roundwood and energywood supply

It is possible to use fixed coefficients for the various timber assortments and energy wood components in the utility maximizing consumer-forestowner optimization problem. These coefficients vary from age-class to age-class, and between the different forest types. The coefficients are used to form price indices for standing forests of varying age, over which the thinning and clearcutting decisions are made.

The wood supply decision, as well as the decision controlling the development of other assets and consumption, are made based on four types of variables: market-level (prices, costs, interest rates), policy, forestowner characteristics (wealth, preferences), and forest-level factors. To describe the forests on the regional (forest center) level adds to the 'production technology' realism of the model. These regional supplies are then summed up to form the total, national level supply.

The feature of the supply side in which the consumer-forestowner values also non-timber amenities of the forest assets besides the monetary timber values, makes the analytics of the model much more complicated as compared to a model where the forestowner is merely a profit maximizer. However, this feature would be a contribution to current numeric timber supply models, and adds realism to the forest policy setting of the model.

The calibration of the supply side model can be based on the inventory data. Besides the inventory data, information is also needed on a regional basis of the energy-wood potentials of different types of forests in Finland (Hakkila 1991, Helynen et al. 2007, Laitila et al. 2004, Ranta 2002, Siren et al. 2001). Supplementary data are needed from the market-level variables and forestowner characteristics. Reliable data on the latter variable may in fact be difficult to obtain.

The stumpage prices are the most relevant wood prices for the forestowners in Finland. Using stumpage prices implies that the wood supply relates to standing forest. Currently, stumpage prices exist for timber, but only to some extent to the energy wood components. This will change, as the demand for energy wood is increasing, as well as the negative side-effects of collecting energy wood from the forests become more pronounced (potential loss of fertility and biodiversity). Therefore, ideally, the wood supply characterization of the model should also be able to incorporate the forestowners' willingness to sell energywood.

Currently, most of the forest chips come from clear-cut sites. These are lower quality fuel compared to the whole-tree chips from young forests. The costs of producing the former are much less than those of the latter. Due to this, the government has introduced a production subsidy for collecting and chipping energy wood from young forests. Also, the larger power plants (>20MW) are better able to use the lower quality clear-cut chips.

In fact, the above situation also brings forward the complexity and potential unwanted side-effects of different policy measures. Only the larger power plants (>20MWh) are part of the CO_2 emission trade scheme that seeks to reduce emissions. Therefore, the emission trade scheme treats differently the larger, and often more efficient, energy producers. This distortion is also strengthened by the subsidy to young forests chips, i.e., for the raw-material mainly used by smaller energy producers.

Besides forest chips, side streams from industrial processes, such as sawnwood chips, bark, and sawdust, form a large part of energy wood supply in Finland. How to model the simultaneous production of main products (e.g. pulp, paper, sawnwood), and the above side-products, is yet to be decided. It is possible that beyond certain energy prices, the multiple output selections between the current main products and energy products become genuine endogenous choices in the decision-making of the firms. Energy wood supply is also generated from recycled construction wood, and the importance of this may increase in the future.

Furthermore, it has to be decided how the model treats the production of wood pellets. Pellet production utilizes forest chips and the industrial waste wood residues, while the pellet production also competes with these as an input in the power and heat sector. The pellet production is anticipated to be rapidly increasing in Finland in the coming years.

Besides the wood from non-industrial private forestowners, the supply side of the model consists of state-owned (Metsähallitus) and corporate forests, as well as the supply from outside Finland. The amount of wood imports (supply) is decided by the Finnish forest industry companies' timber procurement divisions. It is also a function of the export duties set by foreign governments on exported wood.

Whether the supply descriptions of the state and corporate forests should include not only wood, but also forest land for recreational purposes, is an open question. The way that the privately owned forests are modeled through the utility maximization of consumer-landowners will generate automatically areas of old-growth forests that are not clear-cut, and thus represent supply of either temporarily or permanently protected forests. Policy schemes where landowners are compensated for protection of forests can be easily implemented in the model. If protected public forests are included, these have to be modeled in a more straight-forward way.

5.2.5 Dynamics of the model

The model will be dynamic, both in the wood-supply and the demand side. Considering e.g. the expected changes in energy technologies, and the likely impact of energy and climate policies for the adaptation of these technologies, it is important to have a dynamic structure.

Perfect foresight of prices (or static price expectations) on the part of forest owners would lead to a convergence path to a steady state. Otherwise the dynamics in the model could be based by simply solving the outcomes recursively one period at a time.

On the roundwood supply side, age-class models describing the behavior of forestowners become easily non-recursive leading typically to time-inconsistency. This is problematic in a market model. Therefore the model description of wood supply based on thinning and clear-cutting harvests should be recursive.

The model's principal analysis level is at the national level in Finland. However, it is possible to analyse e.g. the roundwood markets at the 13 regional forest district level. Also, in the energy market module, the data allow the disaggregation of the energy markets even at the plant level.

The national level market equilibrium implicitly assumes that the relevant level of market descriptions of the above products in Finland is national. This assumption is better justified in terms of the logwood and pulpwood markets, whereas the energywood markets have more local or regional features across the country. The same applies for the heating markets as part of the power and heat module of the model. Empirical evidence of the validity of the national-level market assumption is in part offered by the prevailing price differences between regions of the different products. For the material-wood (or timber) products, available price information can easily be used to check against the national-level market assumption, while the price information on the energy wood products is less available. However, existing regional price variation does not necessarily imply that the hypothesis of a one single national market has to be rejected.

5.2.6 Policy measures

Chapter 4 provided a discussion and analysis of the different climate, energy, and forest policy measures. Although, the list of policy measures was not exhaustive, the presentation covered many of the relevant policy measures, which are, or could be used in Finland.

The objective is to include the policy instruments in the simulation model in such a way, that it will be easy to adjust the model for introducing new policies, or to change the magnitude of a current policy. The primary interest in analyzing the policy effectivenss and impacts are in their immediate effects on forest and energy sectors. Also, the various welafare impacts within these sectors are studied. Here, the partial equilibrium model natrually limits the analysis in that the model will not be able to capture the full economy wide (general equilbrium) welfare impacts.

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Appendix. Forestry center level data for section 2.2.

Table A.2.2.1. The ownership of forestry land by forestry centers in NFI9 (Metla 2005).

Forestry Center	Non industrial private forest owners	Forest industries	State	Others	Total
			1000 ha		
Ahvenanmaa	103	1	3	9	117
Rannikko	764	49	29	114	956
Etelärannikko	316	44	19	51	430
Pohjanmaa	448	5	10	63	527
Lounais-Suomi	863	72	54	103	1 092
Häme-Uusimaa	771	72	52	78	974
Kaakkois-Suomi	652	101	18	41	812
Pirkanmaa	707	91	105	55	957
Etelä-Savo	960	144	73	59	1 236
Etelä-Pohjanmaa	1 232	31	105	108	1 476
Keski-Suomi	939	270	156	59	1 424
Pohjois-Savo	991	281	68	54	1 394
Pohjois-Karjala	848	325	343	80	1 596
Kainuu	806	282	904	62	2 053
Pohjois-Pohjanmaa	1 897	159	850	216	3 122
Lappi	2 266	166	6 384	292	9 108
Total	*13 799*	*2 044*	*9 143*	*1 331*	*26 317*
Total (%)	52	8	35	5	100

Table A.2.2.2. Total roundwood removals from NIP forests by forestry centres in 2008 (Metla 2009a).

Forestry center	Logs				Pulpwood				Fuelwood				Total			
	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total
								1000 m^3								
Ahvenanmaa	28	20	0	49	61	28	28	118	10	5	19	34	99	54	48	201
Rannikko	364	550	48	961	572	510	384	1465	107	216	323	646	1042	1275	755	3072
Etelärannikko	177	258	38	472	215	211	116	542	48	99	177	324	439	568	331	1338
Pohjanmaa	187	292	10	489	357	299	268	923	59	117	146	322	603	707	424	1734
Lounais-Suomi	695	852	46	1593	638	554	323	1515	211	193	361	765	1544	1599	730	3873
Häme-Uusimaa	542	1520	154	2216	489	829	468	1785	87	177	336	599	1118	2527	957	4601
Kaakkois-Suomi	661	835	93	1589	655	539	361	1554	106	92	227	426	1423	1466	680	3569
Pirkanmaa	454	935	68	1457	420	566	315	1301	83	139	307	529	957	1639	691	3286
Etelä-Savo	976	1033	271	2281	860	714	659	2233	105	75	231	411	1941	1822	1162	4925
Etelä-Pohjanmaa	726	515	29	1270	1142	366	575	2082	198	101	256	555	2066	981	860	3907
Keski-Suomi	574	1064	128	1766	735	600	488	1822	100	80	315	495	1408	1745	931	4084
Pohjois-Savo	466	1119	127	1712	657	755	735	2147	89	85	383	558	1212	1959	1245	4416
Pohjois-Karjala	586	604	101	1291	794	515	496	1805	90	56	226	371	1470	1175	823	3467
Kainuu	369	189	4	562	553	189	276	1017	75	18	92	184	997	395	372	1764
Pohjois-Pohjanmaa	708	345	14	1068	1527	352	917	2795	205	80	308	593	2440	777	1239	4456
Lappi	645	139	1	786	1213	226	274	1713	101	43	232	376	1960	408	507	2875
Whole country	7796	9719	1086	18600	10314	6742	6297	23353	1568	1359	3616	6543	19677	17820	10999	48496

Table A.2.2.3. Commercial roundwood removals from Metsähallitus forests by forestry centre in 2007 (Metla 2008a).

Forestry center	Logs				Pulpwood				Fuelwood	Total			
	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total	Total	Pine	Spruce	Hard wood	Total
							1000 m^3						
Ahvenanmaa	–	–	–	–	–	–	–	–	–	–	–	–	–
Rannikko	5	1		6	4	1	1	6	0	9	2	1	11
Etelärannikko	5	1	0	6	4	1	1	6	0	9	2	1	11
Pohjanmaa	–	–	–	–	–	–	–	–	–	–	–	–	–
Lounais-Suomi	19	1	0	20	16	2	2	20	–	35	3	2	41
Häme-Uusimaa	9	14	2	25	11	11	6	28	0	20	25	8	54
Kaakkois-Suomi	19	13	1	33	11	7	3	21	0	30	20	4	54
Pirkanmaa	35	23	3	62	35	16	10	61	0	70	39	13	123
Etelä-Savo	39	45	5	89	42	29	15	86	2	81	74	20	177
Etelä-Pohjanmaa	23	3	0	26	41	3	11	56	–	64	6	11	82
Keski-Suomi	95	43	5	144	105	33	29	167	1	200	76	34	311
Pohjois-Savo	34	35	2	71	65	38	24	126	–	99	73	26	197
Pohjois-Karjala	142	38	3	182	201	61	40	301	1	343	99	43	484
Kainuu	440	90	2	532	405	138	92	636	0	845	228	94	1 168
Pohjois-Pohjanmaa	165	48	2	215	280	98	69	447	0	445	146	71	662
Lappi	431	23	–	453	981	227	144	1 352	2	1 412	250	144	1 808
Whole country	1 455	377	26	1 858	2 198	663	446	3 307	7	3 653	1 040	472	5 172

Table A.2.2.4. Commercial roundwood removals from forest indusries forests by forestry centre in 2007 (Metla 2008a).

Forestry center	Logs				Pulpwood				Fuelwood	Total			
	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total	Total	Pine	Spruce	Hard wood	Total
	1000 m^3												
Ahvenanmaa	0	0	0	1	1	1	1	2	–	1	1	1	3
Rannikko	3	4	0	7	9	5	2	16	–	12	9	2	24
Etelärannikko	1	2	0	4	4	4	2	9	–	5	6	2	13
Pohjanmaa	2	2	0	4	6	1	1	7	–	8	3	1	11
Lounais-Suomi	50	8	1	59	64	8	7	79	–	114	16	8	137
Häme-Uusimaa	44	91	5	140	64	62	21	147	0	108	153	26	287
Kaakkois-Suomi	123	93	6	222	187	78	29	294	–	310	171	35	516
Pirkanmaa	88	83	5	176	114	69	30	212	–	202	152	35	388
Etelä-Savo	155	133	10	298	224	102	42	369	–	379	235	52	667
Etelä-Pohjanmaa	17	9	1	26	19	10	7	36	–	36	19	8	62
Keski-Suomi	233	191	15	439	349	195	94	638	–	582	386	109	1 078
Pohjois-Savo	185	199	12	397	255	167	101	523	0	440	366	113	920
Pohjois-Karjala	316	134	14	464	404	133	70	607	–	720	267	84	1 072
Kainuu	297	100	1	398	180	184	72	436	–	477	284	73	833
Pohjois-Pohjanmaa	32	10	0	42	57	29	23	109	–	89	39	23	151
Lappi	13	5	–	18	28	13	14	55	–	41	18	14	73
Whole country	1 556	1 061	70	2 687	1 954	1 056	513	3 524	1	3 510	2 117	583	6 211

Table A.2.2.5. Total wood supply by forestry centre and import in 2008 in Finland (Metla 2009a, Mäkelä 2009).

Forestry center	Logs				Pulpwood				Fuelwood				Other	Energy	Other+	Total			
	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total	Pine	Spruce	Hard wood	Total		wood	energy wood	Pine	Spruce	Hard wood	Total
	1000 m^3																		
Ahvenanmaa	28	20	0	49	61	28	29	118	10	5	19	34		30	30	100	54	48	232
Rannikko	374	556	49	980	586	519	388	1494	107	216	324	646		648	648	1067	1291	762	3768
Etelärannikko	185	263	39	487	226	219	120	566	48	99	178	324		177	177	459	581	337	1554
Pohjanmaa	189	293	10	493	360	300	268	928	59	117	146	322		471	471	608	710	425	2214
Lounais-Suomi	722	859	47	1628	667	561	329	1558	211	193	361	765		297	297	1600	1614	737	4248
Häme-Uusimaa	591	1601	159	2352	559	889	497	1945	87	177	336	600		340	340	1237	2667	992	5236
Kaakkois-Suomi	782	934	99	1815	885	625	400	1910	106	92	227	426		315	315	1773	1651	727	4466
Pirkanmaa	554	1019	77	1649	561	649	362	1573	83	139	308	529		201	201	1199	1806	746	3952
Etelä-Savo	1131	1208	285	2625	1110	849	718	2677	105	75	231	411		387	387	2346	2133	1234	6100
Etelä-Pohjanmaa	779	526	30	1335	1216	377	594	2186	198	101	256	555		201	201	2193	1003	881	4278
Keski-Suomi	819	1305	146	2271	1176	792	616	2584	100	80	317	497		588	588	2095	2177	1079	5939
Pohjois-Savo	631	1314	140	2085	1028	947	865	2840	89	85	383	558		193	193	1749	2346	1387	5675
Pohjois-Karjala	939	720	114	1773	1424	696	619	2738	90	56	227	373		273	273	2453	1472	959	5157
Kainuu	946	346	6	1298	1213	402	449	2064	75	18	92	184		250	250	2234	766	547	3797
Pohjois-Pohjanmaa	911	386	16	1314	1932	438	1025	3395	205	80	308	593		201	201	3048	904	1349	5502
Lappi	1038	163	1	1202	2227	464	437	3128	101	43	237	381		107	107	3366	670	675	4818
Whole country	10246	10959	1170	22375	14645	8236	7329	30210	1568	1359	3626	6553		4032	4032	26459	20554	12124	63169
Import	557	660	628	1845	2 877	2 504	8 089	13470					4618	278*	4896	3434	3164	8717	20211
Total	10803	11619	1798	24220	17522	10740	15418	43680	1568	1359	3626	6553	4618	4310	8928	29893	23718	20841	83380

* Imported fuelwood.

Table A.2.2.6. The theorical potential of energywood supply in forestry centers in 2020 (Pöyry 2007).*

Area	Felling residuals	Stumps	Small size tree	Total
			million m^3	
Uusimaa	210	220	190	620
Varsinais-Suomi	295	370	250	910
Itä-Uusimaa	75	85	95	255
Satakunta	285	355	325	965
Kanta-Häme	255	260	160	670
Pirkanmaa	520	595	480	1 595
Päijät-Häme	245	260	190	695
Kymenlaakso	210	245	215	670
Etelä-Karjala	285	365	265	915
Etelä-Savo	725	900	690	2 315
Pohjois-Savo	845	890	595	2 330
Pohjois-Karjala	690	855	710	2 755
Keski-Suomi	740	815	425	1 990
Etelä-Pohjanmaa	285	380	325	990
Pohjanmaa	300	320	180	800
Keski-Pohjanmaa	70	100	160	325
Pohjois-Pohjanmaa	750	725	1 255	2 725
Kainuu	695	635	795	2 120
Lappi	895	930	13 330	3 155
Ahvenanmaa	0	0		0
Total	8 380	9 305	8 620	26 300

Table A.2.2.7. The techno-economic potential of energywood supply in forestry centers in 2020 (Pöyry 2007).*

Area	Felling residuals	Stumps	Small size tree	Total
			million m^3	
Uusimaa	145	155	120	370
Varsinais-Suomi	160	115	235	405
Itä-Uusimaa	40	30	65	135
Satakunta	155	130	165	450
Kanta-Häme	175	120	90	390
Pirkanmaa	300	235	320	860
Päijät-Häme	150	100	115	355
Kymenlaakso	125	95	130	350
Etelä-Karjala	150	115	160	425
Etelä-Savo	385	300	455	1 140
Pohjois-Savo	525	360	300	1 180
Pohjois-Karjala	360	265	275	900
Keski-Suomi	455	340	210	1 005
Etelä-Pohjanmaa	80	60	90	235
Pohjanmaa	130	85	90	305
Keski-Pohjanmaa	20	15	50	80
Pohjois-Pohjanmaa	125	50	235	410
Kainuu	255	105	250	610
Lappi	170	40	265	480
Ahvenanmaa	0	0		0
Total	3 905	2 670	3 515	10 090

* Assumed that energy content of energywood is 2 MWh/ m^3