Woody Biomass as an Energy Source – Challenges in Europe

Joensuu, Finland

25–28 September 2000

Paavo Pelkonen, Pentti Hakkila,
Timo Karjalainen, Bernhard Schlamadinger (eds.)

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Preface

Currently, 3% of the energy production in the European Union on average is based on the use of woody biomass. The utilisation of biofuels has been widely adopted in the Nordic EU countries and in Austria in which 10–20% of energy production is based on renewable bioenergy. The EU White Paper (Energy for the Future: Renewable Sources of Energy – White Paper for a Community Strategy and Action Plan COM(97)599 final (26/11/97)) sets the target to double the use of renewable energy, and triple the use of bioenergy by 2010. This is a great challenge for all the stakeholders who are interested in development of new and renewable sources of energy.

In order to introduce large-scale wood energy systems for the changing societies in Europe, a strong emphasis has to be put on the key elements of the energy sector. Security of wood fuel supply, reliable energy conversion technology, provision of supporting services for new energy applications (such as transportation of pellets to maintain boiler, burner and feeding devices), price competitiveness, and improved fuel quality are necessary preconditions for sustainable production and marketing. This is a real challenge for international Research and Development organizations and institutions that work in the bioenergy sector.

The EU's plan to double the share of renewable energy production from 1995 to 2010 through development of a new industry is calculated to generate 900 000 additional jobs, of which 515 000 would be from the increased use of biomass fuels. This will especially provide opportunities for rural areas in Europe to improve livelihoods and reduce migration of people from the countryside to cities. Production of 'green energy' can be based to a great extent on the existing skills and knowledge of local people.

EU countries have committed themselves to reducing their greenhouse gas emissions in the Kyoto Protocol first commitment period (2008–2012) by 8% from 1990 levels. Increasing the use of renewable energy sources such as wood, to replace fossil fuels, can substantially contribute to meeting these greenhouse gas reduction targets. In addition, biofuels could replace electricity for heating purposes entirely – at least in the Nordic countries. Switching from electricity to biofuels in heating applications would provide the opportunity to utilize the great potential of electricity in, for example, industrial processes.

A cost effective method to significantly reduce CO_2 emissions in Europe is to replace power generation based on coal condensing plants with cogeneration of electricity and heat from biomass. It was argued at the conference that through intensive European-wide collaboration in the development of this kind of energy system and through broad adoption of new innovations, that the carbon dioxide emissions could be reduced by an even greater amount than what is required of the EU under the Kyoto Protocol (Karlsson et al. in this Proceedings). The recent adoption of the EU directive on electricity from renewable energy sources is an important step in that direction, and it is hoped that bioelectricity will play a key role within this new policy.

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The main outcome of the conference “Woody Biomass as an Energy Source – Challenges in Europe” was the recognition of the challenge faced by Europe to increase the utilization of biofuels. A successful strategy for such a large-scale change requires better integration of biomass resource utilization in both Western and Eastern Europe.

There is a clear need for new research on the optimal use of biofuels in Europe. The uncertainties involved in the use of bioenergy include, for example, the effects of harvesting fuelwood on the nutrient balance of forest soil and the availability of land for large-scale fuelwood production in Europe. We need more accurate information on the resources available, and of the opportunities for increasing the use of the – currently under-utilized – biomass resources, especially in Eastern Europe. We need real and concrete measures related to bioenergy production and use in order to improve livelihoods in rural areas in Europe.

These proceedings present selected papers from the International Conference on “Woody Biomass as an Energy Source – Challenges in Europe” held on 25–27 September in Joensuu, Finland. The conference was co-organized by the European Forest Institute and the Faculty of Forestry of the University of Joensuu. It was co-sponsored by the SILVA Network (European Forest Science Academic Network).

The main aims of the conference were to:

- review the current understanding of the role and potential of woody biomass as an energy source in Europe;
- discuss the means for integrating energy production in European forestry;
- clarify the connection between bioenergy and rural development;
- analyse the role of bioenergy in forest management and timber production;
- examine the importance of bioenergy in global carbon balance;
- strengthen the existing, and promote future, research co-operation.

Special emphasis was placed on contributions from the countries in transition, the newly independent countries and Russia, as well as small- and medium-size enterprises in the field of energy technology, and the forest owners.

Two associated meetings took place in Joensuu after this conference:

- A special workshop session (28 September) on “Land-Use, Land-Use Change and Forestry: the Road to COP6” organized jointly by IEA Bioenergy Task 25 (IEA Bioenergy Task 25 on Greenhouse Gas Balances of Bioenergy Systems) and COST E21 (Contribution of Forests and Forestry to Mitigate Greenhouse Effect) in association with European Forest Institute, the University of Joensuu (Finland) and Joanneum Research (Austria). The summary of the workshop is reproduced (with permission from the organizers) at the end of this Proceedings volume. The full report can be found at: http://www.joanneum.at/iea-bioenergy-task38/workshop/joensuu.pdf
- The first whole Action meeting of COST E21 took place on 28–30 September. The papers were published in Biotechnologie, Agronomie, Société et Environnement 2000 vol. 4, no. 4 and can be found at: http://www.bib.fsagx.ac.be/coste21/report/2000-09-28.html

Joensuu, Espoo and Graz

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Wood Energy in the Nordic Countries

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Abstract

The annual use of wood energy is in Denmark 6 TWh, in Finland 68 TWh, in Norway 12 TWh and in Sweden 80 TWh. Over 40% of the wood raw material input of the Nordic forest industries end up indirectly as fuel. In Finland and Sweden, therefore, the share of wood in the consumption of primary energy is larger than in other industrialized countries. Since all industrial wood residues are already used for the production of energy, the future increase in the use of wood energy will be based on the unutilized biomass reserves of the forests, i.e. small-sized trees from young stands and logging residues from final harvest. The paper examines the biomass reserves of the Nordic forests, alternative recovery systems for small-sized trees and logging residues, and the properties of forest chips. Finally, the present use and price development of forest chips in Finland are reviewed.

Keywords: wood energy, logging residues, forest chips, Nordic countries

1. Present Use of Wood Energy

Biomass refers to cellular material from living or recently dead organisms. Biomass is a widespread resource as it includes forest biomass, residues of the forest industries, recycled wood, energy crops, agricultural residues and agrofood effluents, manures and biogas, as well as the organic fraction of municipal solid waste, separated household waste and sewage sludge. Peat may or may not be considered to be a specific category of biomass.

Bioenergy is defined as energy produced by combusting biomass. Globally, biomass is the largest source of renewable energy, and forests are the primary source of biomass.

Because of a harsh climate, long transport distances and the predominance of process-type industries, the per capita consumption of energy in the Nordic countries is traditionally high. As the region is sparsely populated and rich in forests, energy management was reliant on

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wood longer than in most industrialized countries, but after World War II cheap oil rapidly replaced wood as the primary source of energy.

About 45% of the timber produced in the EU is harvested in the Nordic countries (Table 1). Almost 90% of this timber is used as a raw material of the forest industries. The remaining 10% consists of forest fuels, i.e. the woody biomass is used directly for fuel.

Table 1. Forest area and annual fellings in the Nordic countries in 1997. The area refers to forests available for wood supply (Finnish Forest…1999).

	Forest area million ha	Fellings million m^3yr^{-1}	Population Million persons	Fellings m^3 per capita
Sweden	21.2	66.1	8.9	7.4
Finland	20.6	54.2	5.2	10.4
Norway	6.6	11.6	4.4	2.6
Denmark	0.4	2.2	5.3	0.4
Iceland	0.0	0.0	0.3	0.0
Nordic countries	48.8	134.1	24.1	5.6
Other EU countries	46.7	165.4	350.2	0.5
EU, including Norway	95.5	299.5	374.3	0.8

The Nordic forest industries apply efficient technologies, but a substantial part of the raw material is either unsuitable for end products or is lost in processing. Whilst residues are left unutilized and dumped in landfill areas, they must be perceived as harmful waste. However, today they are an important by-product used for the production of energy. The proportion of the energy component in the northern timber flow to various forest industries is approximately as follows:

Product	*By-products for fuel*	*Fuel, %*
Sawn goods	Bark, sawdust, screening residues	15–25
Plywood	Bark, log ends, waste plies, dust	40–50
Mechanical pulp	Bark, screening residues	10–15
Chemical pulp	Black liquor, bark, screening residues	50–60

As much as 40% of the wood raw material input of the forest industries ends up indirectly as fuel, and practically none of this by-product is left unutilized. The primary sources of indirect wood-based energy are black liquor from sulphate pulping, bark and sawdust.

The annual use of wood energy in the Nordic countries was during the late 1990s as follows: Denmark 6 TWh, Finland 68 TWh, Norway 12 TWh, and Sweden 80 TWh. The total consumption corresponded to 166 TWh or about 15 million tonnes of oil equivalent (t.o.e.).

Figures 1 and 2 show the sources of energy in Sweden and Finland. In both countries the share of indigenous energy is about 30%. Wood-based fuels alone, including processing residues from imported wood, produce in Finland 19% and in Sweden 16% of the total consumption of primary energy. The share is larger than in any other industrialized country.

2. Unutilized Potential

The industrialized countries have agreed under the Kyoto Protocol to reduce emissions of greenhouse gases by an average of 5.4% from 1990 levels during the period of 2008–2012.

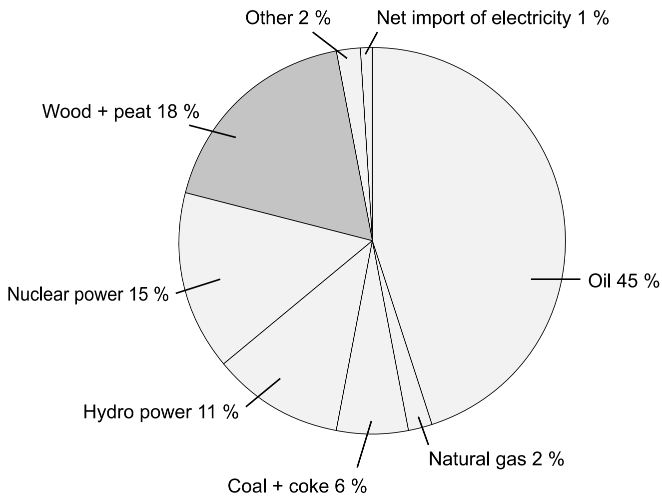

Figure 1. The structure of energy consumption in Sweden in 1996 (Nutek 1997). Total consumption 41 million t.o.e. (tonnes of oil equivalent).

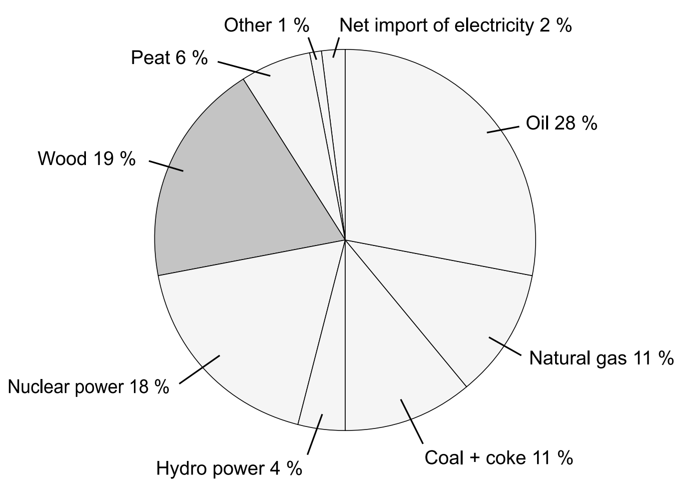

Figure 2. The structure of energy consumption in Finland in 1998 (Statistics Finland 1999). Total consumption 31 million t.o.e.

The obligation is not the same for all countries. In the Nordic countries, the reduction obligation is 21% for Denmark. For Finland it is sufficient to maintain the 1990 level. An increase of 1% is allowed for Norway and of 4% for Sweden. Since the greenhouse gas emissions presently exceed the level of 1990 in all Nordic countries, the task is much more demanding than the percentages above appear to show.

In order to reduce emissions, renewable energy must be substituted for fossil fuels. In countries with large forest resources and well developed forest sectors wood is the primary source of renewable energy. This is particularly the case in Sweden and Finland, but even Denmark with its much smaller land area places great importance on biofuels from forestry and agriculture (Centre for Biomass Technology 1999). Since practically all industrial wood residues are already used for the production of energy, the increase in the use of wood energy must be based on the unutilized biomass reserves of the forests. Two primary sources can be identified: (1) residues left unutilized in conjunction with silvicultural activities and logging operations; (2) and a part of the unutilized annual net increment of biomass (Figure 3). The structure of the net increment is not known, but it includes considerable amounts of small-sized trees which should be cleaned and thinned from young stands for silvicultural reasons.

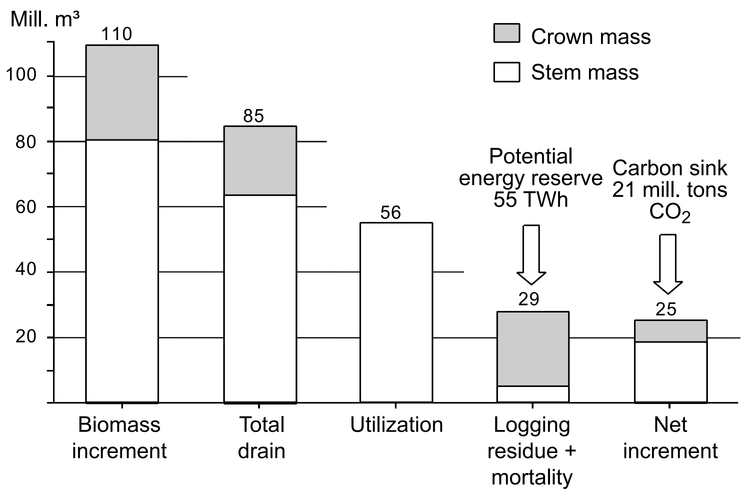

Figure 3. An example of the annual increment, drain and utilization of above-ground biomass in Finnish forests. Increment = drain + net increment; and drain = utilization + logging residue + natural mortality (1–2 million m³ year) (Hakkila and Fredriksson 1996).

The *theoretical unutilized wood fuel potential* of the Nordic forests is roughly 100 million m³ (almost 20 million t.o.e.) annually. More than half of this potential is composed of crown mass. When the ecological and technical constraints of recovery are taken into account, the *technically harvestable biomass reserve* is reduced to about one-third of the theoretical potential, corresponding to some 6 million t.o.e. According to the Swedish University of Agricultural Sciences, considerably higher amounts are available, if the loss of nutrients from forest soil is compensated through fertilization.

When the annual use of forest fuels increases in Finnish conditions by 5 million m³ solid or 1 million t.o.e., the following benefits will be achieved, assuming that two-thirds of the chips are to be produced from logging residues from regeneration areas, and one-third from small trees in young plantations:

- The saving in the importation of fossil fuels would be US$ 100–150 million;
- The value of chips, US$ 100 million, would contribute to the vitality of rural communities;
- The procurement of chips and the operation of chip-fired-plants would create 2500 jobs directly and 3000 jobs indirectly;
- Up to 50 000 additional hectares of young forests would be tended, which would greatly improve the standard of forest management. Furthermore, the removal of logging slash from final harvest would reduce the cost of regeneration by US$ 100 per hectare in an area of 60 000 ha, resulting in a total saving of US$ 6 million;
- The amount of CO_2 emissions would be reduced by 3.5 million tonnes.

3. Nordic Fuel Chip Harvesting Technology

Modern timber harvesting technology is designed, scaled and scheduled for industrial timber. In the Nordic countries the timber procurement system is based on the cut-to-length technology, i.e. the use of single-grip harvesters, forwarders and heavy 60 t trucks equipped with a full trailer.

When the recovery is extended to fuel, trees and tree parts which have been traditionally left unutilized because of their small size or unsuitable technical properties, become merchantable. Crown mass, including foliage, is an essential part of the energy potential of conventional forestry. The procurement system must then be adapted to the integrated recovery of fiber and fuel, or entirely new procurement systems have to be developed. From the viewpoint of cost saving, established logging organizations offer considerable advantages where available.

Only wood that is not demanded by industrial processes should be used directly for fuel (Figure 4). The line between industrial timber and fuelwood varies between countries. For example, the minimum diameter of pulpwood in Finland is 7 or 8 cm, but in Sweden it is only 5 cm. Denmark, on the other hand, does not have a domestic pulp industry. Consequently, potential pulpwood is frequently used for fuel

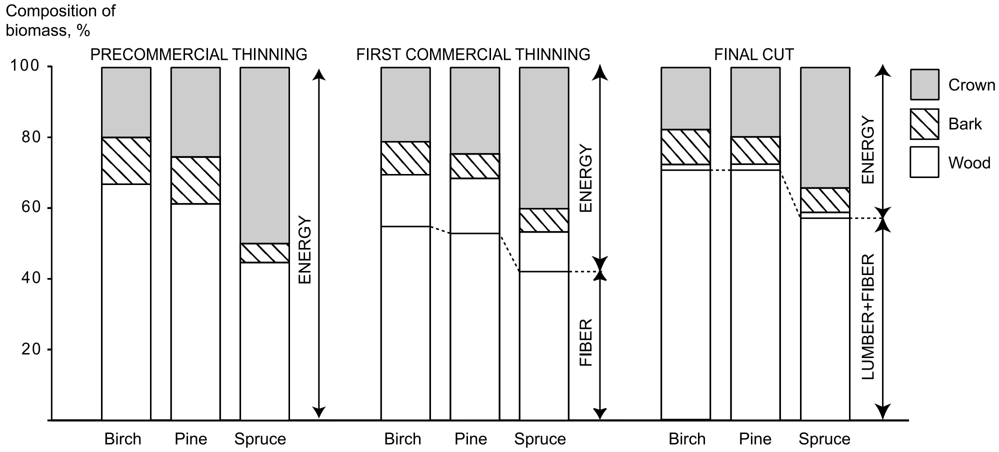

Figure 4. Distribution of woody biomass into industrial raw material (wood only) and potential fuel (crown, bark, undersized wood) in early thinnings and final cuttings (unpublished material from the Finnish Forest Research Institute).

3.1 Whole-tree chips from pre-commercial tending

Pre-commercial thinning is defined as a spacing operation to reduce the density of a young stand. *Cleaning* is defined as a tending operation to remove competing hardwood from young naturally regenerated stands or plantations. Post-thinning densities average about 2000 stems per hectare after these operations.

Benefits from pre-commercial thinning and cleaning are many: increased growth of residual trees, improved quality of timber, shorter rotation lengths, and improved ability of the stand to resist windthrow and snow. Early tending also facilitates the mechanization of subsequent commercial harvesting operations. Pre-commercial thinning and plantation cleaning are well-established practices, but they are still based on manual technology. Therefore, tending of young stands is costly and often neglected.

If biomass is used for fuel, the traditional stem-only harvesting can be replaced by whole-tree harvesting, i.e. the branches of trees are not removed before recovery, and the whole-tree is reduced to chips. Such rationalization has many radical consequences:

- The yield of chips increases by 15–35% when all above-ground biomass is accepted;
- Labour input is reduced by 20–30% when trees are not delimbed;
- The cost of harvesting is reduced by 25–40%, as less work is needed for a larger yield of fuel;
- More efficient equipment and larger spaces are required to handle and transport whole trees;
- More attention must be paid to the quality control of chips to ensure trouble-free feeding of fuel into the boiler;
- The storage duration of chips must be reduced due to the rapid deterioration of nutrient-rich foliage;
- The nutrient loss from forest soils increases by 50–150%. Therefore, it may become necessary to leave foliage at the site.

To improve the efficiency of operations, it may become feasible to delay the pre-commercial treatments in order to increase the size of trees before removal. In Finland, public support is awarded to establish markets and to ensure an economical supply of wood fuel from early thinning and plantation cleaning. However, despite the development of technology and financial support, pre-commercial thinning continues to be one of the most expensive sources of wood fuel.

3.2 Integrated recovery of fiber and fuel from first commercial thinnings

The first commercial thinning at the age of 20–40 years, depending on growth conditions, is a critical part of good management practice. If this treatment is omitted or seriously delayed, the stand begins to deteriorate and the stems become slim and vulnerable to snow breakage. Consequently, well-timed thinning is crucial for the later development of the plantation.

Early commercial thinnings are not being carried out in the Nordic countries at the rate demanded by sound silviculture, since the cost of harvesting is 2–4 times as high as for final cuts. Further, the loss of small-diameter wood is high in various phases of harvesting and processing, particularly when debarking in drums.

New technology is urgently needed for integrated recovery of fiber and fuel from the first commercial thinnings. A common feature of most development projects is the principle of *multi-tree handling*. Examples of emerging techniques are:

- Felling heads for one-grip harvesters allowing multi-tree handling in small-tree operations;
- Combi machines performing in succession both cutting and forwarding of timber in small-tree operations;
- A stationary processing terminal for delimbing, debarking, chipping and screening of small-tree biomass for efficient separation of fiber and fuel.

How much of the biomass can be used for fiber and how much is left for fuel, depends on the tree species, tree size, structure of the industry, prices of pulpwood and fuelwood, and the available technology. In Denmark, trees removed in the first commercial thinning are used mainly for the production of fuel chips. In Finnish conditions, an optimal use for the above-ground biomass from the first commercial thinning of Scots pine stands could be as follows:

- 60% of biomass for the production of juvenile pulp for special papers;
- 25% of biomass (bark, crown mass, stem tops) for fuel;
- 15% of biomass (foliage-rich crown mass) to be left at the site for ecological reasons.

3.3 Recovery of fuel from final harvest

Small-sized trees were earlier considered to be the most important source of forest chips. However, the recent adoption of fully mechanized logging technology has made residues from final harvest a more attractive source of energy. In the Nordic countries crown mass is typically the primary component of logging slash from the final harvest.

As long as cutting was carried out by chainsaw in the northern European *cut-to-length system,* slash was left evenly scattered at the logging site. Separate bunching was a costly operation that resulted in impurities and difficulties in chipping. Now that practically all clear-cutting in the Nordic countries is carried out with one-grip harvesters, the felling and delimbing operation can be adapted to accumulate the slash in larger heaps. This improves the productivity of subsequent collection and transport to roadside by about 30%, results in cleaner chips, and raises the percentage of recovery to 65–80%.

Chips reduced from logging residues at the stump, landing, terminal or plant are the cheapest and most commonly used source of commercial forest fuel (Figure 5). The annual production of chips from logging residues is in Sweden 2.2 million m^3 solid. As a result of increased availability of processing residues from sawmilling, and large-scale importation of recycled wood from abroad, little increase has taken place during the last few years. In Finland, about 0.4 million m^3 solid of chips from logging residues was used in 2000, and the use of logging residues is growing rapidly. In Denmark and Norway residues from final harvest are not a significant source of energy.

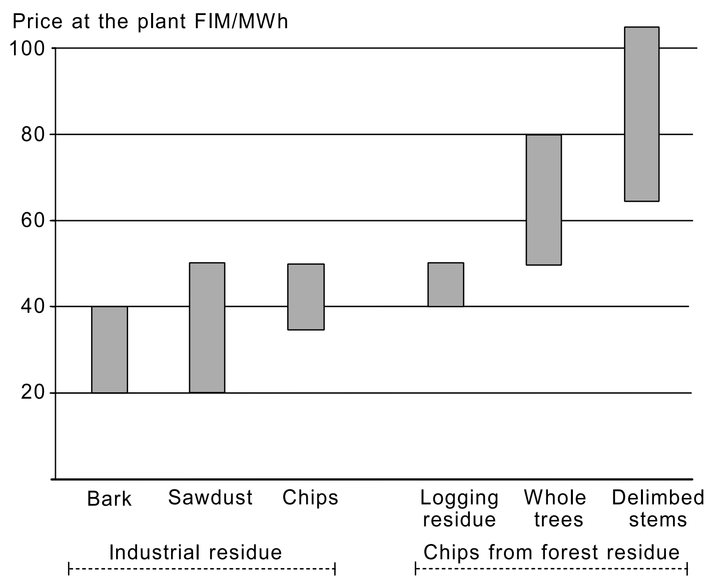

Figure 5. The price of wood fuels (excluding VAT) paid by heating plants in Finland in 1995 (US$ = 6.5 FIM) (Hakkila and Fredriksson 1996).

4. Fuel Quality

Varying and unpredictable quality is a disadvantage for wood fuels. Among the undesirable characteristics are high moisture content and low energy intensity, which increase the cost of transport and storage. Compared with oil, the load space requirement is 10 times as high for crushed birch bark, 14 times as high for forest chips and 25 times as high for crushed pine bark (Figure 6). This is why wood fuels are typically used only locally.

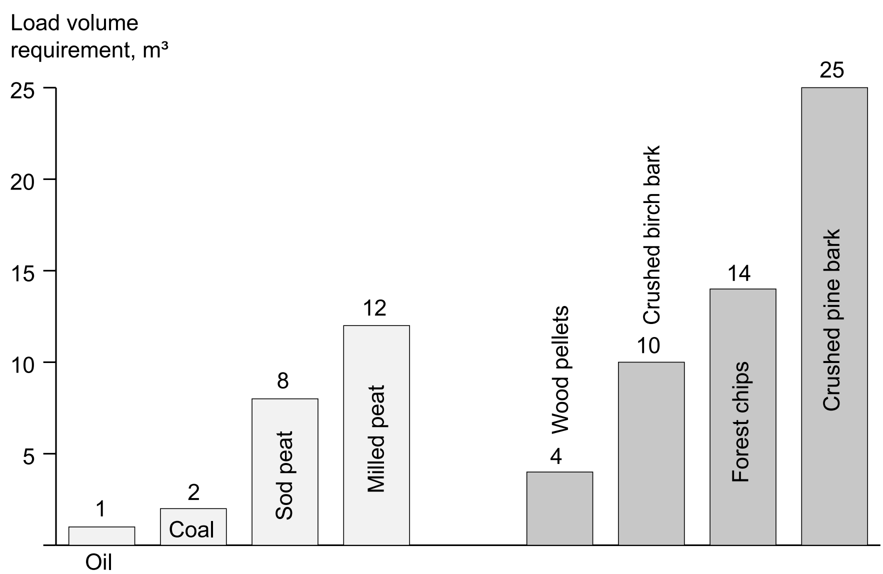

Figure 6. Load volume requirement of selected fuels per tonne of oil equivalent energy.

The primary means to improve the competitiveness of wood fuels is to reduce the cost of procurement. A parallel option is to improve the quality and reduce its erratic variation. High and consistent quality means higher heating value, higher efficiency in combustion, easier handling, lower cost of transportation, better storage properties, less ash and better control of emissions. Indirectly, high fuel quality permits lower investments for chip handling and feeding equipment.

Since the quality of fuel chips and other unrefined wood fuels is not always satisfactory, refined wood fuels such as powder, pellets and briquettes have captured a large part of the commercial wood fuel market in Sweden. In 1997, fuel chips accounted for 45%, sawdust and bark 28%, and refined wood fuels 27% of the Swedish market (Hillring 1999). Corresponding figures are not available for Finland, but a majority of commercial wood fuels is composed of bark and sawdust, whereas the role of refined wood fuels is still small.

The effect of fuel properties on the efficiency of combustion and chip feeding is dependent on equipment. Small boilers are less tolerant of quality variation than large power plants, but no facility is immune to variable fuel quality. The following properties are critical:

- Moisture content;
- Particle size;

- Ash content and purity;
- Specific dry mass (kg/m^3 loose) or energy density (MWh/m^3 loose).

An international market is opening up for wood fuels. For example, Sweden imports fuel chips and sawdust from the Baltic countries, recycled wood from Germany and wood pellets from Canada. Finland imports fuel chips from Russia, but only on a small scale. Common quality standards would facilitate international trade, but they are not yet available. The lack of standards is also a constraint at the national level, since utility companies are used to working with fuels of known quality.

5. The Present Use of Forest Chips in Finland

The Finnish Wood Energy Technology Programme has recently surveyed the use of forest chips in Finland (Hakkila et al. 2001). All energy plants whose annual use of forest chips was more than 250 m^3 solid (625 m^3 loose) in 1999 were included. Altogether, 150 such plants were identified.

The survey did not include the small-scale use occurring in some 5000 farms and buildings. Neither did it include the operations of small heat enterprises, the number of which was estimated by the Work Efficiency Institute at about 80, with the average size of chip boiler being 0.3 MW. It is estimated that these omitted small-scale users consumed some 180 000 m^3 solid of forest chips in 1999. The total consumption of forest chips is shown in Table 2.

Table 2. Consumption of forest chips in Finland in 1999.

	Use of forest chips	
	m^3 solid	%
Heating plants	273 000	36
Combined Heat and Power (CHP) plants:		
- Forest industries	109 000	15
- Other CHP plants	185 000	25
Plants using more than 250 m^3yr^{-1}, total	567 000	76
Estimated small-scale use	180 000	24
Total	747 000	100

In Finland, forest chips are combusted typically mixed with other solid fuels such as bark, sawdust, peat or coal. For the forest chip-fired heating and CHP plants (forest industries excluded), forest chips actually consisted of only one-quarter of the total use of wood-based fuels. An even more important fuel for them was peat. Therefore, mixing and co-firing of forest chips with other fuels play an important role in technology and procurement logistics. In Sweden, co-firing of forest chips is not as common as in Finland.

The results a recent survey are compared with an earlier study in Figure 7. The total consumption (small-scale excluded) tripled in five years. The growth was based on chips from logging residues. Little growth took place in chips produced from small-sized trees, but a shift from delimbed stems to whole trees occurred within this category. This means that the impact of fuel chip production on the tending of young forests was smaller than initially expected.

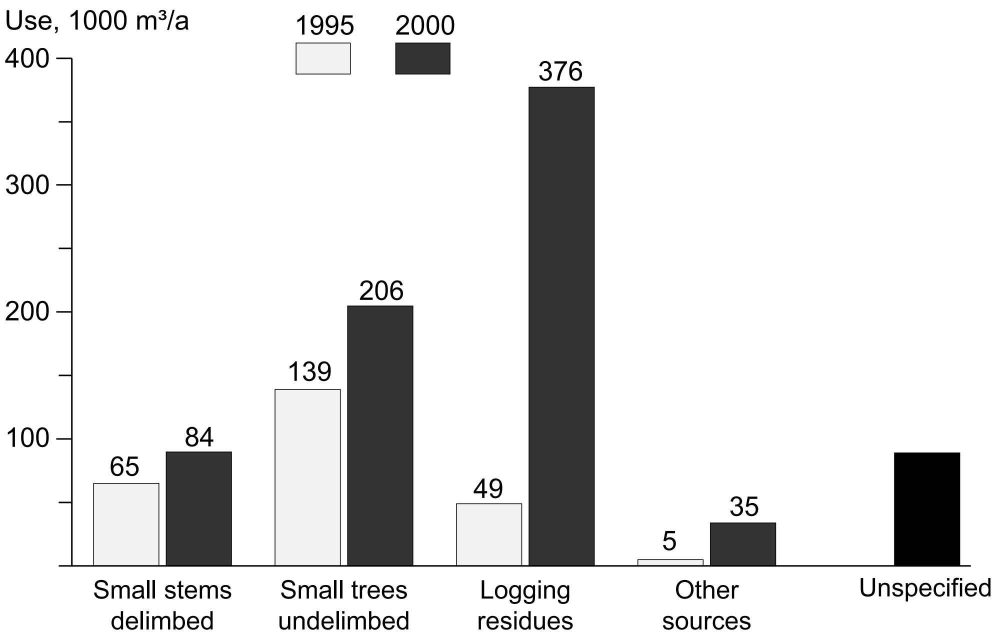

Figure 7. The sources of forest chips in Finland in 1995 and 1999. Small-scale use excluded (Hakkila and Fredriksson 1996, Ylitalo 2001).

In Sweden the sources of forest chips are as follows: logging residues from final harvest 2.2 million m³ solid; rotted stemwood from final harvest 0.5 million m³; and small trees from thinning operations 0.4 million m^3yr^{-1} (Andersson 2000). During late 1990s, the use of forest chips did not increase, since the availability of cheap processing residues from the sawmill industries improved, the importation of wood fuels from other countries grew rapidly, and in many small-scale plants chips were replaced by pellets.

Denmark uses annually 0.3–0.4 million m³ of forest chips, which are reduced primarily from pulp-wood sized trees from early thinnings. Simultaneously, the use of straw for fuel in Denmark is about four times as much (Heding 2000).

6. The Cost of Forest Chips in Finland

In the Finnish survey, the present users were asked to name the technical and economic barriers preventing them from increasing the share of forest chips in their fuel palette. In order of importance, the following constraints were presented:

1. High cost of chips;
2. Lack of procurement organization or insecurity of deliveries;
3. Technical problems of reception and handling of chips at the plant;
4. Insufficient boiler efficiency in winter time;
5. Unsatisfactory quality of chips.

Although high cost continues to be the most critical barrier, a radical reduction took place, not only in the real but even nominal prices of chips, during the last two decades (Figure 8).

The average price of forest chips at Finnish heating plants (forest industries and large CHP plants excluded) was 53 FIM/MWh in 1999. In Sweden the average price was substantially higher, 80 FIM/MWh for heating plants and 75 FIM/MWh for the industry (Energimyndigheten 2000). In Finland this favorable trend is a result of the following factors:

- Decrease of 20–30 % in the pay rates of all forest machines and timber trucks in the 1990s;
- Development of equipment and chip procurement systems;
- Development of procurement logistics through education and experience;
- Growth in the scale of chip procurement operations;
- Shift from delimbed stems to whole trees and further to logging residues as the source of chips;
- Absence of stumpage price for forest residues, and financial support to chips produced from small trees from early thinnings.

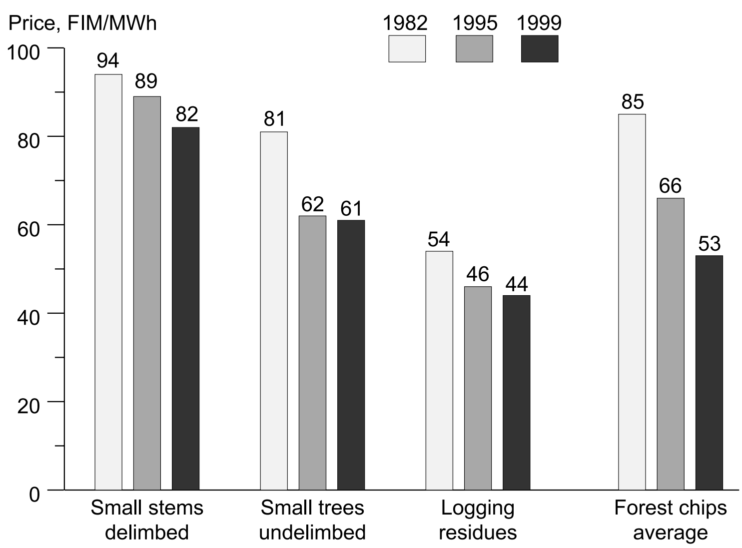

Figure 8. The development of prices of forest chips at heating plants in Finland. VAT excluded (Hakkila et al. 2001).

Price differences between the various types of wood fuels started to level out during the second half of the 1990s. The price of bark and sawdust increased as a result of increased demand, and the price of chips from delimbed stems decreased. The prices of chips from whole trees and logging residues seemed to decrease slightly, but the change was not significant. The shift from small trees to logging residues as the primary source of forest chips reduced the average price (Table 3).

Heating plants less than 10 MW in size still prefer chips produced from small-sized trees. This is partly a result of municipal ownership, as the municipalities give a strong emphasis towards social impacts such as job opportunities and silvicultural benefits. Chips from small trees are also thought to be of better quality (they are generally drier, contain less foliage and chlorine, and have a more even particle size distribution), which is important for small plants. Unfortunately, this means higher priced fuel. For 0.5–1 MW heating plants the average price of chips was 73 FIM/MWh, whereas for plants with a capacity of >10 MW, the price was only 48 FIM/MWh.

Small plants also suffer from another disadvantage compared with the large CHP plants. Their demand for heat fluctuates seasonally, and their overall annual efficiency is somewhat weaker. However, the efficiency has increased due to improved equipment, experience and quality control of chips (Figure 9).

Table 3. Average prices of wood fuels paid by heating plants in 1995 and 1999 in Finland. VAT excluded.

Source	1995	1999 FIM/MWh	Change %
Industrial residues:			
- Bark	32	38	+19
- Sawdust	33	36	+11
- Chips	44	43	–2
Forest biomass:			
- Delimbed stems	89	82	–8
- Whole trees	62	61	–2
- Small trees, average	88	65	–26
- Logging residues	46	44	–4
- Forest chips, average	64	53	–17

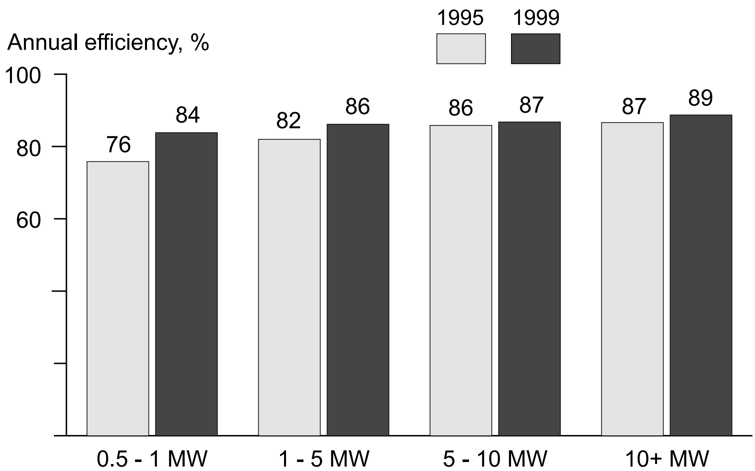

Figure 9. The annual energy efficiency of forest chip fired heating plants in Finland in 1995 and 1999 by size class.

In Finland, the goal of the Wood Energy Technology Program is 2.5 million m³ solid of fuel chips for 2003 (Figure 10), and the goal of the Action Plan for Renewable Energy Sources (Ministry of Trade and Industry 1999) is 5 million m³ solid for 2010. The increase is expected to take place mainly in large CHP plants of power and forest industry companies. In addition, a large number of smaller users will appear, as dozens of new heating plants have recently received investment aid from the Ministry of Trade and Industry to adapt their technology for forest chips and other wood fuels.

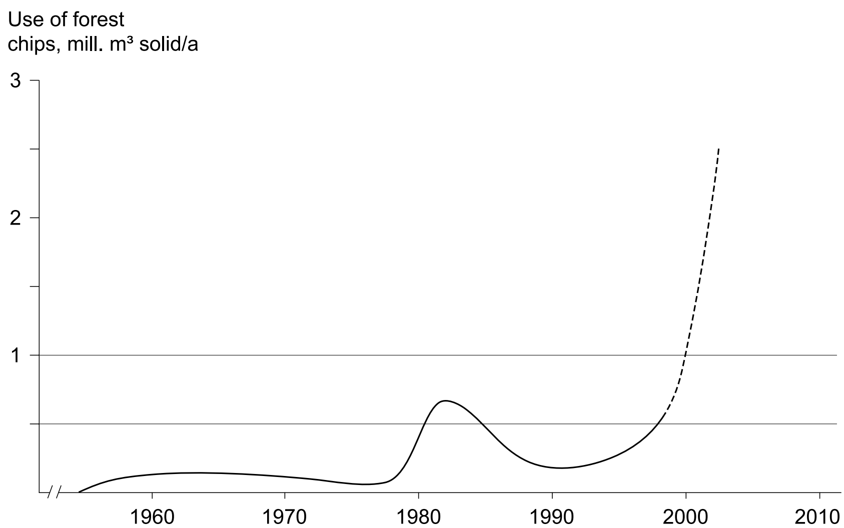

Figure 10. The use of forest chips in Finland during 1960–1999 and the goal (dashed line) for 2003 of the Wood Energy Technology Program.

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The Role of Bioenergy and Related Land Use in Global Net CO_2 Emissions

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Abstract

This paper addresses the role of biofuels in the current world energy system, and discusses important mechanisms that determine the net reduction of greenhouse gas emissions through bioenergy systems. Key ingredients for improvements in the greenhouse gas balance are the optimization of process efficiencies of biomass conversion into useful energy, and the minimal use of auxiliary fossil energy in these processes. In addition, carbon sequestered in the terrestrial biosphere due to bioenergy-related changes in land use must be factored into the analysis. Bioenergy has the potential for providing a significant share of future energy supply, and it is likely to play a key role in meeting the emission limitation targets in the Kyoto Protocol.

Keywords: carbon, bioenergy, biofuels, climate change, efficiency

Introduction

In the search for energy systems that have minimum impact on the concentration of greenhouse gases in the atmosphere, biomass fuels appear to offer a carbon-neutral, renewable source of energy. Plants extract carbon dioxide (CO_2) from the atmosphere during photosynthesis and accumulate it as carbon in plant matter. This carbon is released back to the atmosphere as carbon dioxide during combustion.

To give perspective to the role that biomass fuels might play in mitigating the increasing concentration of carbon dioxide in the atmosphere, we raise three fundamental questions: (1) How much energy do biofuels supply now? (2) What is the true reduction in carbon emissions from the use of biomass energy? and (3) How much energy might biofuels supply in the future? Our answers to the first and the third questions summarize previous results to show

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the scale of prospective change in the bioenergy sector and our answer to the second question analyses some key questions involved in assessing the 'Kyoto-effectiveness' of such change.

Question 1: How much energy do biofuels supply now? The contribution of biomass fuels to the current world energy system is not well documented or well understood, largely because much of the fuel is not traded in formal markets. Best estimates suggest that biofuels currently provide energy at a rate of approximately 50 exajoules per year, some 14% of world primary energy use (Woods and Hall 1993). Most of this consumption occurs in developing countries, where biofuels provide 38% of total primary energy on average and over 95% of total primary energy in countries like Nepal, Chad, and Tanzania. Bioenergy provides a smaller fraction of total primary energy in most developed countries. Use of bioenergy in countries like the USA and Austria, for example, amounts to about 4% and 10% of total primary energy use, respectively, although consumption of about 13 GJ per capita in both countries is comparable to that in many developing countries (Table 1). Biofuels are used very differently in different countries. In developing countries biomass fuels are generally used primarily in the household sector for heating and cooking whereas in Austria and Sweden, for example, they have found wide application in district heating plants, and in the USA they are used primarily for industrial applications in the forest products sector.

Table 1. Use of commercial and biomass fuels in 13 countries chosen to illustrate the different patterns of use among countries with a variety of economic, climatic, and demographic conditions (Schlamadinger and Marland 1996). All data are for 1991 except for the data on bioenergy consumption, which are for the late 1980s.

Country	Total energy consumption [PJ]	Bioenergy consumption [PJ]	Share of bioenergy [%]	Population density [cap./km^2]	Total energy per capita [GJ/cap.]	Bioenergy per capita [GJ/cap.]
Austria	1 053	100	9.5	94.3	137	13.0
Germany	15 012	84	0.6	230.8	189	1.1
Japan	17 390	6	0.0	331.9	141	0.0
Poland	3 595	40	1.1	126.5	94	1.0
Sweden	1 971	230	11.7	21.1	230	26.8
USA	84 321	3 482	4.1	28.1	337	13.9
Brazil	5 155	1 604	31.1	18.5	35	10.8
China	36 632	9 287	25.4	129.2	32	8.1
Egypt	1 502	380	25.3	56.3	29	7.2
India	16 554	8 543	51.6	301.6	20	10.1
Malaysia	1 488	663	44.6	58.6	83	37.1
Tanzania	954	925	97.0	32.5	37	35.6
Zaire	435	362	83.2	18.2	12	9.7

Question 2: What is the true reduction in carbon emissions from the use of biomass energy? It is often perceived that biofuels are neutral with respect to emission of the greenhouse gas CO_2 because the CO_2 released during combustion is subsequently withdrawn from the atmosphere when the biomass is regrown. Ideally this is a renewable, solar energy system where photosynthesis produces a fuel that is easily stored and used, and the CO_2 emitted is recycled in a sustainably managed production system. If we examine the full system, however, we find that production, harvest, transport, and conversion of biofuels require

significant inputs of energy and that this energy is generally provided by fossil fuels[1]. These fuel inputs could be supplied with biofuels, but the net effect would be to reduce the net available production of biofuels on a parcel of land. The limiting resource defining the potential of biofuels for greenhouse gas mitigation is the land that is available; plus the net fuel production possible per unit of land and the opportunity to use that land in other ways (e.g. reforestation).

Table 2 shows the energy balance, and the total carbon emissions avoided, when one hectare of land is used in production of ethanol from sugar cane in Brazil, and of ethanol from corn in the USA. The various percentage numbers include process efficiencies (for photosynthesis, fermentation, etc.), mass losses (such as when only a fraction of the biomass is removed at harvest), and auxiliary fossil energy inputs (for example, in the distillation process to produce ethanol). Taking into account what energy carrier is replaced (in both energy chains this is gasoline), one can calculate the amount of carbon emissions that is displaced through the use of one hectare of land for producing ethanol. It is obvious that production of ethanol from sugar cane in Brazil yields much greater reduction than production of ethanol from corn in the USA. If land is the limited resource, which it is in many settings, then such considerations of emission reductions per unit of land will be important.

Table 2. Efficiencies in the full fuel cycles for ethanol from sugar cane in Brazil and ethanol from corn in the USA (Kheshgi et al. 2000).

	Brazil Sugar Cane Ethanol	USA Corn Ethanol
Sunlight (latitude dependent)	220 W/m^2	170 W/m^2
Efficiency of capture in biomass	0.93%	0.60%
Proportion harvested	53%	35%
Proportion fermentable sugar and starch	47%	76%
Efficiency of chemical conversion to ethanol	71%	71%
Proportion left after auxiliary energy inputs	87%	25%
Net energy produced	0.31 W/m^2	0.05 W/m^2
Emissions avoided (assuming ethanol displaces gasoline and neglecting emissions involved in supply of gasoline)	2.08 tC/ha/yr	0.32 C/ha/yr

Most important from Table 2 is that emissions from fossil fuels and efficiency losses through the system greatly reduce the amount of C emissions offset that can be achieved from a given area of land. Simple use of biofuels does not guarantee significant reductions in CO_2 emissions, and the potential for emissions offsets is modest unless the system has high efficiencies and low fossil fuel requirements. Other biofuels systems have higher efficiencies throughout than the systems illustrated in Table 2. We find that if the productivity of land is high, if biomass is produced and used efficiently, and if one has a long time perspective; then there is large per-hectare potential to use biofuels to displace fossil fuels and reduce net CO_2 emissions; and biofuels production can yield greater carbon benefits than many other land

1 Note that fossil fuels also require significant amounts of energy for their production and transport.

uses, such as reforestation. If productivity is limited and/or biomass is produced and used with low efficiency, then production of biofuels is likely to produce less benefit (with respect to net CO_2 emissions) per hectare than other alternatives for use of the land.

It is worth noting that the Kyoto Protocol to the Framework Convention on Climate Change (an international treaty intended to reduce net emissions of greenhouse gases to the atmosphere – see UN 1997) treats biofuels in such a way that there are no reportable CO_2 emissions from the biomass in a sustainable system. The Protocol provides that CO_2 emissions from biomass be reported as the changes in carbon stocks. This approach effectively recognizes the link between the fuel source (where photosynthesis takes up CO_2 from the atmosphere) and the point of combustion (where CO_2 is released to the atmosphere) so that there are no net CO_2 emissions for the system.

The Kyoto Protocol does not treat all carbon the same. Whereas displacement of fossil fuel emissions (e.g. through use of biofuels) would produce credits under the Kyoto Protocol by reducing national CO_2 emissions, removing carbon from the atmosphere into growing biomass would produce credits in only limited and prescribed circumstances (Schlamadinger and Marland 1998). The Kyoto Protocol accounts for changes in carbon stocks in the biosphere in developed countries from afforestation, reforestation, deforestation and, to a limited extent, for other land-use activities such as forest management, grazing land management and cropland management. In many cases the use of bioenergy is synergetic with other activities that enhance carbon stocks, activities such as afforestation or reforestation.

The Kyoto Protocol also permits a country to claim credits for carbon sequestered through afforestation and reforestation in a developing country under the ‘Clean Development Mechanism’. Savings of CO_2 emissions through use of bioenergy can be part of mitigation projects that are undertaken in other countries, i.e. under Article 6 (‘joint implementation’) or Article 12 (the ‘Clean Development Mechanism’).

In Figure 1, we use our carbon accounting model, GORCAM, to illustrate the net effect on CO_2 emissions to the atmosphere if one hectare of land was used to produce wood fuel on a short harvest-rotation cycle and the fuel was used to displace coal in an electric power plant. The diagram shows total savings in emissions of CO_2 to the atmosphere because carbon is sequestered in the biosphere and because fossil fuel is displaced by the biofuel. The numeric details of the scenario shown are less important than the demonstration of principles and relationships, but the parameter values used here suggest what is possible with modern technology on highly productive land in the USA (see Schlamadinger and Marland 1996 for details).

If we focus on the actual point of combustion, the amount of carbon in fossil fuels that can be displaced by using one ton of carbon in biofuels can be calculated as:

$$D_f = \frac{efficiency\ of\ bioenergy\ system}{efficiency\ of\ displaced\ fossil\ system} \times \frac{C\ emission\ per\ J\ of\ fossil\ fuel}{C\ emission\ per\ J\ of\ biofuel}$$

where: D_f is the ‘displacement factor for fuels’.

In the example in Figure 1 the displacement factor was assumed to be 0.6, a value that is typical for combustion of biomass today, i.e. biomass is used with an efficiency only 60% that of coal conversion. Generally, if fossil-fuel-fired plants at the margin of current energy systems in industrialized countries were replaced by biomass-fired plants, we would expect D_f to be between 0.5 and 1. D_f could approach or even exceed 1 if very efficient use of biomass (such as in systems for combined production of heat and power) displaced fossil-fuel systems for producing heat and power separately. On the other hand, in many developing countries additional biomass might often supply additional energy rather than displace fossil fuel uses, in which case D_f would be close to zero. Note that the top line in Figure 1 shows the gross fuel displacement, but the line just below it, marked with the arrow, shows net fuel displacement when we acknowledge that the biofuel system would require more input of fossil fuels for operation of the fuel cycle than would the coal-based system it displaces.

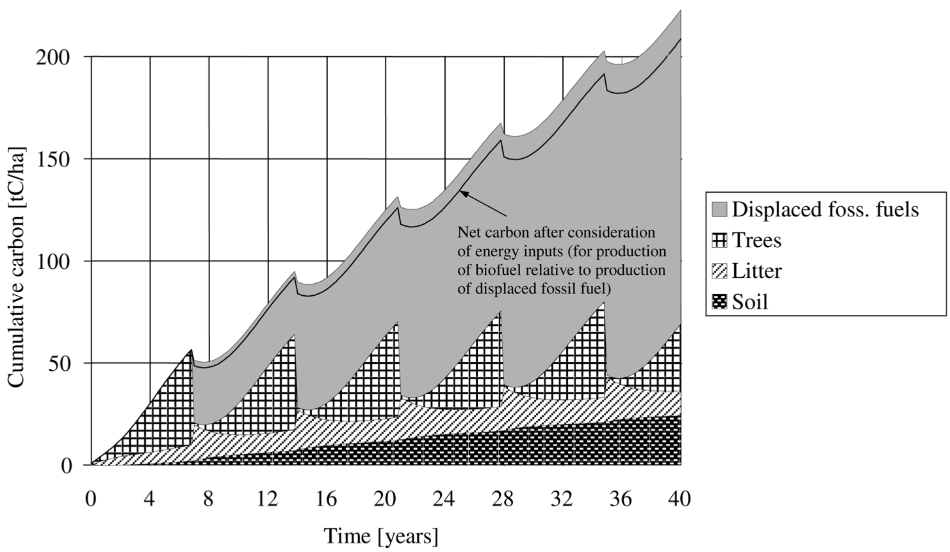

Figure 1. Model results for the carbon benefit of replacing coal with wood from a fuel plantation. The diagram shows carbon accumulated over time in a plantation for producing woody crops on a short rotation. Besides the carbon accumulated on the land (in trees, soil and litter), the diagram also shows the carbon retained in fossil-fuel reserves that have not been exploited because biofuels replaced fossil fuels.

As noted, if land is to be used to mitigate the atmospheric increase in CO_2, there are important tradeoffs between different land uses, in particular there are tradeoffs between storage of carbon on site and displacement of carbon emissions through the use of biomass products. Analysis of full systems suggests that forest management choices can affect the global carbon cycle by affecting the carbon stored in the forest, the carbon stored in wood products, the extent of direct fossil fuel displacement, and the extent to which forest products substitute for alternate products with different levels of energy required for their production and use.

Harvested material from plantations can be used either as fuel or as timber and pulp, with the proportions flexible but dependant on, for example, rotation length and species selection. In addition, large-scale changes in land use and energy systems may cause feedbacks in other parts of the economy, an effect sometimes referred to as ‘leakage’. Thus, for a system-wide estimate of carbon effects of new plantations; the timber, energy and land markets need to be modeled in an integrated way (Read 1998, 1999).

We note that some analysts view the value of displaced fossil carbon to be greater than the value of sequestered biomass carbon. They argue that: (a) emissions from fossil fuels can be measured and verified more easily than changes in the carbon stocks in biomass and soils; (b) reductions in fossil-fuel emissions in one year are not at risk of being reversed at some later time, whereas some biotic carbon stocks might be lost to the atmosphere at a later time; and (c) carbon sequestration is a one-time option whereas biofuels can produce greenhouse gas benefits by displacing fossil fuels on a continuing basis. The text of the Kyoto Protocol does not recognize these differences, but they have been recognized and are subject to methodological work in the negotiating bodies of the Framework Convention on Climate Change.

Question 3: How much energy might biofuels supply in the future? The bottom line is that biofuels can displace fossil fuels and they can yield net benefits in terms of CO_2 emissions to the atmosphere. The magnitude of the net benefit will be determined by the amount of biomass wastes that can be captured for use as fuels and by the quantity and quality of land made available for dedicated fuel crops. It will also depend on the incremental benefit of using the land for fuel production rather than for other purposes. Wright and Hughes (1993) have suggested that the land available for biofuels in the USA may be as much as 28 x 10^6 ha, and that this could eventually reduce USA fossil-fuel CO_2 emission by an amount equivalent to 20% of the 1990 total. The potential global contribution of bioenergy has been estimated to be between 60 and 145 EJ in 2025, and between 95 and 280 EJ by 2050 (see Table 3).

Table 3. The potential role of biomass in future global energy use. Potential contributions (in EJ) are shown for three times in the future (Hall and Scrase 1998 and references therein).

Scenario		Year	
	2025	2050	2100
Shell (1996)	85	200–220	–
IPCC (1996)	72	280	320
Greenpeace (1993)	114	181	–
Johansson et al. (1993)	145	206	–
WEC (1993)	59	94–157	132–215
Dessus et al. (1992)	135	–	–
Lashof and Tirpak (1991)	130	215	–

Conclusions

In summary, it can be said that current emissions of CO_2 to the atmosphere would be larger if present demands for biofuels were met instead by fossil fuels. There appear to be greater opportunities for biofuels to fill part of the global demand for energy in the future and this can avoid additional emissions of CO_2, both through the stock-change effect of sequestration during the process of establishing biofuel plantations, and through the flow effect from displacing fossil fuel with biofuel. Biomass fuels can be produced from an area of land with sustainable harvest on a repeated basis. The total net CO_2 mitigation that can be achieved over time will depend on the quality of the land, the efficiency with which biofuels are produced and used, the energy-sector impacts of additional biofuel use, and the alternatives for using the land in other ways. The details of bioenergy systems are very important in determining the emission reduction that can be achieved. Technology development for efficient production and conversion of biomass energy can have a major impact on keeping costs down and using land efficiently.

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System Perspectives on Bioenergy, External Effects and Power Utilisation in Europe

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Abstract

Combustion of fossil fuel within stationary energy systems emits large amounts of CO_2, a gas that may be considered as the most important greenhouse gas. In the European power systems, unit dispatch apparently involves coal-condensing plants being on the margin as the most expensive technology on the common deregulated market. Therefore, we suggest all electricity consumption to be accounted 1.0 kg CO_2/kWh, corresponding to the emissions from coal-condensing power. Furthermore, global warming and other energy related external costs are generally not covered by applicable fuel prices. The ExternE program has estimated monetary values of such costs, and these estimates are considered in an analysis of a regional energy system. By applying a system perspective (i.e. combining relevant characteristics of bioenergy, external effects, and the different use and supply of electricity of the different countries), we identify biomass and cogeneration as powerful tools to obviate the use of fossil fuels, primarily through replacement of coal-condensing power. We demonstrate a cost-effective method to significantly reduce CO_2 emissions in Europe, indicating a remarkable welfare gain. With a working deregulated European power market and an equal treatment of environmental and other resources, the 'environmental debt' could be cut by 80% of its present value.

Keywords: bioenergy, external effects, carbon dioxide, electricity

1. Introduction

In a few years there will probably be a deregulated and functional power market in Europe. This indicates, more or less, the same prerequisites for all EU member states, and that electricity will be traded as any other common industrial product. It is also likely that some kind of environmental fees will be in effect in order to fulfil the Kyoto agreements. In this situation it is interesting to study the entire European power system and calculate the most cost-effective transformation, from the existing situation with subsystems, to a future common market.

Petroleum products and coal are prevalent energy carriers within European stationary energy systems. Combustion of such fossil fuels free large amounts of fixed carbon as carbon dioxide (CO_2) which is considered the most important of the greenhouse-gases (IPCC 2001). Combustion of biomass, on the other hand, is here regarded as a CO_2-neutral process. This is a straightforward assumption. For a comprehensive CO_2-assessment of the full fuel chain for bioenergy (considering, for example, the role of auxiliary fossil fuel use for transport, distribution, fuel preparation, facility construction and dismantling) see, for example, Schlamadinger et al. 1997 or Jungmeier et al. 1998.

Therefore, biomass can be seen as a powerful tool to displace fossil fuels and to reduce the rate of CO_2-accumulation in the atmosphere. Further, combined heat and power production is also an interesting technology offering increased fuel efficiency as compared to separate heat and electricity production, and thus, potentially also reducing CO_2 emissions.

Moreover, there are indirect costs for the society arising because energy related activity fails to fully account for its impacts. Such external costs are, for example, negative effects on health, materials and environment due to emissions to the air, water and ground. Studies have shown that these effects are not negligible and should be taken into consideration (European Commission 2000).

The structure of the paper involves, to begin with, a general description of the electricity supply and use with related CO_2 emissions, focusing on the Northern European countries. Next, some CO_2 accounting principles are outlined and briefly discussed, with emphasis on international cross-border power trade. Furthermore, calculations of CO_2 reductions, using cogeneration instead of separate generation of heat and power, are carried out. Afterward, the concept of external effects is introduced. A case study, where the impact of considering external costs in a regional energy system, is performed using a linear programming optimisation model. Finally, in the concluding discussion, general conclusions are drawn concerning the possibilities for the Nordic countries to reduce CO_2 emissions.

2. Electricity Supply and Use in Europe

The specific amount of used electricity per inhabitant and the relative proportions of power sources differ considerably among the European countries. Both aspects are illustrated in Figure 1. The power systems of Sweden and Norway can be categorised as energy constrained because of the availability of significant amounts of hydropower. Other countries often have a higher degree of capacity constrained power systems due to the reliance on thermal power plants with a certain installed capacity. Furthermore, countries with hydropower based power systems generally have a higher per capita use of electricity than those with fossil fuel based power systems. However, with the on-going process of deregulation and increased international exchange all countries will gradually participate in a common electricity market.

When considering the possibilities of replacing electricity use with cogenerated district heating, we should recognise that possibly 60% of the Nordic countries electric power is used for heating purposes. The electricity use per inhabitant in Nordic countries (including Norway, Sweden, Finland and Denmark) equals 16 MWh/yr, while the German use per inhabitant is only 6.2 MWh/yr (Swedish National Energy Authority 1999). This distinct difference depends to a great extent on the electric power used for heating. Conceivably, an explanation could be the amount of electricity intense industry, such as metallurgical and mechanical pulp and paper industry. German industry used 229.6 TWh during 1998 (Staschus 2000) equalling 2.8 MWh per inhabitant, while Swedish industry used 53.7 TWh equalling 6.1 MWh per inhabitant (Swedish National Energy Authority 1999). Still, there is a significant difference leaving a large potential for substituting electricity with heat from, for example, combined heat and power generation. Dag (2001) further addresses the issue of industrial electricity use on a deregulated energy market.

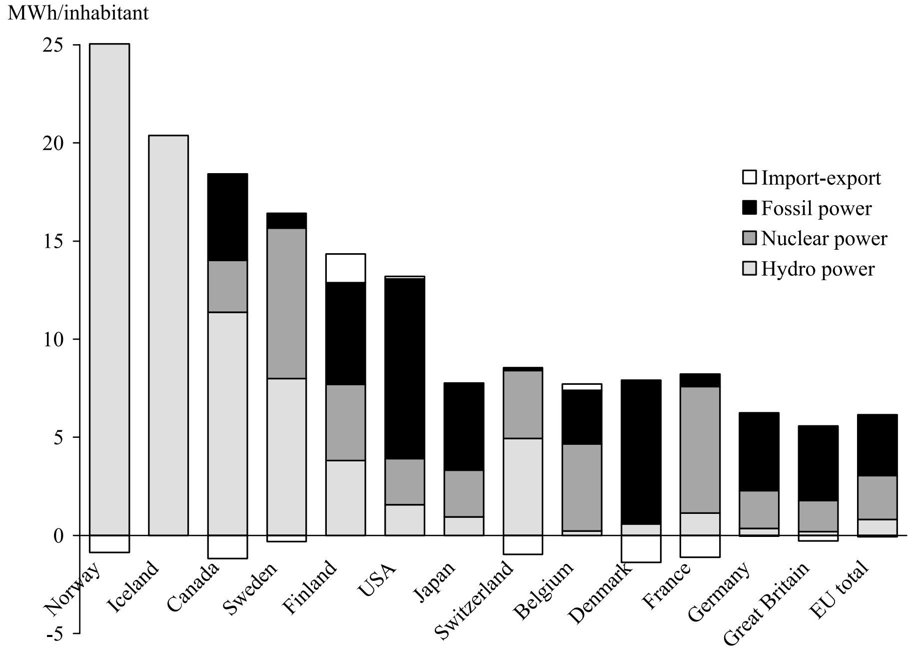

Figure 1. Electricity generation with relative distribution per type of power, 1997. Source: Swedish National Energy Authority (1999b).

3. CO_2 Emissions Accounting

Cross-border transmission of electricity raises the question of emissions accounting. Rydén et al. (1993) discuss cogeneration from a local perspective in an energy systems study, with examples from five Swedish municipalities. Electricity generation and emissions are not primarily seen in an international perspective. However, there is ‘import’ and ‘export’ of electricity over the municipal border. To what extent should a municipality be charged for emissions caused by ‘outside’ generation? How should a municipality be credited for electricity conservation or additional generation? Three alternative accounting schemes are:

1. Outside municipality electricity is considered to be emissions free and no emissions credit is given for export. This scheme gives a correct description only from a narrow municipal point of view.
2. The emissions from electricity generation are calculated as a national average for all generation over a certain period. This scheme would allow a summation of emissions from all independent municipal systems to a correct national CO_2 account.

3. Outside electricity is considered generated in the last dispatched unit in the national electric system, i.e. the marginal producing technology, possibly a condensing power plant. Consequently, imported electricity is debited with the emissions from this plant, and conversely, the budget is credited in the case of electricity export. This scheme gives a correct emission balance for comparison between different generation alternatives, seen from a national perspective. In this case efficient cogeneration usually reduces the nations carbon emissions.

From an international perspective, two additional accounting schemes could be considered:

4. Import of electricity to a municipality or a country causes CO_2 emissions corresponding to international average emissions. Export of electricity to another municipality or country is credited correspondingly.
5. Emissions from imported and exported electricity are calculated corresponding to emissions from generation with last dispatched units within the international electric system.

The fourth and second schemes are similar because they are based on average emissions caused by the whole power-generating sector. The fifth and third schemes are similar because of the marginal dispatch reasoning. We consider the fifth accounting scheme the most interesting because it gives an accurate signal to producers and consumers with respect to the greenhouse effect. Hence, with the fourth and fifth scheme, a correct summation of total emissions from several systems would be possible if the exports and imports of all countries were equally accounted for. We argue that the system boundaries should include international perspectives because of increasing cross-border trade in combination with the global warming problem.

4. An International Electric Power System

More than 35 TWh was exchanged between Sweden, Norway, Finland, Denmark and Germany/Russia during 1998. This exchange corresponds to nearly 10% of the total use and followed from an incomplete deregulated market.

When considering the electric power system in Sweden as coupled with Norway, Finland, Denmark, Germany and Poland, changes in supply or use of electricity in any of these countries influence an international balance. The cross-border trade in electricity raises the concept of international marginal generation. One assertion of marginal generation could be that variable costs determine the unit dispatch within the total system at each moment. Actors with various options for power generation available (e.g. hydropower stations and different thermal power plants) use an operating strategy according to a certain sequence, a merit order dispatch protocol. This merit order presumably starts with committing the units with the lowest variable costs, after which units with gradually higher and higher variable costs are committed, i.e. a least cost dispatch of generators.

The important question yet to be settled is which power generation technology, and its corresponding CO_2 emissions, is replaced when additional generation is put into operation. Moreover, which power technology is decreasing its output with declining demand, and increasing its output with increased demand?

The general answer is coal-condensing power. This technology is ‘on the margin’ at every time throughout the year on a perfectly liberalised and functioning European power market. This will be the situation irrespective of variations in precipitation affecting the hydroelectric energy supply. The corresponding CO_2 emissions thus equals 1.0 kg/kWh, as will be further addressed below.

According to basic economic theory, a single company’s supply curve equals the marginal cost curve above the variable unit cost curve. In other words, a company is prepared to offer their products as long as the market price provides an allowance to cover the fixed costs. For a whole line of business, the sectors total supply curve is made up of the sum of every company's supply curve.

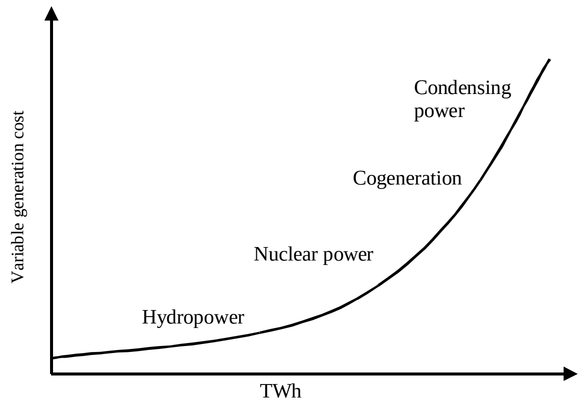

Figure 2. Schematic supply curve for power generation including Northern Europe.

The shape of the supply curve for all North European power supply is shown schematically in Figure 2. Being typical base-load generation, hydro and nuclear power provide a significant share of the Nordic electricity supply. Industrial back-pressure and municipal cogeneration supply demands for steam and district heating respectively and these generally have higher variable costs than hydro and nuclear power. District heating is rather common in Sweden, Finland and Denmark, and heat loads are generally large enough to make cogeneration possible (but not necessarily profitable) most of the year. Spot prices on electricity rather than heat loads determine operation of cogeneration. Swedish cogeneration plants can also often be operated in by-passed mode.

A superimposed demand curve would cut the supply curve within the condensing power segment. This would be the case regardless of years with high or low precipitation.

From Figure 3, it is clear that condensing power is a marginal generation segment, being on the margin with a substantial contribution of electricity every month during the year. Evidently, condensing plants may be seen as the last dispatched units in the electrical system. Other sources of power (primarily hydropower) are used to balance supply and demand.

Adding up typical CO_2 emissions renders approximate cumulative emissions of CO_2 (Figure 4). All in all, 2423 TWh generated within the EU corresponds to around 900 million ton CO_2.

5. CO_2 Reductions with Cogeneration

5.1 CO_2 reductions with no marginal displacement

The fuel energy savings ratio (FESR), as a performance criterion for cogeneration plants involves comparison between the amount of fuel required to meet the given load of electricity and heat in a cogeneration plant with the amount of fuel required to meet the same loads in separate plants (Feng et al. 1998).

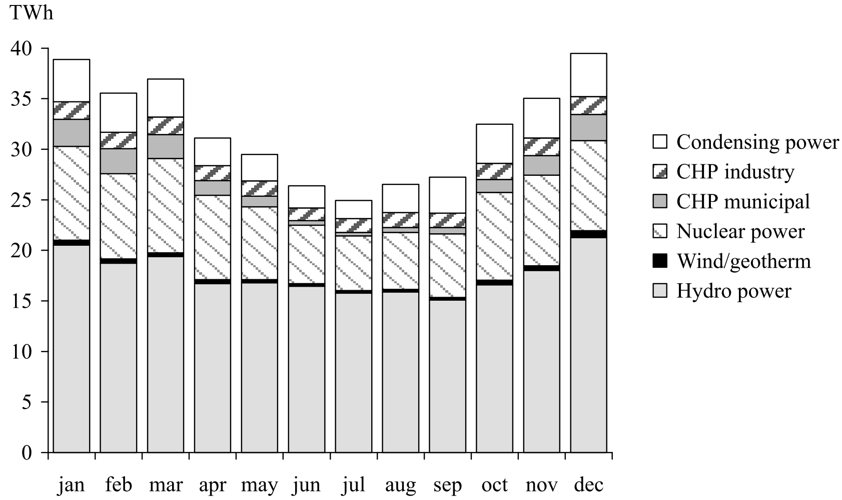

Figure 3. Monthly Nordic power generation 1999. Source: Nordel (1999).

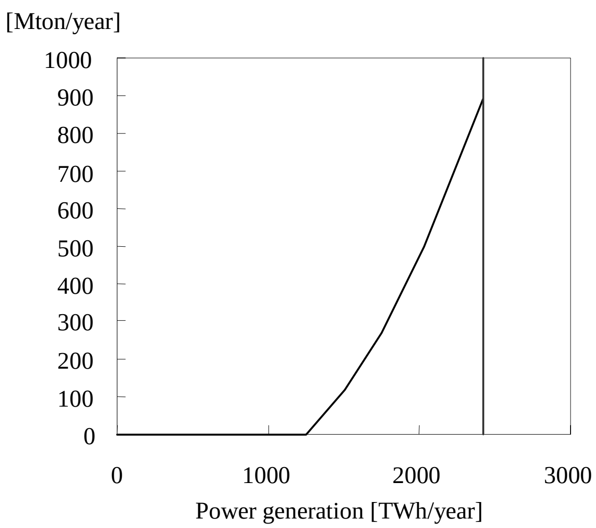

Figure 4. Cumulative CO_2 emissions from EU countries power generation. Source: Werner (2001).

$$FESR = \frac{F_{separate} - F_{CHP}}{F_{separate}}$$

Here, $F_{separate}$ is the amount of fuel used in separate production of heat and electricity, which is compared to the amount of fuel, F_{CHP}, used in a combined heat and power (CHP) plant.

The FESR, usually obtaining a value somewhere between 0.05 and 0.35, directly measures the extent of fuel savings (i.e. the improved energy utilisation) in a cogeneration plant as compared to separate generation. Therefore, it may be seen as a reasonable criterion.

In a study of the energetic feasibility of cogeneration compared to the separate production of heat and power (Martens 1998) it is emphasised that rational use of energy and reduction of CO_2-emissions are not intrinsic to CHP. The amount of fuel saving and CO_2 reduction strongly depends on performance of the CHP plants and the separate generation plants. It was found that within a set of Dutch CHP plants, the fuel energy savings were up to about 20% compared with 'modern technologies' for separate production of heat and electricity (Martens 1998).

According to the International Association for District heating, District Cooling and Combined Heat and Power (EuroHeat), cogeneration increases the efficiency compared with separate heat and electricity production by around 30%, offering proven CO_2 reductions of around 500 kg/MWh heat. They state that the European Commission has established this figure as a European average. The figure depends somewhat on the conditions. In countries with extensive use of gas the figure will be lower, around 350 kg/MWh, while in countries using a great amount of carbon (e.g. Germany) the figure is about 35% higher than 500 kg/MWh (EuroHeat 1999).

5.2 CO_2 reductions with marginal displacement

In a common European electricity market, additional cogeneration will replace the worst and most expensive condensing power plants, as illustrated in Figure 5. From a Nordic perspective, this aspect is particularly interesting because the prospects for biofuelled cogeneration with no gross CO_2 emissions. Even if the cogeneration plant is fuelled with a fossil fuel, the heat used for district heating will be credited for displacement of marginal power generation, as indicated by Figure 5.

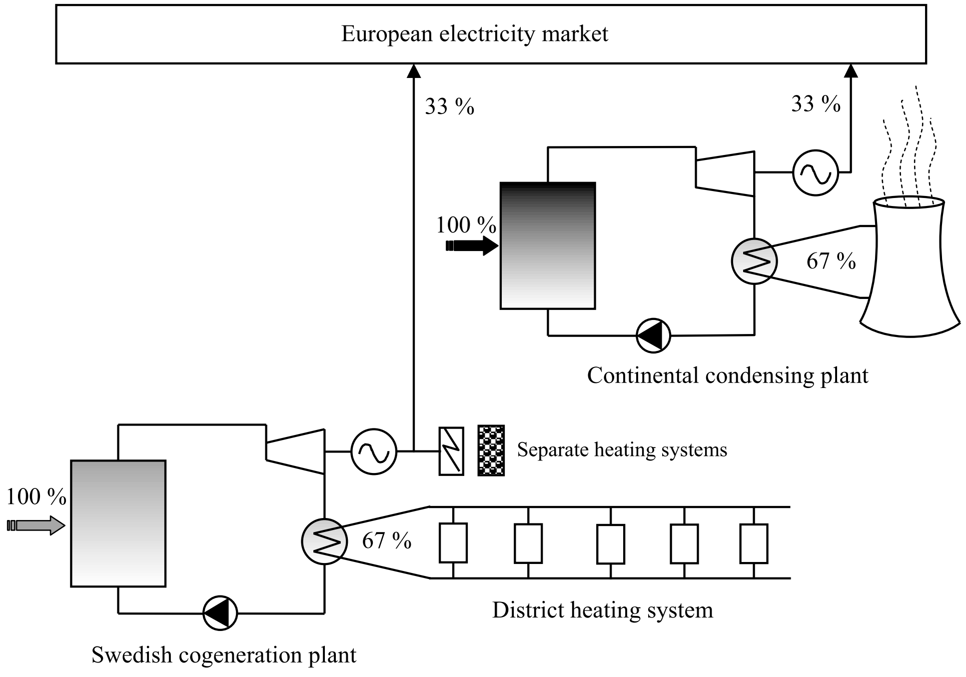

Figure 5. Cogeneration vs. condensing plants on a European electricity market.

The emitted amount of CO_2 from a coal condensing plant, $E_{coal\ cond}$, principally equals

$$E_{coal\ cond} = \frac{EF_{coal}}{\eta_{\mathrm{cond}}} \qquad \text{(Equation 1)}$$

where: EF_{coal} is the emissions factor for coal, and η_{cond} is the efficiency of coal condensing power generation.

The efficiency with marginal coal condensing power generation with Rankine cycle in this example is assumed to be 33%. This is obviously relatively low, especially compared with the best available Rankine cycle plants or combined cycle plants. However, marginal generation plants are, by our definition, the least efficient. Thus, each saved megawatt-hour of electricity reduces the carbon emissions by 1036 kg/MWh by reducing the marginal generation.

But what are the limitations for this consideration? Where does marginal generation end? In Figure 4, the current EU electricity supply was ordered according to a least CO_2-emissions dispatch, i.e. the first portion of supply (foremost hydro and nuclear power) not emitting any CO_2. However, the right-hand side shows a wide section with increasing CO_2-emissions where coal-condensing power dominates. According to this illustration the coal-condensing segment is wide and there can be a significant reduction of marginal coal-condensing power before it ends being marginal generation.

In order to assess CO_2 reductions made with some different cogeneration technologies and fuels, assumptions are made according to Table 1. Both combined-cycle technologies and Rankine cycles are represented as well as fossil fuels and renewable fuels.

The gross emissions of CO_2 per MWh heat generated in a combined heat and power plant, E_{CHP}, can be expressed as:

$$E_{CHP} = EF\frac{1+\alpha}{\eta_{tot}} \qquad \text{(Equation 2)}$$

where: EF denotes the emissions factor, α the electricity to heat ratio, and η_{tot} the overall efficiency.

The reduction of CO_2 with cogeneration per MWh heat, due to coal condensing power replacement, $E_{CHP\ red}$, could be expressed as:

$$E_{CHP\ red} = \alpha\frac{EF_{coal}}{\eta_{cond}} \qquad \text{(Equation 3)}$$

Example numerical values are shown in Table 1. The net emissions of CO_2 per unit of heat from a cogeneration plant, $E_{CHP\ net\ red}$, thus equals the difference between total emissions of CO_2 (Equation 2) and the reduction due to coal condensing replacement (Equation 3), i.e.:

$$E_{CHP\ net\ red} = EF\frac{1+\alpha}{\eta_{tot}} - \alpha\frac{EF_{coal}}{\eta_{cond}} \qquad \text{(Equation 4)}$$

When heating buildings the resulting net emissions of CO_2 for various fuels and technologies, when coal-condensing power is the marginal source of electricity, are illustrated in Figure 6.

Table 1. Assumed characteristics for some typical cogeneration technologies and their CO_2 emissions per MWh heat.

Technology			Electricity to heat ratio	Total efficiency	CO_2 emissions factor [g/MJ$_{fuel}$]	Total emitted CO_2 [g/MJ heat]	Reduction of CO_2 through displacement of marginal coal condensing power [g/MJ heat]	Net emissions of CO_2 [g/MJ heat]
Coal	CHP	Rankine cycle	0.60	0.88	95	173	–173	0
Heavy fuel oil	CHP	Rankine cycle	0.60	0.88	76	135	–173	–35
Natural gas	CHP	Combined cycle	0.95	0.85	55	126	–273	–147
Biofuel	CHP	Rankine cycle	0.50	0.85	0	0	–144	–144
Biofuel	CHP	Combined cycle	0.95	0.85	0	0	–273	–273
Coal condensing power		Rankine cycle	–	0.33	95	(288 g/MJ$_e$)	–	–

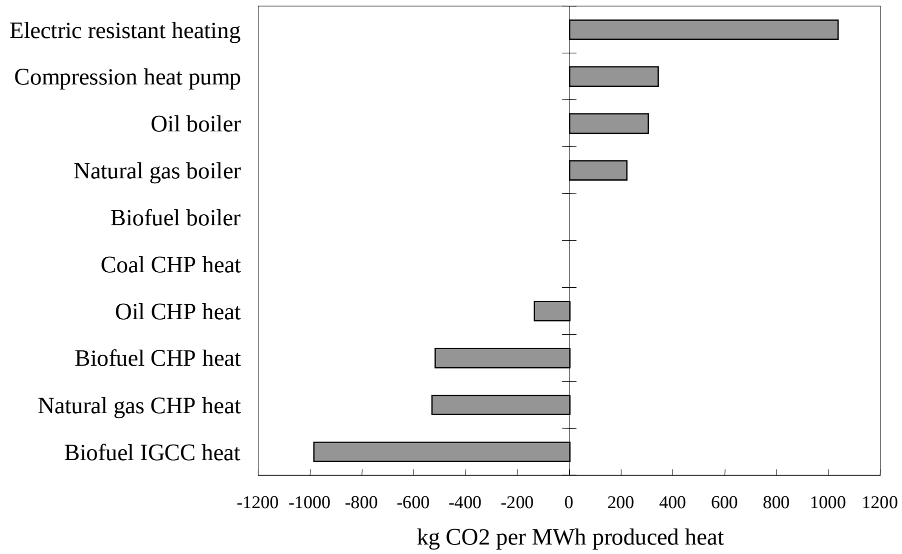

Figure 6. Net emissions of CO_2 per MWh heat for various fuels and technologies when coal-condensing power is marginal power production in the European power system. Source: Werner 2001.

Although cogeneration fuelled with natural gas, oil and coal, unmistakably have gross emissions of CO_2, these are offset by a reduction of marginal coal-condensing production.

When switching from a heating technology not based on combined generation to district heating the resulting net change in CO_2 emissions will be:

$$EF_{CHP\ fuel}\frac{1+\alpha}{\eta_{tot\ CHP}} \quad - \quad \frac{EF_{heat\ only\ fuel}}{\eta_{tot\ heat\ only}} \quad - \quad \alpha\frac{EF_{coal}}{\eta_{cond}} \qquad \text{(Equation 6)}$$

The net change in CO_2-emissions when switching from one heating alternative to another can be estimated by taking the difference between the net emissions of the two alternatives according to Figure 6. For example, when switching heating technology from electric resistant heating, to district heating based on biofuelled cogeneration, the resulting net emissions of CO_2 will decrease by 1036–(–518) = 1554 kg/MWh heat.

Switching from a heat-only oil boiler with 88% efficiency, to heat from oil cogeneration (as in Table 1), the resulting decrease of net emissions would be 311–(–126) = 437 kg/MWh heat. With this substitution, the ‘local’ emissions would increase (from 311 to 497 kg/MWh heat), as the cogeneration plant uses oil for both heat and power generation. However, the ‘global’ emissions would decrease (by 623 kg/MWh heat) because of the displacement of marginal coal-condensing power.

Thermally driven absorption heat pumps have been installed for district cooling purposes, for example, in Linköping, Sweden. Absorption heat pumps have two major benefits compared with the more usual compression heat pumps. First, they add favourable heat load to the district heating system during summertime, thus extending the utilisation hours of cogeneration plants. Secondly, they will also be able to reduce the CO_2 emissions in a similar way as above.

Replacing compression heat pumps with cogeneration heat driven absorption heat pumps will reduce CO_2 emissions by reducing the amount of marginal electricity used by compressors, and by adding further combined generation.

6. External Effects

External effects are defined as *"The costs and benefits which arises when the social or economic activity of one group of people have an impact on another, and when the first group fail to fully account for their impacts"* (European commission 1995:1). Mostly it is external costs that are considered, for example, the negative effects on health, materials and environment due to emissions to the air, water and ground. External effects should be taken into consideration in order to move towards a more sustainable society. Sooner or later we have to pay for the external costs, for example, through increased health care costs or lower crop yields.

Several studies have focused on external effects due to energy conversion, mainly production of electricity (Ottinger 1990; European Commission 1995). The results show that they can be substantial. One of the most recent studies is ExternE with the main objective to develop a common comprehensive methodology for evaluating external effects and to apply the methodology to a wide range of different fuel cycles for power generation as well as energy conservation options. The national implementations of the methodology show that the aggregated external cost of producing electricity varies considerably among the countries. Most countries in the study have an external cost of between 20 milli and 60 milli Euro/kWh produced electricity (using low estimated values), and between 40 milli and 80 milli Euro/kWh produced electricity (using high values) (European Commission 2000). Furthermore it was calculated that the aggregated external cost amounted to approximately 1% to 3% of GDP in the majority of the countries. East Germany had the greatest aggregated external cost of 30% of GDP. These results show that the external cost of energy conversion can be considerable. It is, therefore, important that the external costs of an activity are considered. It is often less costly to avoid the environmental damage instead of trying to rectify it.

7. The Impact of Considering External Costs in a Regional Energy System

An analysis of the effect on the technical solutions in a regional energy system when monetary values of external effects are included has been performed (Carlson 2000). The analysed region is the county of Västernorrland, which is situated in the centre of Sweden. The economic and technical description of the regional energy system is carried out with MODEST (Henning 1999). MODEST is a modelling tool for optimising energy systems and the objective is to minimise the system cost of satisfying a demand for heat during an analysis period. The system cost is the discounted value of all costs included in the model, for example, price of fuels, investment costs and energy taxes, during an arbitrary number of years. The result of the optimisation is a technical description of a cost effective energy system. It includes the use of new and existing heating plants, the type of energy carriers to use and the optimal size of investments.

Figure 7, shows a simplified node schedule of a regional energy system. The heat load to be satisfied is divided into two major parts, individual heating and district heating. The individual heating is further divided into single-family houses and multi-dwelling buildings and premises. Heating in single-family houses today are described by 11 different types of heating equipment, while heating in multi-unit dwellings and premises are described by four alternatives. The main energy sources in use for heating in the individual sector are oil and electricity. New heating possibilities in single-family houses include new pellet burners as well as stoves and boilers fuelled with pellets. In multi-dwelling buildings and premises it is possible to invest in boilers fuelled with processed wood fuel. District heating systems included in the model are those producing more than 10 GWh heat/yr. The description of each district heating system includes existing heating plants and specific conditions. New investment options are heat-only boilers and CHP-plants fuelled with woody biomass.

The demand for heat in the individual heating sector in Västernorrland is approximately 1110 GWh/yr in single-family houses and 285 GWh/yr in multi-dwelling buildings and premises. Seven district heating systems are included in the analysis and the total production of district heat is around 1040 GWh/yr, where the smallest system produces 14 GWh/yr and the largest 541 GWh/yr.

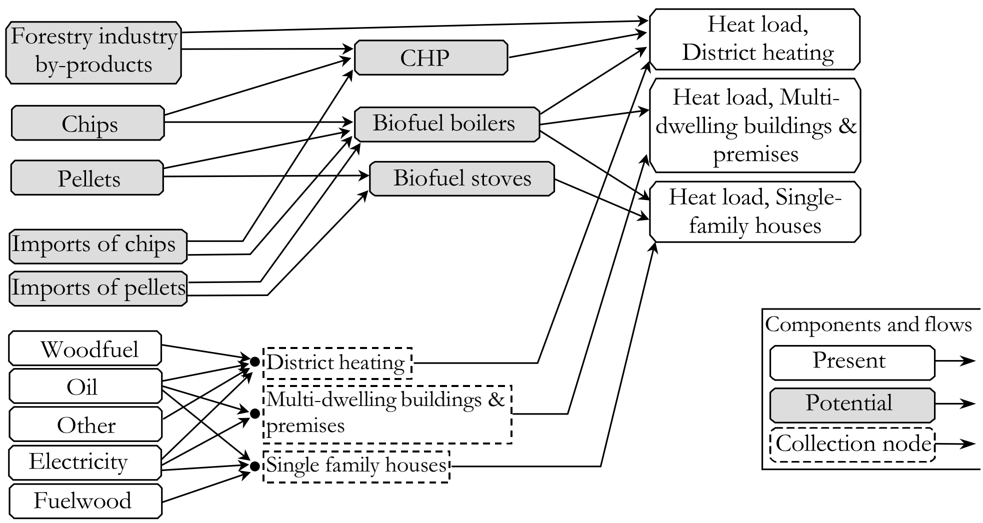

Figure 7. Simplified node schedule of a regional energy system.

Four cases are analysed:

1. Today
2. Business
3. External cost
4. Employment

The analysis period is 10 years and the discount rate is 6%. The perspective of the study is the utilisation of different energy carriers and thus the potential of biofuel in the market is studied.

'Today' represents business as usual where the existing energy system is preserved during the entire analysis period. In 'Business' the possibility to invest in new heating plants fuelled with biomass is introduced. Institutional rules and regulations of today are still valid. Monetary values of external costs due to atmospheric emissions of SOx, NOx, particulates and CO_2 are included in the 'External cost'-case. Taxes are excluded in this case since they can be seen as a valuation of external cost. In the case called 'Employment', besides the monetary values of external costs, the positive value of increased employment in the region due to increased use of biomass for heating are also considered. (A potential decrease of employment due to reduced oil and electricity use is assumed to take place in other regions and are not included in the study.) The monetary values of the external effects applied in the study are listed in Table 2. External costs for different fuels, in Euro/MWh fuel, are determined by the external costs according to Table 2, given in Euro/ton, and average emissions factors (NUTEK 1997).

Costs and benefits are included by adding them to, or subtracting them from, the energy carriers that gives rise to them. For example, using oil for heating single-family houses means an external cost of 14 Euro/MWh fuel, which is added to the cost of oil. Electricity for heating has an external cost equal to that of coal-condensing power, i.e. 41 Euro/MWh (Carlson 2000).

Table 2. Estimates of external costs. Source: Nilsson et al. (1998).

Emission	External cost [Euro/ton]
CO_2	46
NO_x	2147
SO_2	2583
Particulates	3286
Ground level ozone (NO_x)	350

The result of the study shows that biofuel proves to be a competitive alternative to oil and electricity for individual as well as district heating. Table 3 lists the amount of demanded woodchips in district heating systems and processed woodfuel in the individual heating sector. Nearly 70% of the use of those two energy carriers in ‘Today’ are replaced by woodchips and processed woodfuel when investments in new biofuel heating plants are options in the optimisation. In six of the nine studied district-heating systems it is economical to invest in heat-only boilers fuelled with woodchips. They mainly replace existing oil-boilers, and the total installed new capacity is 37 MW. The amount of woodchips needed in ‘Business’ is more than four times greater than in ‘Today’.

When external costs are added woodchips becomes an even more competitive fuel in district heating systems and the use is almost double the amount in ‘Business’. In this case it is profitable to install boilers fuelled with wood chips in all except one of the studied district heating systems. The total new capacity is 79 MW. However, use of pellets for individual heating is lower compared with the ‘Business’-case. This result depends on the energy taxes for oil in the individual heating sector that are higher than the monetary value of the external effects included in the analysis. Since oil in this scenario becomes relatively cheaper for individual heating compared with processed woodfuel it is economic to use somewhat more oil than it is in the ‘Business’-case.

In the case where the value of employment is considered, approximately 300 GWh more woodchips is needed per year in the district heating systems, where the aggregated new capacity is 114 MW, and 400 GWh more pellets for individual heating, compared with ‘External cost’

Altogether, the result implies that wood chips and pellets, are competitive alternatives to oil and electricity for heating. The woodchip demand ranges from 342 to 924 GWh/yr, and the demand for pellets ranges from 1071 to 1479 GWh/yr in the different cases.

Table 3. Amount of demanded woodfuel in Västernorrland. Source: Carlson (2000).

Case	Woodchips [GWh/yr]	Pellets [GWh/yr]
Today	63	–
Business	342	1264
External cost	614	1071
Employment	924	1479

Figure 8, shows the aggregated external cost of the regional energy system. Continuing with business as usual leads to external costs amounting to 53 million Euro/yr. This figure is cut by more than 50% by including investment options (e.g. boilers fuelled by woody biomass). The sum is slightly less when monetary values of external costs are included in the optimisation. Worth noting is the fact that the external costs for heating in the individual heating sector is somewhat higher than in ‘Business’, which depends on the fact that more oil is used than in ‘Business’. Since oil has higher external costs than biofuel it leads to that the aggregated external cost in this scenario is higher for individual heating than in ‘Business’. However, the total sum for the region is lower due to the fact that more oil and electricity is replaced by biofuel in district heating. When the benefits of increased employment are added to the optimisation, the demanded amount of wood chips and pellets is considerably larger than in the other cases, as can be seen in Table 3. This is also reflected in the external costs that heating gives rise to in the region. Compared with ‘Today’, the environmental cost is almost 80% lower. In Figure 8, only the cost of environmental damage is presented. When the benefits of increased employment are added to the column representing ‘Employment’, it will lead to a negative cost (i.e. a benefit) of 8 million Euro/yr, in the region.

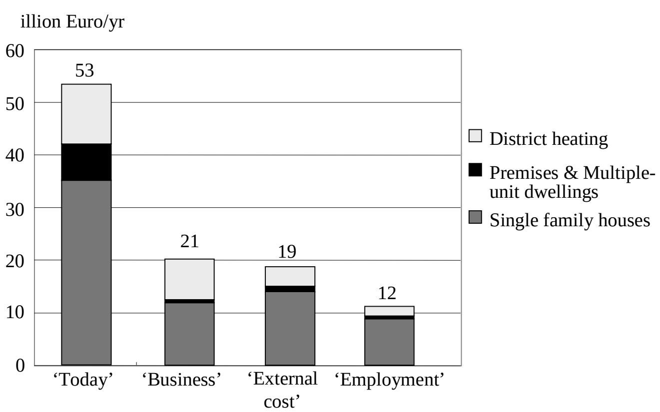

Figure 8. External cost of energy for heat in Västernorrland. Source: Carlson (2000).

Table 4. Future cost of the energy system of Västernorrland. Source: Carlson (2000).

Case	Future cost [million Euro]
Today	950
Business	780
External cost	680
Employment	570

There is a difference between the cases of the costs that are included in the optimisation, which leads to difficulties in making justifiable comparisons of the different cases concerning the system cost. In order to do this comparison a new cost concept is introduced. It is called Future cost and it is calculated for the first two cases according to: Future cost = System cost – Taxes + External cost. Table 4 lists the future cost of the different cases. As can be seen, the most expensive solution is to continue with business as usual. It costs nearly 1 billion Euro over a ten-year analysis period including operational costs (taxes excluded) and external cost. By investing in biomass-fired heating plants according to the conditions valid in ‘Business’ leads to a future cost of 780 million Euro, which is considerably lower than ‘Today’. Including the external cost in the optimisation leads to a future cost of 680 million Euro. When the value of employment is considered, it leads to a system cost of 570 million Euro. By modifying this figure so that operational and external costs (but not the benefit of employment) are considered, an increased cost of just over 110 million Euro is arrived at. Thus the ‘Employment’-case end up in the same range as ‘External cost’.

8. Discussion

Fossil fuels are subsidised in all European countries since external costs are not covered by applicable fuel prices. This hidden subsidy acts as a market barrier for implementation of new CO_2 neutral technologies based on renewable energy sources. A cost-effective method has been shown to significantly reduce CO_2 emissions in Northern Europe, indicating a remarkable welfare gain for the entire union. The main issue is that electricity should be used for electricity specific purposes and not for heating. Unit dispatch of the electrical system involves coal-condensing technology being on the margin as the most expensive power technology on a common deregulated market. We suggest that in environmental impact assessments all electricity consumption should be accounted by 1.0 kg/kWh (given the suppositions outlined in this paper, and primarily due to the actual emissions from marginal coal-condensing plants). The figure for fossil fuel used for heating purposes should be 0.3 kg/kWh (corresponding to a typical heat-only boiler).

Since biomass is a fuel with zero net emission of CO_2 it may be seen as a way to obviate the use of fossil fuels through replacement, preferably for cogeneration, and thereby decreasing the amount of CO_2 emissions.

A reduction of 150 Mton CO_2 annually would be feasible if: electric resistant heating in the Nordic countries was replaced by (for example) biofuel and natural gas heating, efficiency measures were introduced, cogeneration was increased and the excess power was exported to countries with coal condensing generation. The Swedish electricity use would be cut by 40 TWh while additional cogeneration could add some 30 TWh. Together these measures would amount to approximately a 70 Mton reduction of global CO_2 emissions. If a similar approach was adopted in Finland and Norway, another 80 Mton annual reduction could be achieved. A 150 Mton annual reduction corresponds to about a 15% reduction of all CO_2 emitted from the entire European power system. This is even higher than the obligations of the Kyoto Protocol, which states an 8% decrease.

The European ExternE program has attempted to estimate the monetary value of external effects. Such environmental fees on fossil fuels have been used in the case study in this paper. With a mathematical simulation model applied to the use of biofuel in three Swedish regions, it has been shown that biofuel is a competitive alternative to oil and electricity for heating purposes. Altogether, the environmental debt could be cut by 80% of its present value (Carlson 2000). The future cost for the more environmental friendly energy system is not higher than the running costs of the existing system.

By exporting power from the Nordic countries, together with new cost-effective cogeneration, a benefit amounting to about 20 billion Euro in net present value could be achieved (see Karlsson et al. 1995). We could achieve profitable investments in, for example, cogeneration, conservation measures and additional transmission capacity to the Continent with a total of 25 billion Euro, and also employment could be increased by an estimated 500 000 man-years. This is just the addition from the Nordic countries. The only necessary stipulations are a functional deregulated European power market, like those found for other industrial products, and an equal treatment between environmental and other resources in the society.

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Challenges for the Use of Bioenergy in Northwest Russia

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Abstract

The paper presents some modern quantitative estimates of gross, technical and commercial potentials of the wood biomass energy in Russia, namely Northwest of Russia. The commercial potential of wood biomass utilization in Russia is estimated at 15–25 million ton of c.e. Some 40% of the wood biomass commercial potential are concentrated in the Northwest of Russia. The paper analyses the dynamics of bioenergy development in the Northwest of Russia, and describes some promising bioenergy-related projects. A possible source of funding for bioenergy development in the Northwest of Russia is trading CO_2 emission quotas. Some quantitative estimates of the above-listed challenges for bioenergy use are presented using the Republic of Karelia as an example. The work was executed with support of Russian Fund Fundamental Researches (No. 98-02-03350).

Keywords: wood potential, bioenergy projects, CO_2 emission quota, Northwest Russia

Role of Biofuel in Russia's Power Engineering

Conducting reforms in Russia and changing the social and economic situation have substantially changed the main factors that affect the structure of Russia's fuel and energy economy. The latter, in particular, is reflected in the fundamental tenets of Russia's new energy strategy that contribute to the increasing role of biofuel as a local renewable energy resource in fuel-energy balance.

Russia's new energy strategy had been developed by the mid-1990s and was presented legally in 1995. Presidential Act No. 472 of 7th May 1995 outlined basic trends in the energy policy and structural changes of Russia's Fuel Energy Complex (FEC) up to 2010, and Resolution No. 1006 of 13th October, 1995 made by the Government of Russia approved "Russia's Power Engineering Strategy (fundamental tenets)".

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The main goal of Russia's Power Engineering Strategy is to determine ways to provide conditions for the most efficient use of the energy resources and production potential of FEC in order to increase the well-being of the population and to favour the economic development of Russia**.** The following aspects are of primary importance in Russia's Power Engineering Strategy:

- To steadily supply enterprises and population with energy carriers.
- To use fuel and energy resources more efficiently and to provide conditions for transition to the energy-saving way of development.
- To reduce the impact of power engineering on the environment.
- To maintain the export potential of the fuel and energy complex.
- To ensure the energy independence and security of Russia.

As a matter of fact, the use of biofuel on a larger scale agrees with all the above priorities outlined in Russia's power engineering strategy.

Table 1 shows energy production and energy consumption dynamics in Russia (Rodionov 1999). Over the period 1985–1999 the production of energy resources in Russia declined considerably. This is due, on the one hand, to their decreased demand caused by the economic crisis and, on the other, to a drastic reduction in the internal investment potential of enterprises and their ability to borrow funds. As a result, the amount of prospecting drilling has diminished by five times and that of development drilling by three times. The amount of geological prospecting has declined sharply and gain in oil and gas reserves has also declined, threatening the development of the oil and gas complex after 2010 and Russia's energy and economic security for a long period of time (Dobretsov et al. 1997).

Oil and gas have commonly been Russia's hard currency reserves. Therefore, the retention of FEC's export potential makes it necessary to use Russia's natural resources, primarily gas, more rationally for domestic purposes. In this situation, it is logical and reasonable to use biofuel in Russia on a larger scale.

Table 2 shows the production of individual fuel types in Russia. In 1985–1995, the production of biofuel, such as peat and wood, declined from 25.7 million ton carbon equivalent (c.e.) (1.6% of total fuel production) to 10.2 million ton c.e. (0.8%) (Dalin et al. 1996).

Russia's peat reserves account for 55% of global peat reserves and are estimated at 144.4–161.2 billion ton of air-dry (humidity 40%) peat (Bezrukikh et al. 1994). Based on the inexhaustible wildlife management concept, ecologically allowable amounts of peat production for Russia are 50 million ton/year. This estimate is comparable with the maximum volumes of real fuel peat production in the USSR: 57 million ton in 1952. Fuel peat production dynamics is shown in Figure 1 (The State Contract… 1999)**.** In the mid-1970s, Russia produced 200 million ton of peat to meet its demands in power engineering, plant growing, cattle raising, industry, etc. In 1985–1995, peat production decreased from 100 million ton to 13.5 million ton. Therefore, in the next few years ecological restrictions cannot really impede fuel peat production.

As a result of the discovery of tremendous oil, gas and coal reserves in Russia, the volume of fuel peat produced after 1970 has diminished. This decline was partly compensated by a rise in the amount of fuel peat produced for agriculture in the 1980s.

The economic crisis, which started in the 1990s, caused an appreciable decline in peat production. Many peat companies and related industries, such as peat machine-building and drainage amelioration in agriculture and forestry, have gone bankrupt. Their revival is an economic and social problem, rather then a technical one, because Russia has enough experience and knowledge to solve it.

Forest biocenoses are known to play an important and versatile role in the life of the nature and society. They fulfil air- and water-protecting functions all over the world, help maintain

Table 1. Development of the fuel and energy complex in Russia in 1985–1999.

Parameter	Year											
	1985	1988	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy resource consumption, million ton c.e.	1160	1260	1268	1256	1193	1116	955	938	929	927	–	916
Energy resource production, million ton c.e.	1690	1914	1855	1736	1636	1526	1434	1401	1393	1362	1367	1386
including:												
- oil & condensate, million ton	542	569	516	462	399	355	318	307	301	306	303	305
- gas (natural) billion m^3	462	590	641	643	640	618	607	596	602	571	591	591
- coal, million ton	395	425	395	353	338	306	272	263	257	244	232	249
Electric energy production, billion kWh	962	1066	1082	1068	1008	957	876	860	847	834	827	845
Primary oil refining, million ton	309	310	298	286	258	223	186	182	176	178	164	169

Table 2. Recovery of different fuel types (million ton c.e.) in Russia in 1985–1995.

	1985	1990	1991	1992	1993	1994	1995
Oil & condensate	776.0	738.0	661.0	571.0	506.0	453.0	439.0
Natural gas	533.0	739.0	742.0	740.0	713.0	700.0	687.0
Coal	270.0	270.0	241.0	230.0	209.0	185.0	179.0
Shale	1.7	1.3	1.2	1.1	0.9	1.0	1.5
Peat	2.9	1.8	1.6	2.7	0.9	1.0	1.5
Firewood	22.8	19.0	17.4	16.2	13.7	10.5	8.7

biodiversity, provide ambient conditions and are responsible for the lifestyle of many nations. In forested regions, they are economically vital, providing a source of wild food, recreation facilities and attracting tourists. Besides, forests have always played an important role in Russia's power production.

In the 1950s and 1960s, more wood was used in woodworking and pulp and paper industries and less wood was consumed as fuel. For example, the share of wood fuel was as high as 47% in 1948 and only 29% in 1960. Total wood production in 1960 was 369 million m^3 (21% of global wood consumption). In the 1980s, the share of wood fuel was still high: 23.4% (83.3% million m^3). In 1998, 22.2 million m^3 of firewood were used for heating and were sold to the population and various organizations. Figure 2 and Figure 3 show firewood consumption dynamics in North and Northwest Russia (Goscomstat 1999). When the price of energy carriers rose, the volume of wood fuel produced by the population increased. This pattern is most characteristic of North Russia where forests are close to residential areas.

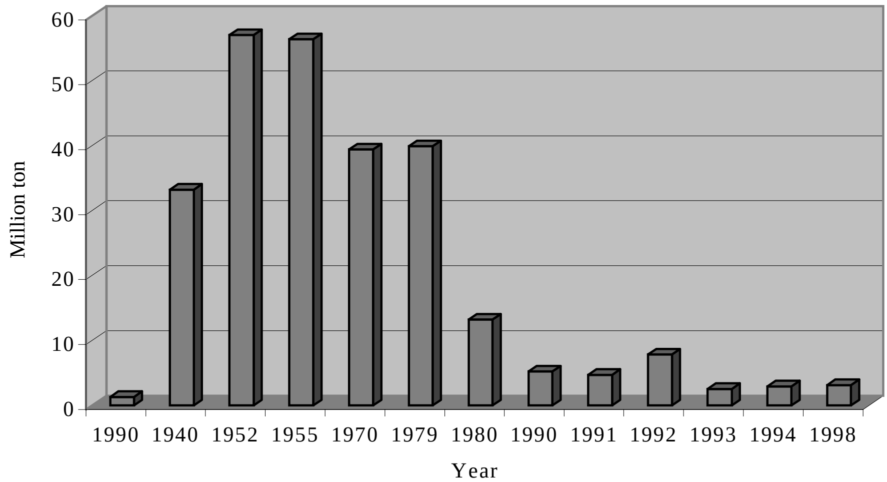

Figure 1. Fuel peat mining in Russia in 1990–1998.

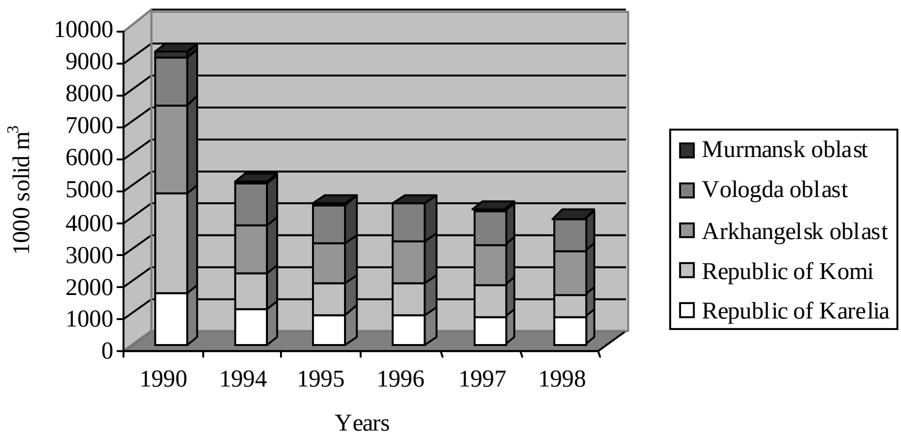

Figure 2. Dynamics of firewood consumption for heating in the North Russia in 1990–1998.

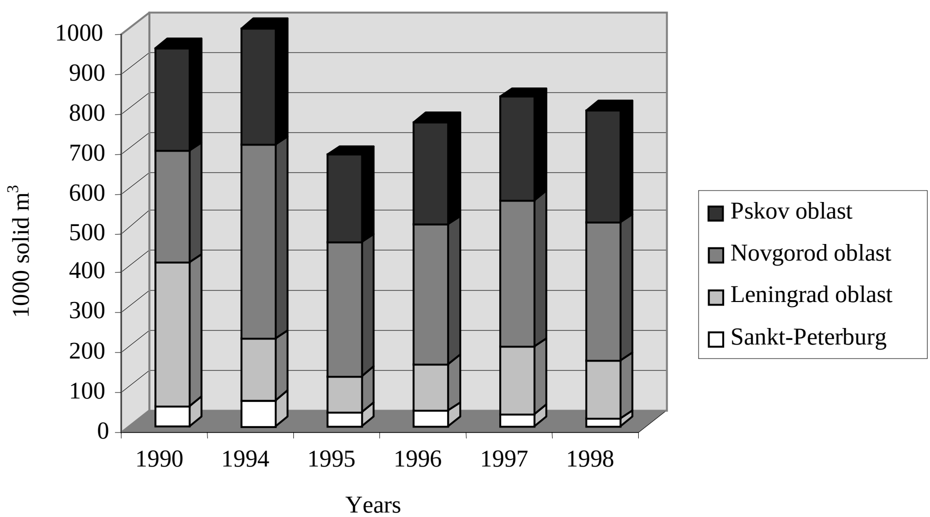

Figure 3. Dynamics of firewood consumption for heating in the Northwest Russia in 1990–1998.

Wood Fuel Resources

The forest resources owned by North and Northwest Russia are characterized in Table 3 (On the Ecological and Economic Impacts…1996). They make up about 10% of all Russia's forest reserves. North and Northwest Russia play a strategic role in domestic timber industry. Nowadays, 50% of pulp and paper products and about 20% of sawn wood are manufactured there. It should be noted that some 30% of timber products manufactured in North and Northwest Russia are exported. This shows the significant role played by these regions on the international and domestic markets.

Table 3. Characteristics of forest resources in the North and Northwest of Russia.

Characteristic	As of 1 January 1993
Total forest area, million ha	85.7
- including forested area, million ha	72.4
Total standing stock, billion m^3	7565
Total annual increment, million m^3	90
Planned logging volume, million m^3	80.5
Actual logging volume, million m^3	31

In North and Northwest Russia, forests are chiefly of economic value: Group III (forests of industrial worth and intended for meeting the timber requirements of the national economy without incurring damage to their protective function) makes up 58%; Group I (forests with water protection, protective, sanitation and health improving functions) makes up 32%; and Group II (including forests in densely populated areas with both protective and limited exploitation values, as well as forests characterised by insufficient timber resources and strictly applied forest exploitation) makes up 10%. The biggest forest resources in this part of Russia are owned by the Komi Republic and the Arkhangelsk Province. The forests are characteristically dominated by valuable coniferous species, such as spruce and pine, that constitute 79.4% of the entire forested area. Another typical feature is the prevalence of mature and overmature stands (51.7%). These forests provide a major source of timber.

Considering available standing timber reserves, wood production volumes and prospects in the development of bioenergy production, I wish to dwell at length on some regions such as the Komi Republic, the Arkhangelsk Province, the Republic of Karelia and the Vologda Province.

The State Forest Assessment System accepted in Russia is oriented chiefly on estimation of the qualitative and quantitative characteristics of the stemwood of growing trees measured in cubic metres of stemwood without considering bark. Being chiefly processed mechanically and chemically, wood is not used to meet energy demands. A unit volume of wood, namely a cubic metre of stemwood, is a quantitative unit used to measure wood reserves. It is the most convenient and precise characterization. However, this assessment system lacks the quantitative (volumetric or weight) estimation of individual forest biomass fractions such as bark, knags, leaves, roots, dead standing wood and windfallen wood. Some of these fractions are commonly used as fuel.

At the request of Mintopenergo (Ministry of Fuel and Energy) Russia, in 1999 we estimated the amount of energy present in Russia’s forest biomass (The State Contract…1999). The results obtained are as follows.

The bulk energy potential of biomass is commonly estimated against the total biomass reserves of forests and against the biomass of forests cut down annually on the basis of an annual estimated cutting area which consists of final cutting and thinning. The bulk energy potential of forest biomass was calculated with regard for the root reserve energy (the potential energy of all the forest wood biomass, i.e. not only the merchantable stem) of each species (Table 4). The energy contained in the root reserves of Russia’s forests is estimated at 38–41 billion ton c.e. The energy present in the estimated cutting area of Russia’s forests is 360–390 million ton c.e. Gross calculations are based on the 1983–1988 forest stock assessment. Based on 1993–1998 data, detailed calculations were also made for all subjects of the Russian Federation.

Bulk potential estimates for Northwest Russia are given in Table 5 and Table 6.

Table 4. Estimated gross energy potential of the wood biomass standing stock.

Species	Total standing stemwood stock, billion m³	Ratio of total stand phytomass and stemwood stock, ton/m³	Relative stemwood density (ratio of oven-dry wood mass and green volume), ton/m³	Relative energy in 1 solid m³ of stemwood, Gcal/solid m³	Relative biomass including fallen and dead standing trees, ton/m³	Allowable cut, million m³/year	Gross energy	
							From standing stock, billion Gcal	From allowable cut, million Gcal/year
Larch	25.4	0.754–0.806	0.52	3.89–4.14	0.8086–0.8606	215.9	98.75–105.1	839.33–893.31
Pine	14.8	0.637–0.667	0.40	3.25–3.39	0.679–0.709	125.8	48.09–50.22	408.99–427.06
Spruce	11.2	0.734–0.793	0.36	3.72–4.00	0.7718–0.8308	104.2	41.66–44.84	387.56–417.19
Stone pine	7.4	0.616–0.780	0.35	3.13–3.91	0.65275–0.81675	62.9	23.13–28.94	196.59–245.98
Fir	2.7	0.546–0.604	0.30	2.74–3.01	0.5775–0.6355	–	7.39–8.14	–
Birch	8.0	0.770–0.786	0.50	3.88–3.96	0.8225–0.8385	109.6	31.05–31.66	425.41–433.9
Aspen	2.6	0.605–0.682	0.40	3.11–3.48	0.647–0.724	44.7	8.10–9.06	139.20–155.77
Lime	0.4	0.802–0.843	0.37	4.05–4.24	0.84085–0.88185	–	1.62–1.70	–
Oak	1.0	0.861–0.943	0.55	4.40–4.79	0.91875–1.00075	–	4.40–4.79	–
Beech	0.6	0.861–1.036	0.53	4.32–5.515	0.91665–1.09165	–	2.59–3.09	–
Ash, hornbeam	0.3	0.916–0.927	0.64	4.64–4.69	0.9832–0.9942	–	1.39–1.41	–
Total:	74.4	–	–	–	–	663.1	268.17–288.93	2397.09–2573.0

Table 5. Estimated wood biomass potential in individual regions of the North Russia.

Russian Federation subject	Total standing stock, million m^3	Total wood biomass energy, million ton of c.e.		Allowable cut, thousand m^3	Gross wood biomass potental, million ton of c.e.	
		minimum	maximum		minimum	maximum
Republic of Karelia	849	419	441	8792	4.34	4.57
Komi Republic	2837	1460	1554	29914	15.39	16.39
Archangelsk oblast	2151	1108	1180	21308	10.97	11.69
Vologda oblast	960	495	520	14216	7.33	7.70
Murmansk oblast	200	101	107	723	0.37	0.38
Total:	6997	3583	3802	74953	38.40	40.73

Table 6. Estimated wood biomass potential in individual regions of the Northwest Russia.

Russian Federation subject	Total standing stock, million m^3	Total wood biomass energy, million ton of c.e.		Allowable cut, thousand m^3	Gross wood biomass potental, million ton of c.e.	
		minimum	maximum		minimum	maximum
Leningrad oblast	583	295	311	7543	3.81	4.03
Novgorod oblast	289	147	155	3455	1.76	1.85
Pskov oblast	156	78	82	1751	0.87	0.92
Kaliningrad oblast	41	23	25	272	0.14	0.15
Total:	1069	543	573	13021	6.58	6.95

The technical potential of forest biomass energy is a portion of the bulk potential energy of forest biomass energy that can indeed be produced from it by means of modern technologies and used as a fuel. It should be noted that the portion of biomass, which is not used for the production of construction, fibrous, forest-chemical wood materials and other substances on serial equipment, is commonly used for energy production. This part of biomass is regarded as logging waste and woodworking residue. The technical potential of forest biomass energy and that the volume of biomass processing waste depend on forest management, logging, transportation and woodworking technologies. Much depends also on biomass enrichment and burning technologies.

The technical potential of forest biomass was estimated for the subjects of the Russian Federation where concentrated final cutting is carried out. Detailed calculations show that the total technical potential of logging waste is 18.3 million ton c.e. (the volume of transported wood is 304 m^3). Calculations were made without considering stemwood bark which is transported together with stems and will be considered in woodworking residue).

A large amount of roundwood produced in the course of felling is subjected to mechanical and chemical processing. Our calculations of timber production waste for Northwest Russia are shown in Table 7 and Table 8. The total technical potential of timber production waste is estimated at 8.5–13.2 million ton c.e. These estimates agree with the results obtained when elaborating the “Concept for the development and use of small-scale of nonconventional power engineering in Russia’s energy balance” (1994) in which the total technical potential of woodworking was estimated at 6.57 million ton c.e. The total technical potential of Russia is 26.78–51.48 million ton c.e. The former estimate of the technical potential of logging agrees with the real volume of felling operations in 1990. The latter estimate corresponds to the maximum amount of final cutting as soon as the estimated amount of felling is achieved.

Table 7. Industrial potential of energy from wood processing residues in the Northwest of Russia.

Region of Russia	Industrial potential, million ton c.e.	Industrial potential of wood processing [The Concept…1994], million ton c.e.
North	2.59–3.484	0.5
Northwest	0.522–0.698	
Total in Russia	8.48–13.201	6.57

Table 8. Total industrial potential of logging and wood processing residues in the Northwest of Russia.

Region of Russia	Industrial logging potential, million ton c.e.	Industrial potential of wood processing, million ton c.e.	Total wood fuel industrial potential, million ton c.e.
North	4.312–4.789	2.59–3.484	6.902–8.273
Northwest	0.595–0.728	0.522–0.698	1.117–1.426
Total in Russia	18.3–38.282	8.48–13.201	26.78–51.483

The estimates of the economic potential of forest biomass depend on local conditions such as the volume of wood cut and transported, wood fuel resources, the local prices of competitive relict fuels, etc. Local conditions vary over a very broad range. The economic potential of Russia’s forest biomass is estimated at 15–25 million ton c.e., about 40% being concentrated in Northwest Russia (The State Contract ... 1999).

Bioenergy Production in Northwest Russia

In Northwest Russia, biofuel is used on a fairly limited scale in electrical power engineering. Milled peat was a major type of fuel used in heat power plant-8 in the Leningrad region.

Fifteen enterprises run by Lentorf JSC (Joint Stock Company) produce peat and supply it as a fertilizer and fuel to consumers (626 000 t of peat in 1994).

Black liquors and wood waste are utilized on a larger scale (9.1% of Karelia's energy resources) in the heat power plants (HePPs) of pulp and paper mills (Borisov and Sidorenko 1999). In Karelia, examples are the HePPs in the Segezha and Kondopoga pulp and paper mills and in the Pitkaranta pulp mill**.**

In the Arkhangelsk province, consumers are supplied with electrical power from the HePPs run by Arkhenergo JSC, timber, pulp and paper and woodworking companies, railway facilities, agricultural organizations, various departments etc. The total output of the power plants operating in the province as of 1 January, 1993 was estimated at 2030 MW, 7165 GWh of electrical power being produced. The output of departmental HePPs is about 40%. The technical and economic indices of HePPs in the Arkhangelsk province are shown in Table 9.

Table 9. Technical characteristics of heat power plants (HePPs) in the Arkhangelsk oblast.

Title	Installed electric capacity, MW	Electric energy production, GWh	Heat capacity, Gcal/h	Heat energy production, thousand Gcal
Arkhangelsk Energy Unit				
HePP JSC "Arkhenergo"				
Arkhangelsk HePP	450	1719	1180	2763
Severodvinsk HePP-1	220	886	870	2358
Severodvinsk HePP-2	300	912	930	1514
Industrial power plant				
Arkhangelsky pulp and paper mill HePP-1	194	1041	929	4678
Arkhangelsky pulp and paper mill HePP-2	12	35.5	159	656
Arkhangelsky pulp and paper mill HePP-3	24	75.5	185	834
Solombalsky pulp and paper mill HePP	36	221	247	975
Arkhangelsky hydrolysis plant HePP	5.5	24.2	65	420
Onezhsky hydrolysis plant HePP	13.5	47	112	466
Kotlass Energy Unit				
Industrial power plant				
Kotlassky pulp and paper mill HePP-1	305	1468	846	4351
Kotlassky pulp and paper mill HePP-2	24	158	151	1001
Kotlassky pulp and paper mill HePP-3	18	88.2	165	657

Three industrial HePPs of the Arkhangelsk pulp and paper plant met the technological needs of the mill and those of the Novodvinsk municipal sector. HePP-1 is the biggest of them. It has an output of 194 MW and produces about 100 GWh of electric power per year and some

5000 Gcal of heat power. Almost 90% of heat is produced by collecting steam from heat turbines. The main fuel used in HePP-1 is coal (84%). Black mineral oil (10%) and wood residue (6%) are less common. The electrical output of HePP-2 in the Arkhagelsk pulp and paper plant is relatively small (12 MW). The main fuel is liquor (95%), and the rest is black mineral oil. The output of HePP-3 in the Arkhangelsk pulp and paper plant is twice that of HePP-2. The fuel types used are liquor (56%), black mineral oil (30%) and wood waste (14%). The electrical output of industrial HePP-1, HePP-2 and HePP-3 in the Kotlas pulp and paper plant is 305, 24 and 18 MW, respectively. One characteristic of HePP-1 is that over 80% of the fuel burnt is gas. In HePP-2 and HePP-3, liquor makes up 45% and 98% of the fuel used, respectively. In HePP of the Arkhangelsk hydrolysis plant lignin (about 12%) is used together with black mineral oil (46%) and coal (42%). In the Onega hydrolysis plant coal is a major fuel burnt in HePP.

The use of wood as fuel is most promising in small boiler plants. In the Leningrad region, about 900 small boiler plants are operating. In the Russian part of the Barents Region there are over 2000 boiler plants, each having an output of less than 20 Gcal/h (Table 10). Among them, there are many small boiler plants where fuel is not used efficiently and maintenance is labour-consuming. They are not reliable, the quality of heat supply is low, and escaping gas is poorly purified.

Table 10. Characteristics of boiler plants in Barents Region as of 1 January 1991.

Title	Murmansk oblast	Arkhangelsk oblast	Republic of Karelia	Total Barents Region
Total number of boiler plants	281	1648	804	2733
those with a capacity:				
- more than 20 Gcal/h	46	39	30	115
- less than 20 Gcal/h	235	1609	774	2618
Total installed capacity of boiler plants, Gcal/h	5500	4759	4654	14913
those with a capacity:				
- more than 20 Gcal/h	826	1743	1471	4040
- less than 20 Gcal/h	4724	3016	3183	10923
Total heat energy supplied by boiler plants, thousand Gcal	12536	7344	7409	27289
those with a capacity:				
- more than 20 Gcal/h	1431	3589	4343	9363
- less than 20 Gcal/h	11105	3755	3066	17926

Most (1609) of the boiler plants operating in the Arkhangelsk province (97%) have an output of less than 20 Gcal/h. The total output of these boiler plants is 3016 Gcal/h (63.4%) and the amount of heat produced is 3755 thousand Gcal (55.7%). The average specific consumption of fuel for heat energy production is 176.3 kg/Gcal and the average duration of the use of set output is 1245 hours.

Analysis of the local conditions under for water-heating and steam boiler plants operating in Northwest Russia has shown that conditions under which it is economically profitable to replace coal by a wood fuel are as follows:

- the boiler plants are equipped with low-output solid-fuel boilers with universal fluidized-bed furnaces that do not require reconstruction or DKVR boilers for re-equipment or the lifetime of boiler aggregates is not over;
- heat power production in a boiler plant is not more than 18–36 thousand Gcal/h;
- boiler plants are owned by enterprises that have sufficient amounts of wood residues or firewood (15–30 thousand solid m^3);
- if the volume of wood waste produced by enterprises exceeds their fuel requirements, then it is reasonable to analyse the production of enriched fuels, such as briquettes and pellets, both financially and economically.

Under the above conditions, wood fuel is more profitable economically than coal and black mineral oil because it is cheaper to burn internal waste than coal.

When coal prices had risen, many boiler plants operating in logging communities in Northwest Russia (fuel is supplied manually) began to burn firewood at the beginning of the heating season. In some boiler plants fuel-supply equipment was renovated. In the past ten years, the first demonstration boiler plants that work on wood and peat have been built. Examples are a boiler plant in the town of Lisino, Leningrad region (woodchips), a boiler plant in the town of Pryazha, Republic of Karelia (peat and wood), a boiler plant in the town of Verkhnetulomsky, Murmansk region (woodchips) etc. Altogether, over 20 boiler plants have been reconstructed so that they can burn wood fuel and peat. TACIS Project 9701 “Strategy of sustainable heat supply of border areas in the Republic of Karelia”, scheduled for 1999–2000, is now in progress in Russian Karelia. Two million Euros were allocated for the implementation of the project. Some other projects that aim at making FEC more efficient in Northwest Russia are now being accomplished as well (Barannik, 1999).

Some Promising Bioenergy Projects

There is a variety of non-conventional and renewable energy resources in Northwest Russia, but biofuel is one of the most important types. Table 11 shows promising bioenergy projects under the “Programme for the development of nonconventional power engineering in Russia” which is now under way. Many projects will be implemented in the Republic of Karelia. It would be interesting to estimate possible export of wood fuel, including pellets, from border areas in Northwest Russia to EU countries.

Calculations show that if wood fuel and peat resources are used rationally, then the amounts of relict fuel supplied to remote parts of Russia are decreased considerably, transportation costs are reduced, more jobs are created, heat supply becomes more reliable and the ecological situation improves. The climatic constituent of projects on the utilization of wood and peat for power production could, under certain conditions, encourage foreigners to take part in Russian power engineering projects. For example, in Northwest Russia funds to support bioenergy production could be raised by selling quotas in the amounts of CO_2 emitted into the atmosphere.

Selling Quotas

In 1992, the preliminary UN Convention on climatic changes was accepted. In December 1997, the *Kyoto Protocol* was endorsed as part of the Convention in Kyoto, Japan. In accordance with the Protocol, by 2008–2012 industrially developed countries must reduce

Table 11. Bioenergy. Program for Development of Nonconventional Power Engineering in Russia, 2001–2005.

Project Name	Organization and basic executors	Period	Investments, million rouble	Expected results
Arkhangelsk Region				
1.3. Village Novo-Lavella, Pinezskij district, Mini – HePP using wood residues. Capacity - 3 MW	Regional Administration	2002–2004	108.0	Reduction of coal combustion in the area. Economic and ecological advantages.
1.4. Village Lajskij, Primorskij district, Mini – HePP using peat (energy module), capacity - 1 MW	Regional Administration; OJSC “Energomash”	2001–2005	14.0	Reduction of coal and fuel oil combustion in the region. Economic and ecological advantages.
Republic of Karelia				
2.8. Putting a modular mini - HePP into operation and reconstruction of boiler plants with transfer to local fuels (peat, sawdust, wood residues). 46 boiler plants with total capacity – 75 MW.	Regional Administration. District Administration.	2001–2005	1800.0	Heat production. Improvement of ecological conditions.
2.9. Town of Olonets. HePP using peat. Capacity – 20 MW.	Regional Administration. District Administration. JSC “Karelenergo”	2002–2004	628.0	Heat production. Improvement of ecological conditions.
Leningrad Region				
4.1. Village Gankovo, Tihvinskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residuesand peat. Capacity – 5 Gcal/h.	Regional Administration. District Administration.	2001–2002	7.0	Economy Efficiency – 1.14 million rouble

Table 11. continued

Project Name	Organization and basic executors	Period	Investments, million rouble	Expected results
Leningrad Region				
4.2. Village Gorka, Tihvinskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residues and peat. Capacity – 4.56 Gcal/h.	Regional Administration. District Administration.	2002–2004	6.4	Economy Efficiency – 1.36 million rouble
4.3. Village Kos'kovo, Tihvinskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residues and peat. Capacity – 3.06 Gcal/h.	Regional Administration. District Administration.	2003–2005	4.3	Economy Efficiency – 0.84 million rouble
4.4. Village Plodovoe, Priozerskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residues and peat. Capacity – 6.9 Gcal/h.	Regional Administration. District Administration.	2003–2005	9.7	Economy Efficiency – 1.02 million rouble
4.5. Village Kommunary, Priozerskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residues and peat. Capacity – 5.0 Gcal/h.	Regional Administration. District Administration.	2003–2005	7.0	Economy Efficiency – 0.64 million rouble
4.6. Village Pochinok, Priozerskij district. Reconstruction of Boiler Plant with transfer of boiler to wood residues and peat. Capacity – 4.8 Gcal/h.	Regional Administration. District Administration.	2003–2005	6.7	Economy Efficiency – 0.82 million rouble
4.7. Village Nazija, Kirovskij district. Demonstration mini-HePP on peat and wood residies. Closed JSC " Processing peat a factory Nazija ". Electricity capacity – 300 kW, Heat capacity – 500 kW.	"Nazija" peat processing plant, STC "Energo-tehnologija", CSIDI	2004–2005	4.0	Meeting the growing energy demand of the "Nazija" peat processing plant.

their total greenhouse gas emission by at least 5% relative to the 1990 level. Many developed countries will have to spend a lot of money to achieve this goal. A participating country, which has to pay a lot to reduce greenhouse gas emission, can buy emission quotas from other participating countries that can reduce emissions at a lower cost.

At the present time, North European countries make various proposals on the investigation of the Kyoto mechanisms. One proposal is to combine efforts to reduce emissions in a country, which is less developed economically, by funding relevant activities by a more developed country and by selling emission quotas. Regional rules for the application of these flexible mechanisms provide a tool to strengthen international cooperation in the implementation of projects and support projects to be launched in Northwest Russia. The power engineering sector of Northwest Russia is a suitable partner for the accomplishment of the Kyoto Agreement.

Russia has a tremendous potential in the efficient reduction of greenhouse gas emission into the atmosphere. One way is to use biofuel and other renewable sources of energy on a larger scale. The climatic constituent of such power engineering projects makes them more viable financially.

In accordance with the Kyoto Protocol, Russia's greenhouse gas emission quota remains on the 1990 level (about 2388.2 million ton of CO_2). The same quota is likely to be considered in estimating the maximum allowable greenhouse gas emissions for the subjects of the Russian Federation. Russian Karelia ought to have the biggest quota because in 1990 fuel consumption in Karelia was maximum (5.6 million ton c.e.). CO_2 emission caused by burning the above amount of fuel is estimated at 14.2 million ton (Borisov and Sidorenko 1999). Relevant results are summarized in Table 12.

Table 12. Estimated atmospheric emissions of harmful substances at combustion of different fuels in Karelia in 1990.

Fuel	Amount of fuel used, thousand ton c.e.	SO_2 thousand ton	NO_x thousand ton	CO_2 million ton
Natural gas	62	0.00	0.11	0.10
Coal	901	75.70	3.46	2.16
Firewood	486	0.00	0.86	1.57
Wood residues	527	0.46	0.10	1.87
Fuel oil	2190	96.13	12.81	4.95
Liquor & other combustible wastes	307	0.18	0.71	0.98
Motor fuel	1119	3.95	4.92	2.53
Total:	5592	176.42	22.97	14.16

As a matter of fact, in Karelia maximum CO_2 emission into the atmosphere varies from 14.5 to 15.5 million ton. Emission caused by burning relict fuel is slightly lower (9.7–10.7 million ton). This estimate is in good agreement with an estimate of CO_2 emission caused by burning relict fuel in Finland (53.9 million ton in 1990). CO_2 emissions in other Scandinavian countries are roughly the same (Figure 4). In the subjects of the Russian Federation CO_2 emission in 1990 was 107.6 million ton, which is about half the amount of CO_2 emission in Scandinavian countries.

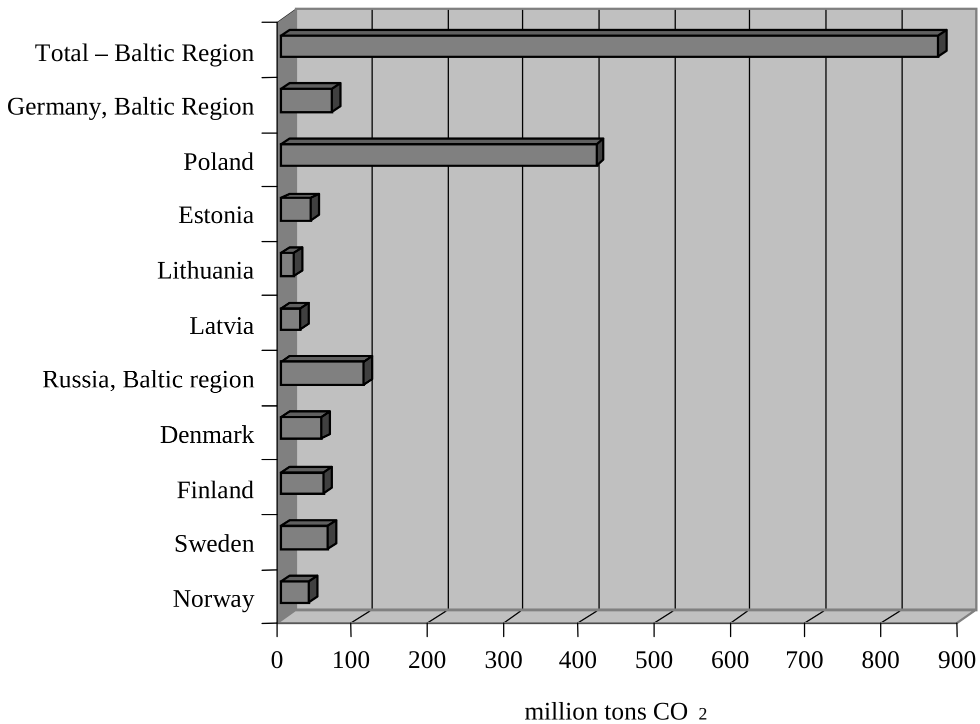

Figure 4. CO_2 emissions into the atmosphere in the Baltic region countries (million ton of CO_2) 1990.

Thus, Russian Karelia is likely to have a CO_2 emission quota, the amount of relict fuel burnt being 10–11 million ton. At the present time, CO_2 is emitted into the atmosphere in smaller quantities as less fuel is now burnt due to the economic recession. In 1995, total fuel consumption in Russian Karelia 3.27 million ton c.e. (58% against the 1990 level) (Borisov and Sidorenko 1999). Accordingly, 6–8 million ton of CO_2 are emitted. The unused portion of the CO_2 quota in Russian Karelia is 3–4 million ton. For comparison, to meet the requirements specified in the Kyoto Protocol, Finland will have to reduce CO_2 emission by 2008–2012 by only 2.8 million ton (5% of 53.9). To solve this problem, Russian Karelia could sell the unused part of its quota to Finland and attract investments to develop, for instance, bioenergy production**.**

What is Russian Karelia's Potential in Further Reduction of CO_2 Emission into the Atmosphere?

The amount of various local energy resources which Karelia can potentially utilize is estimated at 4.8 million ton c.e. The volume of wood residues that Karelia can really use is 0.4–0.6 million ton c.e. Reduction in the amount of CO_2 emitted into the atmosphere could vary from 0.94 to 1.15 million ton if black mineral oil and coal are replaced by wood fuel. A summary table showing reduction in CO_2 emission caused by the use of local fuel and energy is given in Table 13. Northwest Russia's potential in the reduction of CO_2 emission is much higher.

Table 13. Reduction in CO_2 emissions at utilization of local fuel and energy resources in Karelia.

No.	Energy Source (fuel type)	Unemployed resources, million ton c.e.	CO_2 emissions reduction volume, million ton	
			Lower estimate, fuel oil replacement	Upper estimate, coal replacement
1	Hydropower, >1 MW	0.72	1.62	1.99
2	Hydropower, <1 MW	0.62	1.40	1.71
3	Wind power	0.33	0.74	0.91
4	Wood residues	0.41	0.94	1.15
5	Peat	0.80	1.78	2.21
6	Other	0.25	0.56	0.69
Total:		3.13	7.04	8.66

Conclusions

Based on the above, we have drawn the following conclusions:

1. The use of renewable sources of energy, including biofuel, would enable Russian Karelia to exclude the burning of relict fuel in the amount of 3.1 million ton c.e. This, in turn, would exclude CO_2 emission into the atmosphere in the amount of 7–8.6 million ton.
2. It would be necessary to hope, that a reality of the nearest future will become sale CO_2 emission quotas. Selling a free CO_2 emission quota could provide an additional source of funding for the development of bioenergy production in Northwest Russia.

In conclusion, let me formulate some general conclusions:

1. Northwest Russia has the biggest economic biofuel potential and considerable biofuel reserves.
2. The economic potential of forest biomass energy will grow with the rising price of relict fuel. As a result, wood fuel power engineering will develop along with fuel woodchip and pellet production.
3. It would be necessary to hope that sale of CO_2 emission quotas become a reality in the near future. Selling a free CO_2 emission quota could provide additional funding for the development of bioenergy production in Northwest Russia.
4. Considering available resources as well as technical, economic, social and political conditions at the Finnish-Northwest Russian border, it is reasonable to form a “Green Energy Belt” (Titov et al. 2000).

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Some Prospects on Utilization of Wood Wastes

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Abstract

Wood-based energy will grow in importance in all the countries economies in transition in Eastern Europe and Central Asia in the future. Energy related projects will be developed increasingly through environmental development programs (such as the solid waste development programs in Latvia), or integrated into sectoral (such as in the forest sector). These projects will be linked with concrete investments where several international financing institutions can be used in co-financing large projects. Experimental and innovative projects will have possibilities to receive grant financing from international sources such as the Global Environment Facility, and there will be more cooperation between various donor and other agencies, based mostly on a project cycle approach.

Keywords: biomass, energy, countries in transition, investment, funding, International Financing Institutions, development

Background

‘*Fuel for Thought* – A New Environmental Strategy for the Energy Sector’ which was published in 1998, is the paper that outlines the World Bank approach on development of the energy sector in the future. It emphasizes the importance of energy issues to be tackled in a multidisciplinary way integrating not only environmental and energy aspects, but also other sectoral development efforts. For the forest sector development it leads to an integrated approach where also agricultural/rural and regional as well as industrial development should be seen in this context. These efforts are supported at least to some extent by current revision processes of the rural, environmental and forestry strategies in the World Bank. All these strategies will and should be implemented within the remit of Country Assistance Strategies (CAS) prepared in and agreed with the target countries, clients of the World Bank. In CAS, the country also shows its commitment to improve efficiency whether by restructuring its energy sector or by reforming its policies. Besides this commitment the World Bank’s other

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precondition for the energy related activities include the support of the country for competition and private-sector investment and sound regulation of the sector. In addition the country should promote energy efficiency both on the supply side and demand side, and integrate energy pricing with environmental policies (World Bank 1998).

World Energy Council forecasts on current trends on world energy use show an annual growth of 1.4% globally until 2020, with growth in OECD countries of only 0.7% and growth in developing countries of 2.6%. According to the same forecasts, the growth in countries in transition in Europe and Central Asia will be similar to the growth in OECD countries up to 2020, but somewhat faster during the three following decades after 2020 (World Bank 1998).

The new approach also emphasizes the close relationship between climate change and the energy pollutants. It has also led to development of new instruments and development programs through which this relationship can be tackled. The programs most relevant to renewable energy sources within and close to the World Bank group are the Energy Sector Management Assistance Programme (ESMAP) and the Global Environment Facility (GEF). These will both be discussed in the following sections of this paper.

The total energy project portfolio of the World Bank in Eastern Europe and Central Asia (ECA) totaled approximately US$5 billion between 1994 and 1999. This figure includes all the bank adjustment lending operations and analytical and sector-related work in this field. The main problems to be solved have focused on de-monopolization and regulation, prices and fiscal policy, foreign trade, social protection and environmental protection. As the problems tackled are of structural character, no emphasis has been given to specific sources of energy, or even to renewable energy sources. This has led to a situation where the project portfolio for wood wastes as an energy source has been at the level of zero in recent years (World Bank 2000). However, the situation regarding wood wastes can be improved in this respect, and this paper presents some ideas about how to do it.

Energy Problems and Projects in ECA Region

Among the objectives set for the energy sector development in ECA region, the most appropriate ones dealing with renewable energy sources comprise investment policy, social protection and environmental protection. The World Bank will be supporting investments in energy efficiency and the utilization of renewable energy resources through appropriate financial incentives according to the ECA energy strategy. Also guarantees against non-commercial risks can also be used in certain cases in this context (for instance as integrated in the forest sector investments in Russia). Objectives in social protection support the increased used of wood and other rural energy resources in rural areas from the employment and poor urban/rural household points of view. The importance of local government in planning and decision making is growing and replacing the centralized system. This development will support the use of local energy resources (World Bank 1998). In practice, the increasing role of district heating (for instance, in Poland, Bulgaria and the Baltic States) will create the basis for the increased use of wood as an energy source. So far the World Bank has not planned or implemented such projects in the ECA region (Nuorkivi 2000).

The World Bank has conducted forestry projects during the last decade in Albania, Armenia, Belarus, Bosnia and Herzegovina, Georgia, Poland, Romania, Russia and Turkey. Energy issues have not been dealt with in any of these projects. The reasons for this vary, but most often the problem has been that the loans taken by governments are sector specific loans, and energy issues are not included in the forest sector development or administration. Another reason has been that the World Bank loans have very rarely been used in forest industrial projects during the last decade, because of the World Bank forest policy that excluded largely industrial issues at the beginning of 1990s (Alhojärvi 2000).

The World Bank forest policy and strategy are under revision and there are possibilities that it might include a broader approach in the future. Energy issues (in the form of fuelwood, and industrial wood wastes, etc.) and industrial development including all main problems and factors influencing the forest industries, would also be included in the new policy/strategy. In this case the wood wastes and other wood-based energy resources could be tackled and developed through projects implemented in the forest sector (Alhojärvi 2000).

Appropriate Energy Technologies

Although the World Bank has not financed or implemented wood-based energy projects in ECA region during the last decade, it has carried out research and development related to it. In 1999, Quaak et al. presented a comprehensive analysis on the energy technologies used in gasification and combustion of biomass. It concentrates on combined heat and electricity production issues in small (1–5 MW) plants, and integrates technical, environmental and economic issues in a comprehensive manner. Some examples of the techniques have also been used in forest industrial solutions using wood wastes and wood-based energy resources. Kulsum (1994) presented a review of various international experiences and studies on renewable energy technologies. The review concluded, for instance, that the production of ethanol from cellulosic material promises significant decreases in costs in the future. It also stated that gasifier/gas turbine technology will offer a cost-effective method of power generation in the future. In addition an approach where the setting up of the forest energy plantation/power plant serves a dual purpose (i.e. reforestation and electricity generation) might turn out to be the most competitive alternative, although the land use might compete with alternative vital use of land, such as for production of food crops in China (Perlack et al. 1991).

In practice the appropriate energy technology proposed and selected in an energy project is very much dependent on the personal experiences of the World Bank experts used in the project preparation. By increasing the use of district heating plants in countries in transition multi-fuel boilers have become more frequent as basic solutions. Even though, most of them are designed for the use of coal and other economically competitive fuels, more and more often they are designed to be able to use substituting fuels, such as peat or wood (Nuorkivi 2000). These development efforts have mainly originated from the ESMAP pilot project in six countries in transition in Eastern Europe. In recent studies in the Baltic States other technologies (e.g. using wood pellets and briquettes) have been studied as competitive alternatives (Ministry of Environmental … 1999).

The World Bank has not prepared or implemented any forestry project in ECA region during the last decade that would have analysed the appropriateness of forest harvesting technology for wood-based energy or the optimization of wood harvesting including wood for industrial and energy uses (Alhojärvi 2000).

A Case Study in Latvia

Wood-based energy in general, and wood wastes in particular, are likely to be tackled and analysed in a wider concept within the World Bank than has been the case so far. This is due to the acute environmental and energy problems that have to be solved in an integrated manner. As an example of this, a feasibility-study was conducted in Latvia in 1999, which aimed to solve the increasing problem of sawdust originating from the sawmilling. The sawdust was mainly being transported for waste disposal instead of being used as by-products or energy. It is evident that this approach will be used in other countries in transition as well as a basis for investments in Latvia.

International consultants and local experts carried out a feasibility-study in Latvia concerning the design of a 'sawdust and wood waste strategy for Latvia' (Ministry of Enviromental… 1999). There had been a rapid expansion of sawmilling industries, and the amount of sawmill residues had rapidly increased and created a huge solid waste disposal problem in the country. As the sawmilling industries are predicted to grow strongly also in the future, the problem is growing in importance.

Approximately half of the currently generated sawmill residues are used for energy production at district heating plants and by local users of firewood, about 13% is exported and 6% used by sawmills in their own boilers. Currently 440 000 m^3/yr of sawdust has no use in Latvia. If this potential were allocated to use, it would amount to 880 GWh/yr of primary energy. In addition to unutilized sawdust, about 465 000 m^3/yr of other solid residues are not used which corresponds to 930 GWh/yr of primary energy. In comparison with the price of the cheapest alternative fuel, these figures would amount to about US$15.5 million/yr. On average, about 54% of sawdust and about 75% of other solid residues are currently used in Latvia. The problem is most apparent in small sawmills and less developed rural areas.

There are at least six optional uses to which wood residues can be directed to make both use of their economic value and to reduce environmental load: (1) Energy production at district-heating plants; (2) Energy production at sawmills; (3) Chip production for pulp, medium density fibreboard (MDF) and particleboard; (4) Pellet and briquette production; (5) Export of wood chips; and (6) Landfill energy cells, composting, mulching, etc.

An additional factor will be the probable pulpmill to be constructed in the country as the demand for pulp chip production from waste could become a priority for a number of sawmills. However, the pulp chip sales are predicted to remain below that of fuel use.

The main conclusions of the study based on which the strategy will be designed are the following:

1. District heating plants could use markedly larger amounts of wood wastes than today. The main bottleneck is the high unit price of wood-fired boilers compared with boilers fired by other fuels. The price of wood fuel is very low and sometimes close to zero or negative in sawmills, but it is expected to increase with increasing demand in the future. Studies show that wood fuels could be economically transported over much longer distances than is currently the case.
2. 3. and 5. Both economic and environmental reasons justify a maximum utilization of wood residues at the sawmill for energy production. According to the study, large sawmills that produce at least 20 000 m^3 of sawn timber could be feasible sites for boiler investments. The possibility of connecting a sawmill boiler to a district-heating network would enable the building of a boiler at a smaller sawmill as well. Smaller sawmills should start the production of high-quality chips for district heating plants, and collection and delivery systems for wood fuels should be built up. Feasibility-studies should be carried out for kiln-drying capacity, pulp and fuel chip production machinery investment. Sawmills located in the vicinity of district-heating networks should be the first alternatives to be studied. Around 30% of the volume of sawlogs could be made into pulp chips after the log has been sawn into lumber. Processing would require investments in debarking, chipping and screening The minimum sawmill size for such investment is about 10 000–15 000 m^3/a. The planned pulpmill would use 340 000–410 000 m^3/yr of sawmill chips as raw material.

This is estimated to correspond to 17–20% of potential pulp chip production in Latvia in 2010. Until then the chip export would be a valid option that should be further studied, tested and practiced.

4. Pellet and briquette production can be increased from the prevailing level and especially dry sawdust and shavings from further processing of wood should be directed for this purpose. European markets for pellets are constantly growing but are currently saturated due to excess production capacity and imports of pellets from Canada. Market studies indicate that the only way to penetrate export markets is to lower sales prices, in comparison to other manufacturers.
6. A small proportion of sawdust, 1–2%, can be directed to *landfill cells* according to the report. In the long term only low-grade wood waste, which is unsuitable for district heating, briquette and pellet production or for export, could be used in energy cells as stabilization and insulation material instead of peat.

According to the environmental assessment carried out in the study 1 million m^3 of sawmill residues annually used as energy would replace 170 000 tons of heavy fuel oil thus reducing greenhouse emissions by about 0.54 Mt CO_2 annually. This is estimated to be a conservative estimate of the effects. According to the economic assessment the same amount of residues would increase the income of sawmills by an additional US$1.7 million and would eliminate the dumping costs (US$0.43 million). Additionally the employment would increase by 50 permanent jobs in transportation as well as by a similar total increase in loading, unloading and other terminal operations. The estimated annual contractor income would be US$2.55 million and respective annual wage income would be US$0.46 million according to the study.

There are many difficulties in financing of investments. These mostly arise as a result of the serious economic condition of the municipalities in Latvia. The study recommends that the key ministry, namely the Ministry of Environmental Protection and Regional Development, should start identification and preparation of district heating plant investments with the purpose of using Emissions Trading and Joint implementation as financing tools. One probable option could be the Prototype Carbon Fund launched by the World Bank to promote carbon offset trading while bilateral donors are earmarking funds for joint implementation. This combination could become an operational financing tool even in the short term. These investment preparations should be supported by other ministries and the participation in clearinghouses for the preparation and funding of investments would prove to be useful.

According to the study, Latvia should join the emerging regional clearinghouses (e.g. Baltic Chain, Baltic 21). In addition to the public support of the investments, the business development within by-products of sawmills should also be encouraged. This development work could be organized in the most appropriate way by establishing sawmill owners' associations who then could take measures to develop the by-product businesses. There are encouraging examples of this type of institutional industrial development in the Nordic countries, and most recently in Estonia. These associations could also play an important role in market research for both the conventional sawmill products (including primary and secondary processed products), and for by-products. This would be also a path in adding value to the production lines of the industries.

The study recommends that the use of wood fuels should be supported with direct subsidies in the form of financing investments, support for research and development as described above, and also indirectly through taxation as it would be justified on environmental and social grounds.

It is evident that this study will be a base for the design of sawdust and woodwaste strategy for Latvia, but it will also be integrated as a crucial element to the solid waste disposal strategies and action plans at municipal and regional levels. If supported by a combination of public and private efforts as described, it may become a successful solution nationwide, and could probably have even larger impacts owing to its cross-sectoral and integrated approach.

This phenomenon is very common also in Western Europe and North America. For instance, Ince (1998) points out the sharp increase of landfill costs in the last 20 years. Together with the other factors supporting the recycling of fibres in forest industrial processes, it promotes in economic terms the further development of utilization of wood residues and fibres in various forms both for recycled products, by-products and for energy. For instance in Turkey, biomass provides the greatest potential among renewable resources of energy (including solar, wind, hydraulic and geothermal) as a replacement for conventional energy resources in the future (Yalgin et al. 1998). In countries in transition the challenge is usually based on the long and firmly established tradition of using wood and wood wastes. In many countries they represent 30–50% of the energy used for heating purposes because of the forest residues and wastes produced in rural sawmills. As a source of primary energy, the share of wood-based energy is much lower than in Nordic countries, and this is mainly due to the lack of district heating systems (Ilavsky 1998; Pogacnik 1998; Nuorkivi 2000).

Energy Sector Management Assistance Program (ESMAP)

ESMAP is jointly financed by the World Bank and the United Nations Development Program (UNDP). It has acted as a development element for many energy projects in various regions where the World Bank and UNDP are acting. It has a clear mandate in and linkage with poverty alleviation. Thus its projects comprise many that are acting in rural areas and have a social dimension in them.

ESMAP concentrates on issues not yet in the mainstream in the operations of bilateral or multilateral development institutions, or the private sector. It aims at designing innovative approaches to address energy issues. ESMAP activities include one or several of the following:

- Free technical assistance
  - specific studies
  - advisory services
  - pilot projects
- Knowledge generation and dissemination
  - training, workshops, and seminars
  - conferences and roundtables
  - publications

All the six main themes of ESMAP have connections with wood-based energy. However, only a few projects focus on utilization of it in Eastern Europe or Central Asia. In recent years the largest single theme in this region within renewable energy has been the development of heating in Central and Eastern Europe. The project comprised six case studies – one in each of the participating countries Ukraine, Lithuania, Russia, Bulgaria, Romania and Poland. These case studies used a common methodology emphasizing the scope for inter-fuel substitution between District Heating (DH) and alternatives, such as boilers for individual buildings, or apartment boilers using natural gas. The case studies confirmed the general superiority of established DH systems supplied by combined heat and power (CHP) generation plants in densely populated areas. These findings have taken into programming of the World Bank projects in these countries and so the pilot plants have been multiplied in an appropriately modified way in the last few years. This process has also been supported by the

Finnish trust funds used in the World Bank. In addition, the power sector development has included privatization and market pricing as its basis.

Another successful example in Eastern Europe has been the project in Slovenia where the legal and institutional framework was developed for meeting the requirements of foreign direct investment in the country's infrastructure in the energy sector. This project has had a direct linkage with the EU accession of Slovenia and developed the closed sector according to the EU's competition policy, etc.

If ESMAP is to be involved in energy sector development by client countries or donor agencies or foreign consultants, the sector covered by the proposed projects should be included in the CAS of the client country as a whole, the proposed projects should have direct linkages either with the current projects in implementation, and/or they should be supported from inside the bank, both from the country office and the sectoral department(s) involved.

For instance, if a bioenergy project is aimed to be included through ESMAP into the World Bank portfolio in the Russian Federation, it should be either included in the energy sector development program or integrated as an additional element to the development of pilot forest industrial enterprises afterwards. As yet there is no such plan in the pilot forestry project there. The most appropriate method would be to use, for instance, Finnish trust funds to plan this additional element into the activities and functions of the pilot enterprises. This work should be carried out as a joint effort (donor and Russian) and both research institutes/universities and commercial consultants could be used in it.

Global Environment Facility (GEF)

GEF is an umbrella for three different agencies acting in environmental development, namely United Nations Development Program (UNDP), United Nations Environmental Program (UNEP) and the World Bank. Its work covering energy-related problems has been built on the basis of the United Nations Framework Convention on Climate Change (UNFCCC). It seeks to stabilize atmospheric greenhouse gas (GHG) concentrations at levels that would prevent dangerous anthropogenic interference with global climate. GEF operates through 12 operational programs (OPs) in reaching its objectives four of which directly or indirectly deal also with the wood-based energy resources. OP 5 deals with the removal of barriers to energy efficiency and energy conservation; OP 6 deals with promoting the adoption of renewable energy by removing barriers and reducing implementation costs; OP 7 deals with reducing the long-term costs of low GHG-emitting energy technologies; and OP 12 deals with integrated ecosystem management.

These operational programs are implemented through projects in these three implementing agencies globally, regionally or nationally. The most direct OP having influence on wood-based energy resources is OP 6, in which for instance the following technologies are being examined and developed: (1) Biomass and thermal heat, including heat and power, and use of urban and industrial wastes for process heat and district heating; (2) Wind, biomass, photovoltaics, small-scale hydro and other renewable energy for rural electricity supply; (3) Renewable energy for grid-connected electricity (e.g. wind farms); and (4) Biogas digesters for lighting and water pumping. Each operational program and its project may consist of five different components, namely: (a) targeted research; (b) capacity building; (c) institutional strengthening; (d) investments; and (e) training. These investments are mainly designed to act as demonstration projects, with the objective of being replicated in a modified format in other countries and regions at a later stage. These investments are often supported because of this demonstration nature with partial grants and soft loans.

GEF has supported in recent years the following projects in ECA region:

- Operational Program 5:
  - Bulgaria: Energy efficiency strategy
  - Czech Republic: Low-cost/low-energy buildings
  - Hungary: Energy-efficiency co-financing program
  - Poland: Efficient Lighting Project
  - Romania: Capacity building for GHG emission reduction through energy efficiency-Romania
  - Russian Federation: Capacity building to reduce key barriers to energy efficiency in Russian residential buildings and heat supply
- Operational Program 6:
  - Lithuania: Klaipeda geothermal demonstration
  - Three projects in China on renewable energy development, energy from municipal waste, etc.
- Operational Program 7:
  - None

There are enabling activities with respect to climate change in Estonia, Poland, Albania, Azerbaijan, Armenia, Croatia, Georgia, Lithuania, Moldova, Slovenia, Ukraine and Uzbekistan. These efforts have mainly focused in developing the institutional structures in these conditions as to enable them to meet the requirements of the convention on climate change. In practice it has taken the form of various measures to strengthen the environmental ministries and energy units in these countries.

In addition GEF has funded the following renewable energy and regional development projects through its short-term response measures: Szekesfehervar Biomass-Gas combined heat and power (CHP) project in Hungary; Solid Waste Management and Landfill Gas Recovery project in Latvia; Coal to Gas project in Poland; Greenhouse Gas Reduction project in the Russian Federation; and a Coalbed Methane Recovery project in Ukraine.

The projects can either belong to a small-grants program, in which case the project implementation can start soon after the decision-making, or it can be considered as a medium- or large-scale project, in which case the project preparation phase might take 1 to 2 years in GEF and implementing agencies. In summary, GEF may provide an interesting and effective option for new types of project concepts within wood-based energy ranging from research to practical demonstration and emphasizing training and capacity building in its means of development. This process can be supported by various trust funds. In that case the project should take place as a joint effort between the donor country institute or consultant and the recipient. This is also an efficient way to market expertise that exists in the donor country because of the multiplier effects of the demonstration projects. Technological demonstration projects can also be supported by GEF and its sources (Williams et al. 1998).

Russian Federation

Energy is mentioned among the prioritized sectors in the Country Assistance Strategy of the Russian Federation. It can be approached either through the energy itself, or by integrating it into the environmental projects as a component. At least in theory, it can also be linked with other sectoral projects, such as the pilot forestry one, or the partial risk guarantee facility, which has been developed for the coal and forestry sectors in Russia. If speaking specifically about wood waste projects, the most natural approach would be to include it as a subcomponent into development of pilot forest industrial enterprises. The most concrete way to do it is to plan the sawmilling activities so that the sawmill would be provided with a boiler using the sawdust and bark of logs for creating heat to the sawmilling process, mainly to the drying capacity of the sawmill. Another option could consider the same options as presented in the Latvian case study. However, the lack of relevant markets for pelleting and briquetting is a major obstacle for the further processing of waste.

The energy-environment review, a study conducted by the World Bank in 1999, presents a realistic picture of the Russian energy-environmental problems. The picture is rather dramatic and the analysis shows that the country had major energy related, environmental problems. As a consequence it is very likely that wood-based energy will not receive much attention in the World Bank energy projects in Russia. Much deeper and more complex problems have to be solved first, and the forest or wood related opportunities are likely to be overlooked also in the future. The wood-based energy issues can be developed mainly through environmental and forest industrial projects when integrated into the process development issues, very unlikely in other ways.

Finland has had many difficulties to overcome in introducing forest residues and waste wood and wood waste into the bilateral forestry development program between Russia and Finland. Although it has been prioritized as one of the key areas in forestry cooperation, only small steps have been taken. One of the main hindrances has been the lack of a cross-sectoral approach in Russia with respect to these issues. The reason for this is the very separate administrative structures. Energy issues are the responsibility of sectors other than the forest, forest industrial or environmental committees in the regions of Russia. All of which have been involved into the bilateral cooperation at least to some extent. Thus there is no administrative structure to support the development of the natural connection of utilization of wood wastes in these publicly financed projects.

Nevertheless, recent studies suggest that there would be a great potential in Russia to develop wood waste utilization both in solid and liquid form. Gasification would also be a relevant option. Practically speaking, all energy and industrial studies dealing with the forest industries show that there is a great potential in this field, and that it should take place when renovating the existing mills or by new investments (see Asikainen and Mattila 1997; FFTA 1998; Ekono Energy 1998).

The most realistic steps in developing these topics are to include them into actual investment projects where the economic return of the increased utilization of wood wastes show its sensibility and appropriateness in wood industrial process and to start these development processes by bilaterally and trust funded pre- and feasibility studies.

The views expressed in this paper are those of the author, and not the official views of the World Bank.

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Large-Scale Forest Fuel Procurement

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Abstract

Although wood energy is considered to be a local fuel it has to compete on global energy markets with other sources of energy. Procurement of forest fuels calls for cost effective harvesting and transport methods since sources of wood fuel are predominantly scattered over a large geographical area. Economically acceptable transport distance for forest fuel is a fraction of the one for oil because of the low calorimetric density of the material. Finland is now attempting to expand the utilisation of forest fuels, consisting mainly of logging residues, by 2 million m^3 in five years. This means an increase in harvesting of almost five times compared with the current level. The scale of operations will increase markedly, which will have a great impact on harvesting costs. As the annual harvest increases, full employment of machinery becomes easier. On the other hand, the greater is the share of the potential fuel supply that is recovered, the higher becomes the cost of procurement. This results from longer transport distances and the need to operate at less favourable sites. In this paper, the effects of the scale of operation and storage of wood fuel on the costs of procurement are studied. The study uses geographic information system and logging site data of two large forest companies as a basis of procurement cost calculations. The results show that increases in scale favour systems that have good abilities to transport the material effectively. The cost effect of terminal phases becomes less important as the scale of operation increases.

Keywords: energy wood harvesting, bioenergy, wood fuel

1. Introduction

Wood is considered to be a local fuel. Nevertheless, it has to compete on global energy markets with other sources of energy. Procurement of forest fuels calls for cost effective harvesting and transport practices since forest biomass is scattered over a large geographical area. In Finland, forest chips are considered to be competitive with other fuels if the transport

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distance is less than 100 km. Knowledge on cost factors associated with harvesting and transport of forest fuels is essential as procurement systems are designed and operated for forest fuels. Mechanisation of forest work has promoted the development of cost effective harvesting machinery and methods for wood fuel procurement. Consequently, forest fuels are currently becoming competitive especially in Nordic countries.

The volume of biomass used in a single heat plant defines the scale of operation. The potential availability of forest fuels depends on the annual production of forests and annual logging volumes of industrial roundwood. The logging residues (branches, tops and offcuts) from clear cut areas is the largest source for forest fuels (Hakkila et al. 1998). The price of logging residue chips is also lower than the price of small diameter tree chips (Hakkila and Nousiainen 2000). The total volume of residues depends primarily on the tree species (Table 1). Spruce dominated stands are considered to be economically the most attractive for harvesting, because their residue density and total volume are the highest.

Table 1. Volume of logging residues per harvested industrial roundwood (Hakkila 1991). Not all residues can be harvested; typically about 70% of the material can be taken out (Alakangas et al. 1999).

Species group	Volume of residues as % of m^3 (s.o.b) harvested roundwood, %
Spruce	43
Pine	24
Broadleaved	17

The productivity of energy wood harvesting is affected by the conditions at the work site. The terrain, the method used for harvesting the industrial roundwood prior to or simultaneously with recovery of wood fuel, distance to landing, and the amount of potential fuel at the logging site all have impacts on logging costs. In addition, the total amount of wood fuel to be recovered per site affects the need to move machinery from site to site.

A cost comparison at a site level gives information about competitiveness of different logging machines and methods. A site level comparison can not, however, take into account the effect of scale of operation on the harvesting costs. In addition, storage of material can effect on harvesting cost. In this paper, a method based on a geographic information system is demonstrated in the analysis of the scale effect and storage on the harvesting cost of forest fuels.

2. Selection of Stands for Harvesting

Spruce dominated stands have the lowest harvesting costs at the stand level because the density of the material along the forwarding trails is high. In particular, this has an effect on driving distance during feeding for ‘in-wood’ chipping or loading for forwarding of logging residues (Figure 1). The density in pine dominated stands is clearly lower and as a result, loading takes more time. Thus, it appears that harvesting should be directed to spruce stands.

However, when the effect of scale is taken into consideration, the situation changes. The availability of material at a certain area defines the transport distance. In addition, distance from the stand to the roadside also strongly affects the cost of harvesting. If only spruce dominated stands are harvested, the radius of the procurement area grows substantially and the total availability (in North Karelia, Finland) decreases by 23% compared with the situation if all stands are considered (Figure 2). This results from the fact that the radius of procurement area increases since pine dominated stands are not harvested. The calculation is based on logging site data of large forest companies including the location and volumes of timber assortments by tree species that were converted to volumes of logging residues.

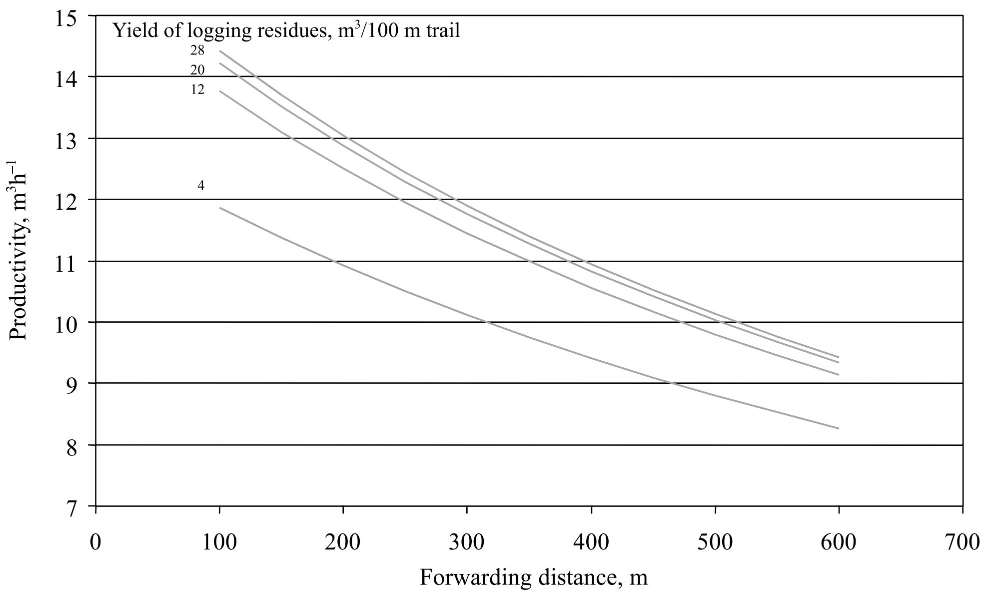

Figure 1. Effect of logging residue density and forwarding distance on productivity of ‘in wood’ chipping.

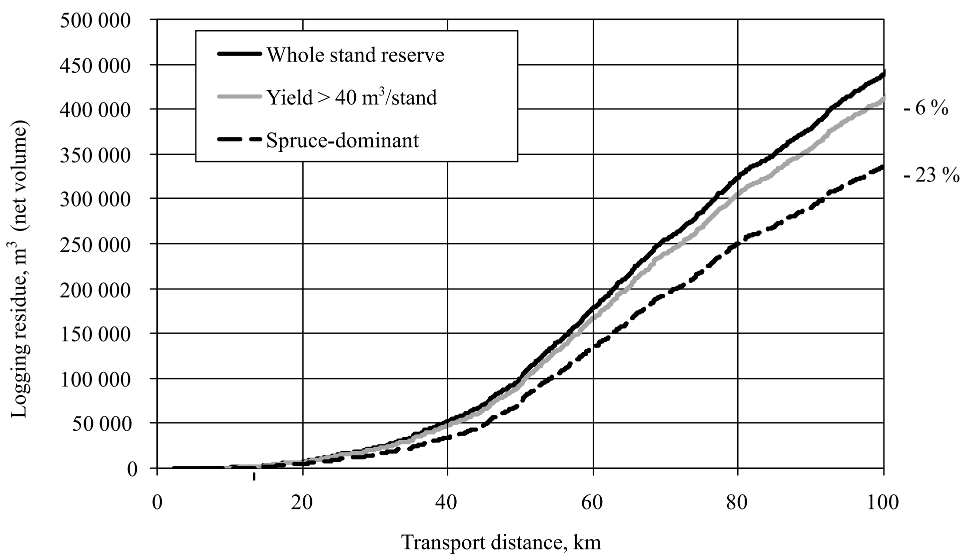

Figure 2. Wood energy potential in North Karelia by transport distance and constraints for recovery, centre point, Joensuu.

3. Effects of Storage and Annual Harvested Energy on Harvesting Costs

The quality of energy wood affects fuel costs in several ways. Impurities such as stones, metals and sand can damage chipper blades requiring more frequent replacements or sharpening.

The moisture content of wood affects the cost of transport. The more water there is in the material, the less fuel is transported. Reducing the moisture content calls for storage of the material either on the site, at landings, at terminal or at the plant. Storing promotes the heating value of the material, especially when the storage involves providing protection from rain.

In the chipping phase, dried logging residues are more difficult to process and the productivity of a chipper diminishes substantially compared with fresh material (Figure 3). Crusher is not that sensitive for changes in the moisture content of the raw material.

In Sweden, baling machines have been developed for processing logging residues (Andersson 2000). The bales are cylindrical, their length and diameter are approximately 3 m and 60 cm, respectively. Storage of material before baling also has a negative effect on baling productivity. This results from the fact that dry residues are stiffer and also the density of bales decreases (Figure 4).

Storage can also cause considerable raw material losses (Brunberg et al. 1998; Andersson 2000). For instance, the storage of spruce residues can lead to 20–30% losses due to defoliation. As a result, recovery rate diminishes and the radius for the procurement area increases, thereby increasing the cost of transport. The effect of storage on harvesting costs varies depending on the supply chain. If chipping is done at the landing, storage of raw material increases markedly the costs of harvesting and transport (Figure 5). This results from the lower chipping productivity and an increased need for moving the chipper between stands because of the smaller recovery percentage per site (Hämäläinen 2000).

If chipping is centralized and material is transported to a terminal in loose form, storage does not markedly affect total costs. This results from the fact that in long-distance transport the total amount of dry mass in the load increases slightly when dry material is transported. In addition, there is no need to move the chipper between stands in this system (Hämäläinen 2000).

Figures 5 and 6 also illustrate the effect of scale on harvesting costs. If the harvested volume increases (vertical axis), the harvesting costs also increase (horizontal axis). This results from increasing long-distance transport and harvesting of sites with poorer harvesting conditions and lower productivity.

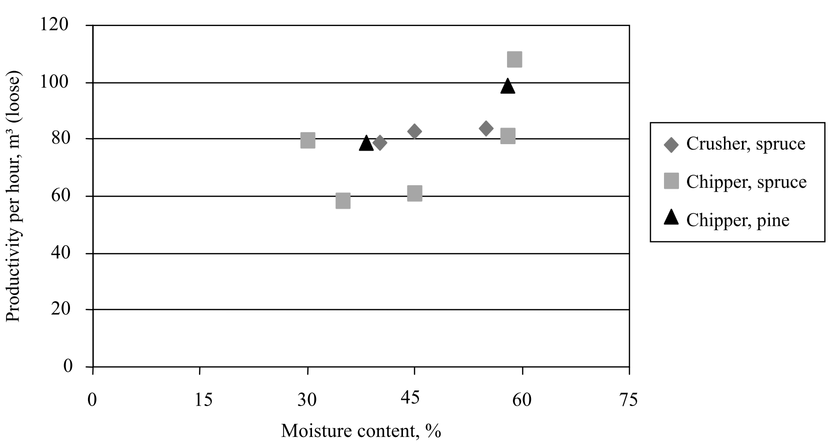

Figure 3. Effect of moisture content on productivity in chipping and crushing.

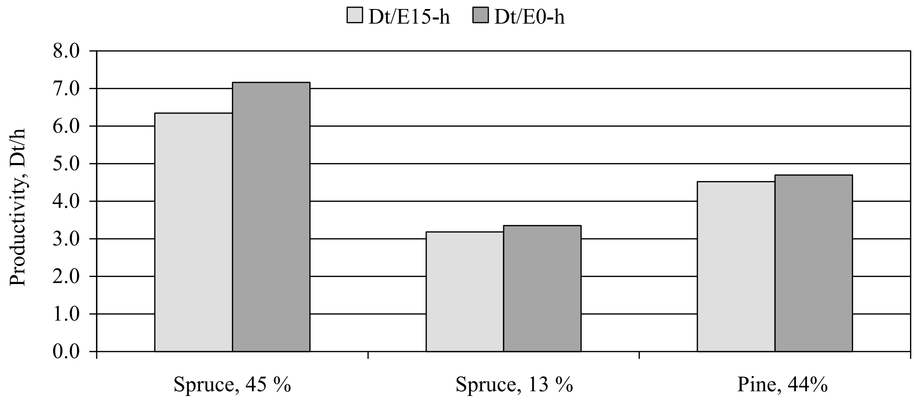

Figure 4. Effect of moisture content on the productivity by Fiberpac baling machine.

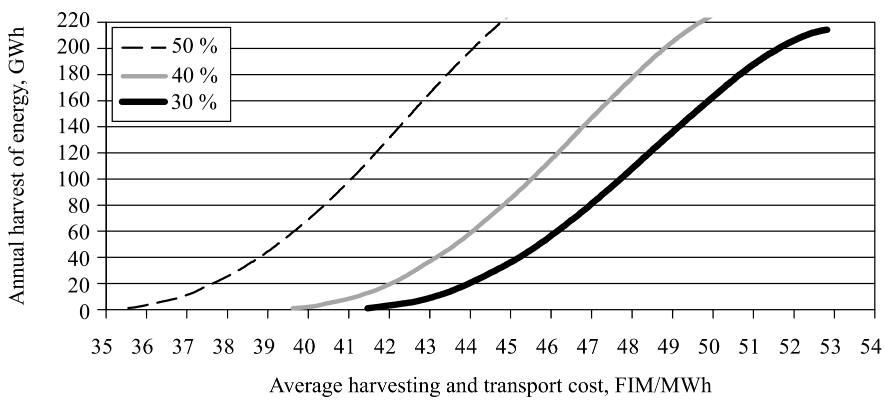

Figure 5. Effect of storage on harvesting and transport costs in a system where chipping is done at the roadside (50% moisture content, fresh residues; 40% moisture content, residues stored at roadside, no material loss; 30% moisture content, residues dried on site before forwarding, all needles fallen).

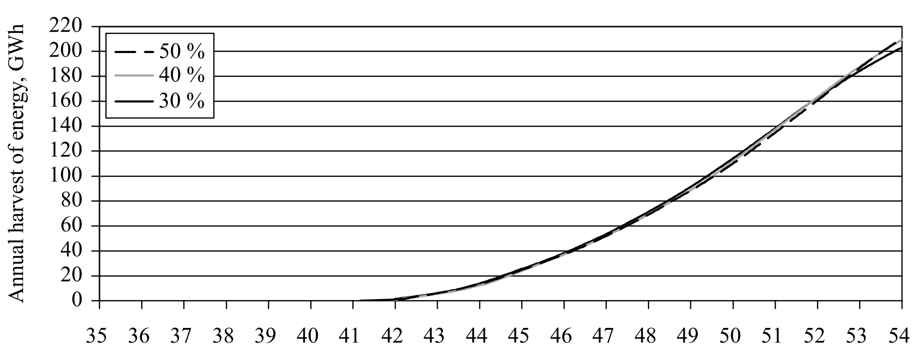

Figure 6. Effect of storage on harvesting and transport costs in a system where loose residues are transported and comminution is done at the power plant (50% moisture content, fresh residues; 40% moisture content, residues stored at roadside, no material loss; 30% moisture content, residues dried on site before forwarding, all needles fallen).

4. Conclusions

The scale of operation has a major impact on procurement costs. Large boiler plants must purchase wood over a wide geographical area. The availability of wood fuels varies depending on the structure and management practice of the forests and the shape of the procurement area. Stands to be harvested should be selected on the basis of cost of the fuel at power plant. If rules of thumb such as ‘only spruce dominated stands are harvested’ are applied, then a considerable part of the resource is left out of harvesting operations.

Storage of material can reduce the moisture content of wood fuel. This increases the calorimetric value of the chips. On the other hand, it often leads to material losses and increased costs in the procurement chain. Of course, if a power plant requires dried raw material, that must be supplied. But it must be kept in mind that supplying seasoned material calls for storage and can lead to material losses and higher fuel cost at the plant.

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Future Primary Forest Fuel Resources in Sweden

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Abstract

Biomass of forest origin contributes considerably to the Swedish energy balance. In 1999 more than 83 TWh (13%) of the energy supply originated from such biomass of which 8 TWh consisted of tops and branches left unutilised in conjunction with industrial timber harvest. Developments of forest biomass potentials for the 21st Century were calculated within a subproject to the project SKA 99 (long term analysis of the potential of forests to produce goods and services). The SKA 99 project addresses: - Future forest resources – Harvesting opportunities – Potential supply of forest fuel – Carbon and nitrogen budgets – Biodiversity. According to the results, the potential of tops and branches will increase substantially during the first 30 years of this century. Compared with current use, the annual potential is four times larger. The gross potential of tops and branches amounts to 67–80 TWh/year, the net potential to 25–37 TWh/year.

Keywords: Forest fuel, biomass, energy, long-term potential, Sweden

The SKA 99 Project

The SKA 99 – in Swedish 'Skogliga konsekvensanalyser 1999', in English 'forest impact analyses' – is a project that describes, in a century-long perspective, the development of the state of the Swedish forests.

The National Board of Forestry set up the SKA 99 project in 1999 in co-operation with the Swedish University of Agricultural Sciences, the Swedish National Energy Administration, the Swedish Environmental Protection Agency and the Swedish National Board for Industrial and Technical Development. The main project, acting as an umbrella, was finished in April 2000 and a main report, a result tables appendix and a compact disc with all results were published. Special reports from the subprojects are currently published.

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The main project serves as a framework for eight different subprojects, taking their interest in feasible and sustainable cutting volumes, the potential supply of forest fuel, the development of the state of the forest environment, the carbon and nitrogen balances of the forests and biodiversity.

The Swedish National Energy Administration is responsible for the Forest Fuel subproject, which may be seen as a development and a continuation of an intermittent series of similar projects carried out by the National Board of Forestry in the 1980s and 1990s.

Scenarios

In the main project eleven different scenarios were designed. Seven of them were based upon the development of the forest management during the 1990s and three of them upon hypotheses on a more intense forest management combined with a greater environmental concern. Finally, in one scenario, based upon the management during the 1990s, a calculated demand for forest fuel was compared with the supply.

National Forest Inventory data were used for input in the models together with premises regarding management practises. Data were provided for 28 districts covering the whole country. Results were calculated for ten ten-year periods.

In order to keep data volume manageable and possible to analyse not all scenarios were calculated for all districts. Only two scenarios cover the whole country. However, results are available for all scenarios in three districts, situated in northern (ACK), middle (WÖ) and southern Sweden (F) respectively (underlined and italics in Figure 1).

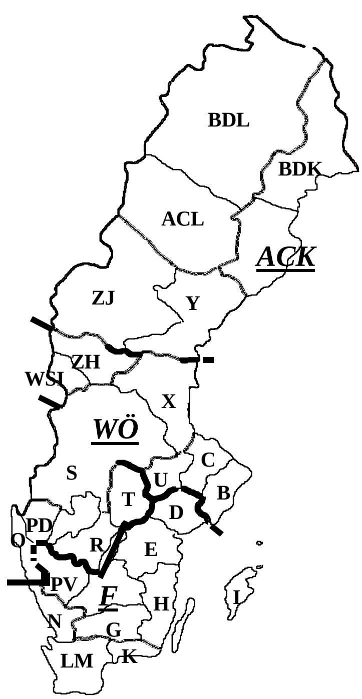

Figure 1. Map of Sweden with 28 calculation districts and four regions.

Forest Fuel Potentials

The aim of the Forest Fuel subproject is to describe the volumes of forest fuel that were available as a consequence of the fellings in the different scenarios. Only one harvest of residues during the rotation period is considered. The gross volumes of forest fuel available are calculated as the tops, branches and needles from final fellings. One reason for not including residues from thinnings and cleanings is that the fuel harvesting is too expensive in these operations and a second is that final fellings provide the largest volumes, considering only one harvest per rotation period.

The net volumes amount to 75% of the gross volume of tops and branches and 25% of the needles. The percentages are based upon consideration of what is practically and economically possible to achieve but they also include elements of arbitrariness.

According to recommendations issued by the National Board of Forestry *forest fuel* should not be harvested more than once during the rotation period of a stand without bringing back the nutrient contents of the ashes. This is also the case for any harvest from areas with acid or peat ground. The recommendations are taken into consideration by the assumption that the ashes are returned to the ground where and when necessary. We have also calculated the volume of ash needed to fulfil the recommendations.

Results

In this paper we present results for the scenarios ‘Forestry of the 1990s’ and ‘More intense forest management with greater environmental concern’. We also show results from the scenario that includes a comparison between supply and demand for forest fuel.

Before the results are presented, there is something to say about the role of forest fuel in the Swedish energy supply system. The primary forest fuel volumes discussed in this paper form a minor, but important, part of the Swedish energy supply system. The total volume of logging residues in the form of tops and branches originating from forest land is estimated to be approximately 8 TWh out of 82 TWh biofuels with forestry origin in 1998. The total energy supply was 622 TWh in 1998. The level of logging activities affects the volumes of most of the different kinds of biofuels based on forest products. In this sense most of the results of the SKA 99 project affect the potential bioenergy supply. However, the Forest Fuel subproject deals with a minor part of that supply.

Gross and net volumes

Figure 2 shows how the gross volumes of primary forest fuel from final fellings are reduced to net volumes in the district ACK. The relation between gross and net volumes are representative for this part of the country. In southern Sweden a little more is left in the net volume, mainly due to the mix of species, with more spruce and less pine in southern Sweden.

Figure 3 shows the calculated gross and net volumes of forest fuel in Sweden during the first five ten-year periods according to the scenario ‘Forestry of the 1990s’. The net volumes, ranging from a little less than 27 TWh per year to over 33 TWh per year, should be compared with the current consumption of 8 TWh per year.

This scenario is based on the silviculture practised during the 1990s and it also reflects the future consequences of the new way of environmental concern that was implemented during that decade.

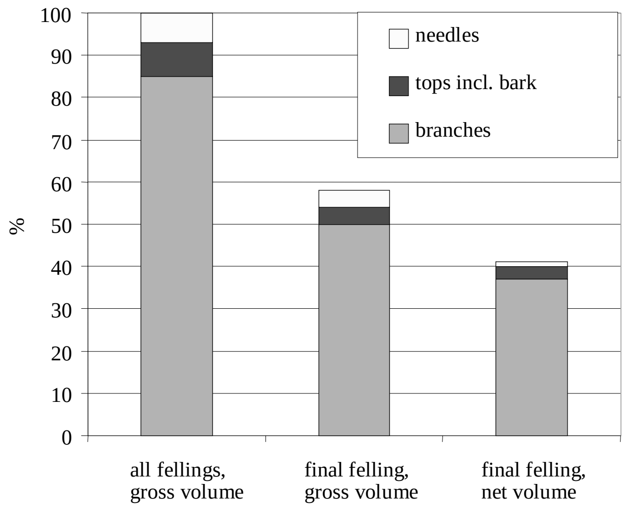

Figure 2. Calculation of gross and net volumes of tops, branches and needles from final fellings. District ACK.

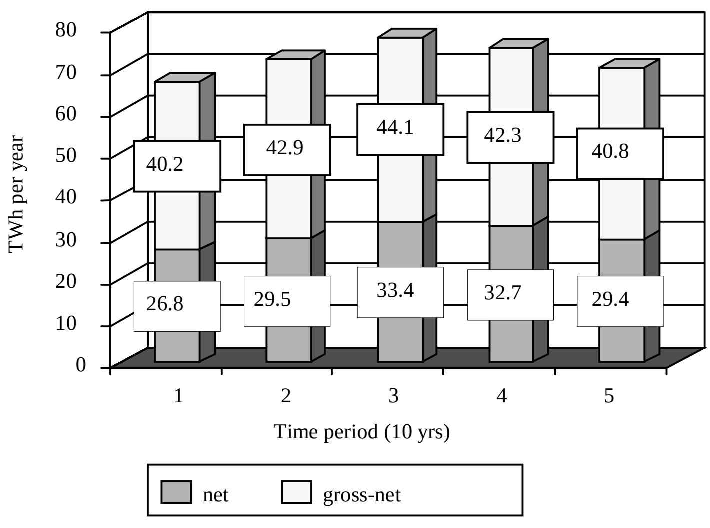

Figure 3. Forestry of the 1990s. Gross and net volumes of tops, branches and needles in period 1–5. All Sweden.

Figure 4 shows the results from the scenario ‘More intense forest management with greater environmental concern’. The results are comparable with the results for the scenario ‘Forestry of the Nineties’. This scenario is based on a silviculture that is characterised by more intense measures regarding production of roundwood and forest fuel compared with the scenario ‘Forestry of the 1990s’. The environmental concern is also more intense in this scenario.

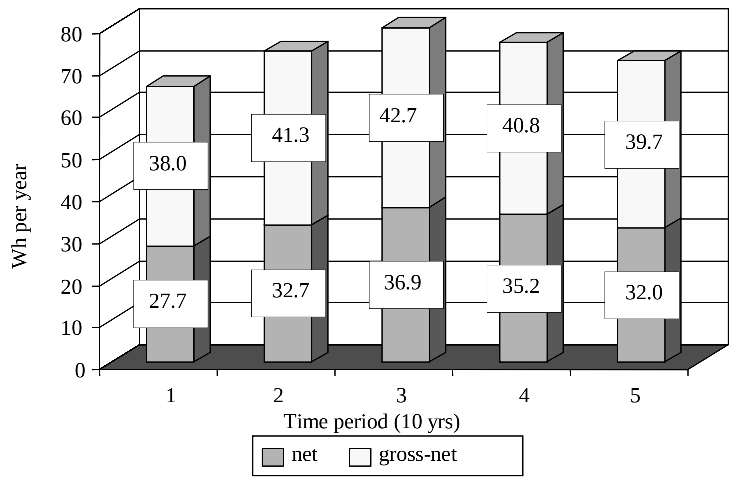

Figure 4. More intense forest management with more environmental concern. Gross and net volumes of tops, branches and needles in period 1–5. All Sweden.

The two scenarios do not differ much in terms of potential forest fuel volumes at the national level, as can be seen in Figure 3 and Figure 4. Neither do the other scenarios, which are evolutions of the two scenarios presented above. In order to expand the views two more scenarios were elaborated. These scenarios are based on ‘Forestry of the 1990s’ and ‘More intense forest management with greater environmental concern’. The two scenarios are supplemented by the assumption that tops thinner than 10 cm diameter are used for fuel. The general condition in all other scenarios is that tops are thinner than 5 cm under bark. Furthermore, some volume was added coming from ‘cleaning-thinning’ (i.e. fellings in stands that should have been cleaned but had been neglected). The results from these two scenarios show that the increment in stemwood adds considerable volumes to the gross and net forest fuel potentials. This kind of expansion of the fuelwood volume may primarily be considered during periods of less demand for industrial roundwood.

Figure 5 shows the gross and net volumes of tops, branches and needles in the second calculation period in the district ACK, one of the districts included in all scenarios.

The 11 different scenarios are listed below.

Sc 1 Forestry of the 1990s (FoN)
Sc 2 FoN with no environmental concern
Sc 3 FoN with doubled environmental concern
Sc 4 FoN with higher regeneration aims
Sc 5 FoN with higher cleaning aims
Sc 6 FoN with half as large game damages
Sc 7 More intense forest management (IFM) with a greater environmental concern
Sc 8 IFM with environmental aims on FoN level
Sc 9 Comparison between Sc 1 and a calculated future demand for forest fuel
Sc 10 FoN with a greater forest fuel harvest
Sc 11 IFM with a greater forest fuel harvest

One of the scenarios (Sc 9) was modelled in order to compare the potential supply of primary forest fuel with demand. Since no forecasts of the future demand for forest fuel were available, calculations were done based on the assumption that demand would increase by 2%

per year during the first 30 years, and by 1% per year during the following 20 years. This calculated demand was compared with the supply according to the scenario 'Forestry of the 1990s'. The result of the comparison is shown in Figure 6.

The results show that a development in line with the hypothetical calculation of demand may very well fit into the potential for primary forest fuel as calculated in the different scenarios.

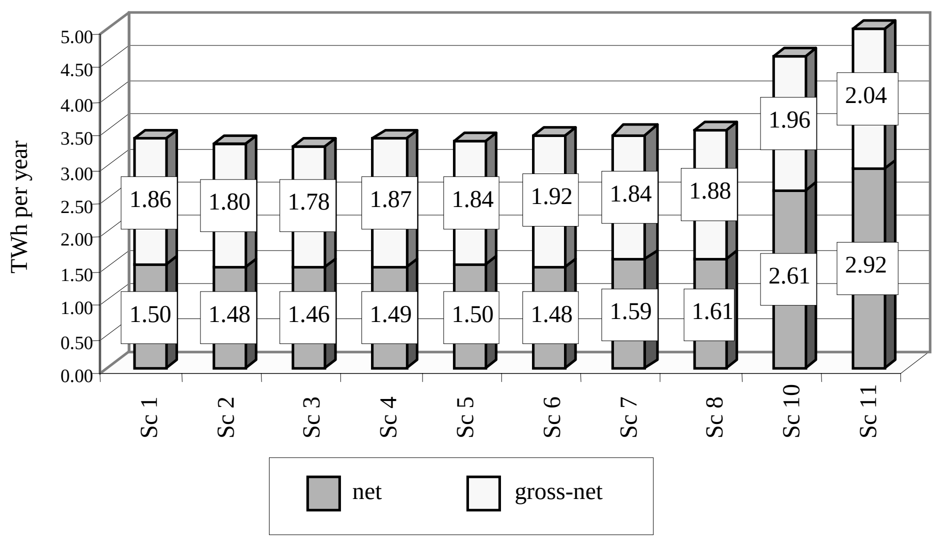

Figure 5. District ACK, all scenarios, period 2, gross and net volumes of tops, branches and needles.

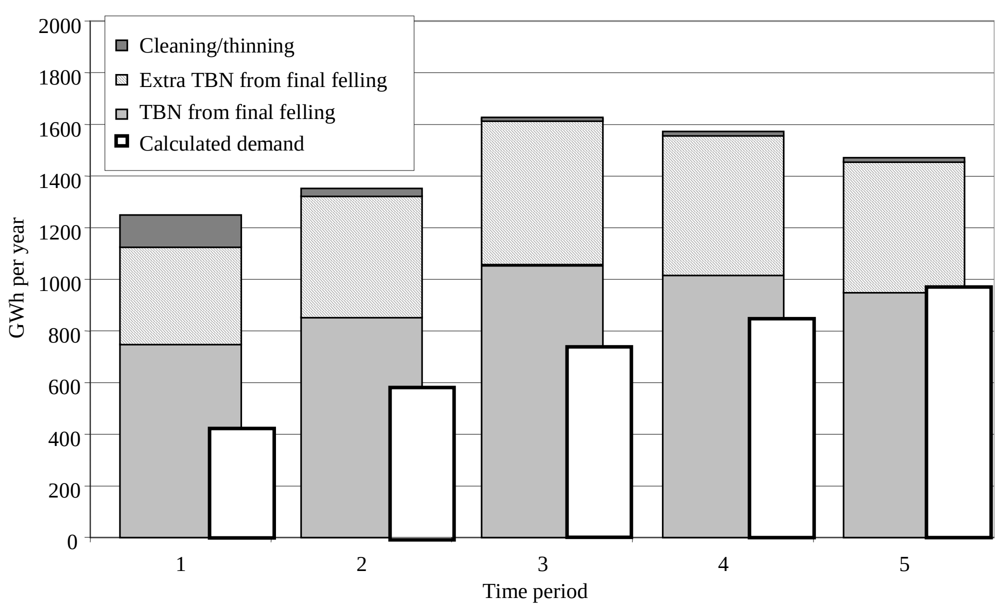

Figure 6. Calculated demand compared with potential supply in Region 3 (districts O, PD, R, S, T), periods 1–5. TBN = tops, branches and needles.

Conclusions

According to the results from the calculations, based on the different scenarios, the potential physical supply of primary forest fuel in Sweden is fully sufficient to meet the domestic demand for that kind of fuel. However, no consideration has been given to the conditions on the fuel market or to price relations of any kind, which may affect the actual use of top, branches and needles for fuel.

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The Effects of Mixtures on Yield and Disease of Willows *(Salix)* Grown as Short-Rotation Coppice

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Abstract

Short-rotation coppice willow is not only seen as the most promising renewable energy crop for Northern Ireland in fulfilment of the Kyoto undertaking, but also a major and much needed diversification opportunity for agriculture. Foliar rust caused by the pathogen *Melampsora epitea* var. *epitea*, is the most limiting factor in the sustainable production of energy from coppice plantations in Northern Ireland, and other parts of Northern Europe. Whilst chemical control of the disease is possible it is neither practically feasible or economically viable, and in a crop being promoted on environmentally sustainable grounds it has negative implications. Consequently alternative strategies were required for its control. This paper outlines the development of the use of inter- and intra-specific mixtures to reduce the impact of *Melampsora* rusts on short-rotation coppice willow plantations. Early trials indicated that the use of mixtures delayed the onset of the disease, reduced its spread and as a result at the end of the season effects on dry matter yield were minimal. In addition all mixtures showed a significant increase in dry matter yield when compared with the mean of their constituents grown in monoculture. Subsequent trials have confirmed these results and further have shown that significant yield compensation is possible within random mixtures to account for components that have ceased to contribute to dry matter yield because of disease or through other physiological reasons.

Keywords: willow, Salix, coppice, biomass plantations, fungal diseases, rust, Melampsora epitea var. epitea, disease resistance, varietal mixtures

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Introduction

Short-rotation coppice willow was first investigated in Northern Ireland in 1975 as a novel source of cellulose for paper manufacture. However, following the oil crises of the mid- to late-1970s the emphasis of the work turned to its use as an energy crop (McElroy and Dawson 1986). Although in real terms energy prices have remained fairly static the interest in short-rotation willow coppice as an energy crop has been maintained because of its ability to address other important environmental and social issues.

Under the Kyoto Protocol the UK has a commitment to reduce carbon dioxide emissions by 12.5% (Anon. 1999) by 2010 based on 1990 levels. In addition, the UK government has adopted a much more challenging target of 20% reduction in the same time frame. The EU has also a published target of 10% of total energy usage to be sourced from renewable energy. These constitute huge commitments and will require action on a range of different fronts including energy conservation and efficiency measures, transport policies and the development and deployment of renewable energy sources. With particular reference to these renewable sources, a recent review of the technologies involved (Anon 1999) identified wind and energy crops, in particular short-rotation coppice willow, as having the greatest potential in the context of Northern Ireland.

These environmental issues are of strategic importance on a global scale. However, on a local scale there are other important issues, which the production of energy from short-rotation coppice willow addresses. In general, agriculture in Northern Ireland is grass based with 85% of agricultural land being devoted to beef, milk and sheep enterprises. This generates 70% of total agricultural production. Farm incomes have been in sharp decline across the UK since their peak in 1995. This is particularly so in Northern Ireland with its heavy dependence on an exporting beef industry. In the period 1995–1997 total farm income representing returns to the farmer dropped by 35% from a total of £305 million to £190 million. There were further declines of 52% and 22% in 1998 and 1999, respectively. This reduced total farm income to £71 million, which was the lowest level since 1980, and represented a total decline since 1995 of almost 80% (Anon. 2000). In these circumstances the opportunity offered by short-rotation coppice willow as an energy crop and as a sustainable alternative agricultural system is significant. Furthermore, it is a realistic alternative given the restrictions posed by the mild, wet, oceanic type climate and heavy soils encountered in Northern Ireland.

Willow Rust

Melampsora epitea var. *epitea* is a complex of heteroecious rusts, the most common group of which alternate on Larch (*Larix* sp.) to complete the sexual part of their cycle. The sexual cycle offers the opportunity for genetic recombination and as a result many pathotypes exist and more will continue to be identified in response to selection pressures exerted by long-term ‘clonal’ willow plantations (Pei et al.1996).

Melampsora epitea var. *epitea* was first identified in Northern Ireland on a small commercial block of *Salix burjatica* Korso (Dawson and McCracken 1994) and simultaneously at other sites across the UK in 1986 (Hunter et al. 1989). The variety had previously been grown for more than ten years in Northern Ireland with no adverse effects. However, so serious were levels of infection in 1986 and subsequent years leading to early defoliation, dieback and stool death, that this variety can no longer be considered a commercial candidate. Early fungicide trials had indicated that the disease could be controlled with fungicides. However, it was not considered a commercial possibility because of cost, environmental considerations and the practical limitations of effective application of chemicals in such a dense crop stand (Royle and Ostry 1995).

Mixture Trials

Consequently the use of mixtures was investigated as a strategy in the sustainable control of *Melampsora* spp. rust in short-rotation coppice willow plantations. The initial trials were established in 1987 and consisted of a limited number of varieties grown in structured intimate mixtures. The varieties used in these early trials were *S. burjatica* 'Germany', *S. viminalis* '683', *S. viminalis* Bowles hybrid, *Salix* x *dasyclados*. Over a number of three-year rotations, these mixtures behaved in a consistent way, reducing the impact of rust by delaying its onset and reducing its build up throughout the season. (McCracken and Dawson 1998). In addition, yield benefits in the mixture plots were recorded with all mixtures giving a significant increase in dry matter yield compared with the mean yield from its constituent varieties (Figure 1).

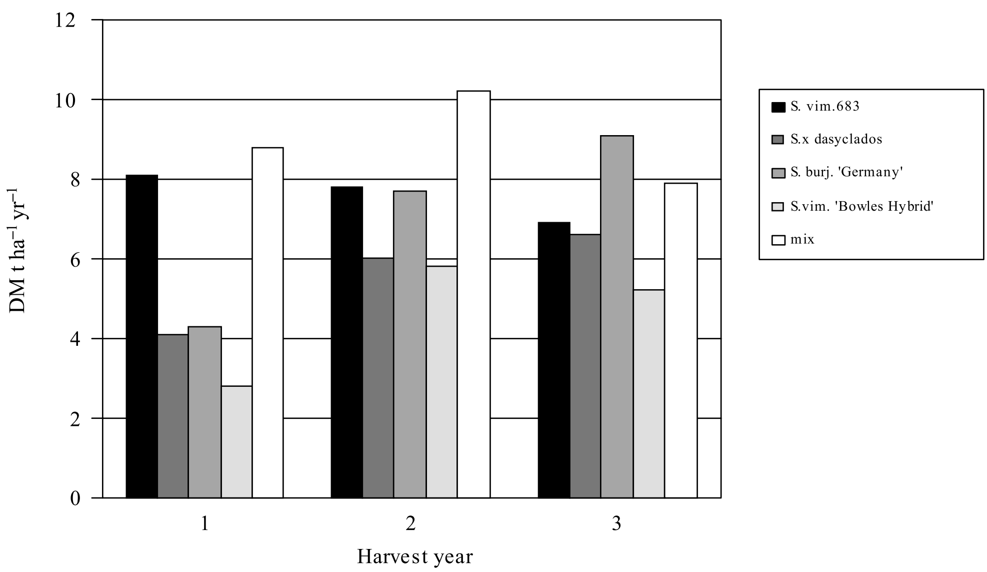

Figure 1. Dry matter yields (t DM $ha^{-1}yr^{-1}$) from monovarietal and mixture stands of short-rotation coppice willow (1994).

These early trials, whilst showing the advantages that mixtures had in the non-chemical control of disease, had a number of limitations. They largely used older, non-improved varietal material. The numbers used in the mixtures were small (a maximum of six) and the effect of planting density was not addressed. Consequently in 1997 a new mixture trial was initiated to further evaluate mixtures in the context of numbers of varieties and planting density.

New Mixture Trials

The establishment of these trials began in 1994 at Castlearchdale, County Fermanagh, Northern Ireland, in plots adjacent to the original trials. Twenty *Salix* varieties and hybrids were included in 5-, 10-, 15- and 20-way mixtures as indicated in Table 1, and also planted as single varieties plots (minimum size 32 m x 11 m). Three planting densities 10 000, 15 000 and 20 000 were included as split plots in the experimental design. Block 1 was established in 1994, and block 2 in 1995. Block 1 was cut back at the end of the 1994 and 1995 growing seasons, and block 2 at the end of the 1995 growing season.

These varieties were chosen for inclusion from a varietal selection trial that had been planted in 1990. The basis of their selection was, productivity, resistance to rust and as far as was practicable genetic diversity. The varieties selected for the 5-way mixture had all shown some level of susceptibility to rust: *S. dasyclados* x *aquatica* ‘V7511’, *S. dasyclados* x *caprea* ‘V794’ and *S. burjatica* ‘Germany’, on a regular basis and at moderate levels; *S. mollissima-undulata* ‘SQ83’ with variable levels; and *S. viminalis* ‘77082’ showing only low levels of rust. These five were then subsequently ‘diluted’ by incorporation into 10-, 15- and 20-way mixtures with varieties which showed no or low levels of susceptibility to rust.

Table 1. *Salix* varieties and hybrids included in the mixture trials.

Variety Number	Included in 5-, 10-, 15-, 20-waymixtures	Variety Number	Included in 15-, 20-way mixtures
3	*S. burjatica* ‘Germany’	12	*S. viminalis x caprea* ‘V789’
4	*S. mollissima-undulata* ‘SQ83’	18	*S. viminalis* ‘77683’
13	*S. dasyclados x aquatica* ‘V7511’	21	*S. viminalis* ‘78101’
17	*S. viminalis* ‘77082’	29	*S. viminalis* ‘78195’
26	*S. dasyclados x caprea* ‘V794’	34	*S. schwerinii x aquatica* ‘V7534’
	Included in 10-, 15-, 20-way mixtures		Included in 20-way mixture
14	*S. viminalis x aquatica* ‘V7503’	1	*S. viminalis* ‘77699’
23	*S. viminalis* ‘78118’	6	*S. viminalis* ‘Gigantea’
28	*S. viminalis* ‘78183’	9	*S. viminalis* ‘Gustav’
32	*S. schwerinii x viminalis x dasyclados ‘V7531’*	45	*S. schwerinii x aquatica* ‘V7533’
48	*S. viminalis* ‘870146 ULV’	46	*S. viminalis* ‘870082 ORM’

Recording of disease began in spring/summer 1996 when the two blocks were at the same development stage, i.e. regrowth from a freshly coppiced stool. Leaf samples were taken at two-week intervals from all varieties both as mono-varietal plots and as individual varieties from the various mixtures. From the 100 leaf samples, the degree of rust infection was estimated using percentage of leaves with rust and percentage of rust cover per leaf. These rust indices were combined and a cumulative rust score calculated by adding the current score to the previous total. This gave a measure of infection throughout the season and took into account leaves which, for whatever reason, had fallen between recording dates If this approach had not been taken, disease levels would have been underestimated, or, particularly near the end of the growing season, would have apparently fallen (McCracken and Dawson 1992). These records have been maintained for five years on the varying ages of coppice growth and yield data was obtained in the winter of 1998 when both blocks were harvested as three-year-old crops.

Mixtures and Disease

The response of individual varieties to their inclusion in mixtures was generally dependent on their inherent susceptibility to rust. The twenty varieties in the trial divided themselves into three categories on this basis.

Firstly, those varieties which at the outset were known to have moderate to severe susceptibility to rust (e.g. *S. burjatica* 'Germany', *S. dasyclados* x *aquatica* 'V7511' and *S. dasyclados* x *caprea* 'V794') showed a reduction in rust levels and disease impact when included in mixtures (Figure 2). However, the levels of reduction in disease impact were not sufficient to ensure that these varieties made any significant contribution to mixture yields. In addition the 'dilution' effect of increasing numbers in the mixtures, did not have any measurable effect on disease expression. In mono-varietal plots these varieties have effectively died out.

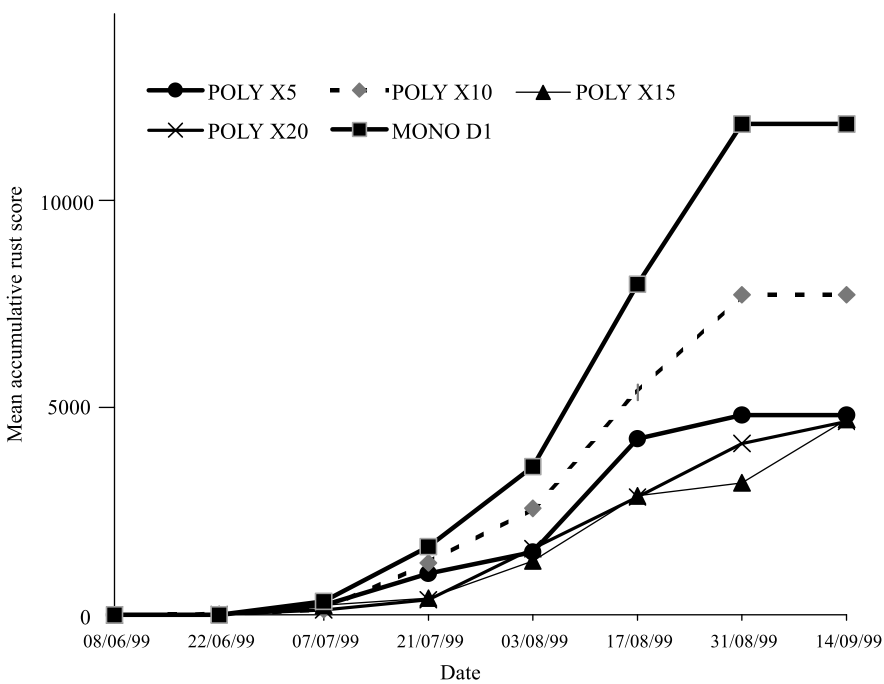

Figure 2. Disease progress in susceptible varieties grown in mixtures and mono-varietal plots, e.g. *S. dasyclados x aquatica 'V7511'*.

Where varieties had shown generally low levels of rust susceptibility, disease development was either slowed down in comparison with that in mono-varietal plots (e.g. *S. viminalis* 'Gustav'), or as was the case more frequently no significant differences were recorded between disease progress in mixtures or monoculture.

With the third group of varieties, the *S. schwerinii* hybrids, which had low susceptibility to rust, their inclusion in mixtures provided no disease advantage at this stage.

Mixtures and Yield

These trials have confirmed the findings of the original trials. In all cases the dry matter yield from mixtures was greater than the mean yields from their constituent varieties grown in monoculture (Figure 3). The 5-way mixture produced a significantly lower yield than the 10-, 15- and 20-way mixtures.

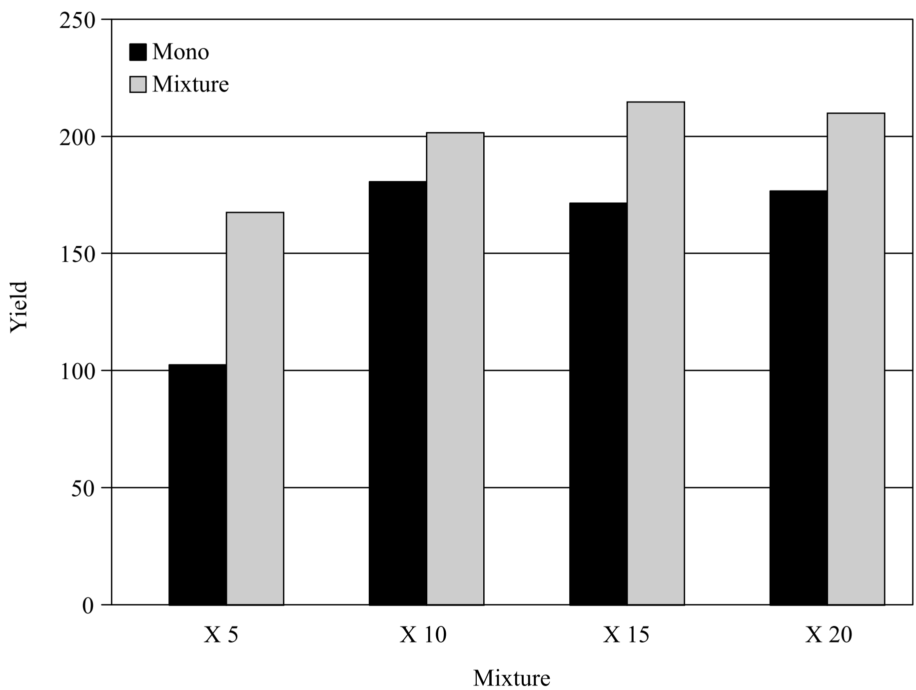

Figure 3. Mean dry matter yields from 5-, 10-, 15- and 20-way mixtures of Salix varieties compared with the mean yields of their constituent varieties grown in monoculture.

In the 5-way mixtures the highly rust susceptible varieties *S. burjatica* 'Germany', *S. dasyclados x aquatica* 'V7511' and *S. dasyclados x caprea* 'V794' which made no significant contribution to dry matter yields represented 60% of the total mixture. In these circumstances the remaining 40% of the mixture, were unable fully to compensate for the loss of the three susceptible varieties. However, yields from the 10-, 15- and 20-way mixtures, were significantly higher than the 5-way mixture. Additionally no significant differences were recorded between yields in the 10-, 15- and 20-way mixtures indicating that these mixtures can fully compensate yield for up to a 30% loss in their constituent varieties.

The performance of individual varieties in mixtures varied. In some instances the contribution to overall yield was positive (e.g. *S. schwerinii x aquatica* 'V7534' and *S. viminalis* 'ULV'). In others it was negative (e.g. *S. viminalis x caprea* 'V789') (Figure 4).

In some varieties (e.g. *S. viminalis* '77082') yield varied according to the numbers of varieties within a mixture. *S. viminalis* '77082' showed a highly positive contribution to the 5- and 10-way mixtures. However, in the 15- and 20-way mixtures, its contribution was not significantly different from the expected (Figure 4).

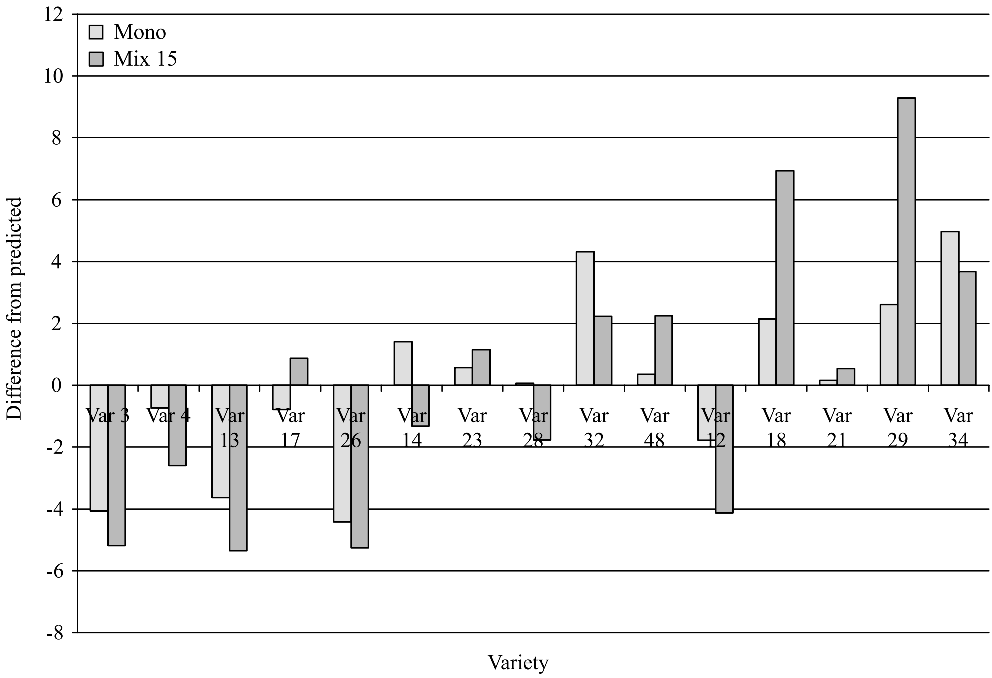

Figure 4. Percentage difference from expected DM yield in fifteen Salix varieties grown in random mixture. The expected yield is calculated on an equivalent area basis and represents the yield from individual varieties grown as monocultures.

Discussion and Conclusions

It is clear that the reaction of a variety to inclusion in a mixture is dependent on its susceptibility to disease (in this case *Melampsora* spp. rust) and to its ability to compete with the other constituents of the mixture. Where a variety has a known moderate to severe susceptibility to rust its inclusion in a mixture will improve its performance with respect to disease impact and productivity. However, the improvement is unlikely to be of practical importance. Where varieties had low levels of susceptibility inclusion in mixtures had at best positive effects on disease development and subsequent yield, but generally no significant differences were recorded. Similarly where varieties were effectively resistant, there was no obvious advantage in their inclusion in the mixtures. However, from the point of view of increased diversity reducing the potential disease pressures, and improving the sustainability of a plantation, their inclusion would be justified.

With the numbers of species/varieties included, the yield from 10-, 15- and 20-way mixtures was not significantly different. However, yield from the 5-way mixture was significantly lower because of the inability of the remaining varieties fully to compensate for the loss of contribution to dry matter by the three highly rust susceptible varieties. In these circumstances it could be argued that ten varieties in a mixture would reduce the effects of up to 30% of the mixture becoming susceptible to the disease. All of the mixtures in the trial were planted as fully random mixtures. It is argued that other mixture configurations such as line mixtures or mosaics would not give the same opportunity for this compensatory effect on yield. With the commercial planting machinery available fully random mixtures are not a practical alternative. Here ‘short-run’ random mixtures are the best compromise. In these mixtures a short-run of an individual variety, corresponding to the number of cuttings produced by the mechanical planter from a full one-year-old rod, is followed at random by another variety.

In addition it is imperative that the enhanced performance in terms of productivity and disease susceptibility of the new material becoming available from dedicated breeding programmes is maintained and the use of mixtures in commercial plantations would facilitate this.

In summary, it is recommended when planting commercial areas of willow coppice, that: (i) intra-species, and/or inter-species mixtures should always be used; (ii) these mixtures should be as diverse as possible to reduce the selection pressure on the pathogen; (iii) mixtures should contain as many components as possible to maximise the opportunity for yield compensation; and (iv) varieties that have shown rust susceptibility, or that have become rust susceptible at other locations, should not be included. If these recommendations are implemented the sustainability of short-rotation willow coppice plantations will be improved and selection pressure on the pathogen reduced ensuring the useful life of new rust tolerant varieties will be maximised.

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CO_2 Mitigation Cost: A System Perspective on the Heating of Detached Houses with Bioenergy or Fossil Fuels

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Abstract

The CO_2 mitigation cost of whole energy systems, from natural resource to end-user, have been analysed in a Swedish context, when heating detached houses with bioenergy or fossil fuels. Both electricity-based systems employing heat pumps, boilers, or resistance heaters, and local fuel-based systems were considered. The base-load electricity was produced in condensing plants using wood chips or natural gas, while peak-load electricity and fuel used for transportation were produced from crude oil. The heat pump systems and the local boiler systems, excluding the pellet boiler system, exhibited the lowest heating cost. The heating cost of electricity-based systems other than heat pump systems was higher due to a lower end-use efficiency. The difference in heating cost between the same type of fossil fuel- and biomass-based systems was less than 12%. All Swedish energy taxes and environmental fees were excluded in these cost calculations. The biomass-based systems emitted about one-tenth of the CO_2 emitted by the fossil-fuel systems. The removal of CO_2 from the flue gases from large natural-gas-fired condensing plants could reduce the CO_2 emission by about 70% and this will increase the heating cost. However, regarding heat pumps, this increase is small due to the high end-use efficiency. The CO_2 mitigation cost of replacing an oil boiler or a natural gas boiler system by a wood boiler-, pellet boiler- or heat pump system ranges from US$–130 to 640/tonne carbon avoided. The mitigation cost is sensitive to changes in fuel prices.

Keywords: carbon dioxide mitigation cost, energy system, detached houses, heating

1. Introduction

In this study, we have analysed the CO_2 mitigation cost of fuel-based energy supply systems employed to heat detached houses. The fuels considered are wood, logging residues, short-rotation forest (*Salix*), natural gas and oil. The houses analysed are assumed to have an annual heat demand of 20 MWh with an 8 kW peak demand. The end-use conversion technologies compared are an electric boiler, an electric horizontal ground or water source heat pump, electric resistance heaters, a natural gas boiler, an oil boiler, a pellet boiler and a wood boiler. The heat sources available limit the general application of the type of heat pump considered here. The level of technology is chosen to match the best available today.

The emission of CO_2 and the cost of the various heating systems are calculated when the same amount of heat is delivered to a detached house. Then, the CO_2 mitigation cost is calculated as the cost difference between the systems compared, divided by the difference in CO_2 emission.

The whole energy system from the natural resources to the required energy services, including the extraction, transportation and refining of fuels, is considered in the calculations. The net flow of CO_2 from bioenergy systems will depend on fossil fuel input and on how wood fuel harvesting influences the biological carbon stock. Hence, changes in biological carbon stocks, as well as the CO_2 emission from fossil fuels, are considered for biomass-based systems.

Nearly 50% of Swedish electricity was produced in large-scale condensing plants in 1997. The corresponding figures for Scandinavia and the European Union were 28% and 76%, respectively (IEA 1999). The ratio of future electricity demand to other energy carriers is expected to increase (WEC and IIASA 1995). Thus, part of the electricity base-load production will probably also be based on condensing plants in the future, e.g. in countries around the Baltic Sea. We assume that the base-load electricity used in the electric heating system is produced in large wood-chips- or natural-gas-fired condensing plants.

The technology used for biomass-based power production is biomass integrated gasifier/combined cycle (BIG/CC) and steam turbine technology. BIG/CC is still under development (Ståhl and Neergaard 1998) and has been included in this study to demonstrate the potential of the technology should it be commercialised. Fossil-fuel-based power production is based on combined cycle technology using natural gas as the use of this technology is expected to increase due to its high conversion efficiency and relatively low cost (WEC and IIASA 1995). The peak-load electricity is assumed to be produced by oil-fired gas turbines.

Decarbonization of flue gases is included in the analysis for natural-gas-fired condensing plants. The collection of CO_2 and its disposal, for example, in exhaust gas or oil wells, is being actively investigated in a number of countries. This could provide an important means of reducing CO_2 in the longer term in large-scale, fuel-fired plants (IPCC 1996; Herzog et al. 2000).

Gustavsson and Karlsson (1999) have shown that district heating with cogeneration is often more resource-efficient with lower emission than other heating systems. Here, we assumed that the geographical distribution of urban areas gives a low heat demand per unit urban area, and hence district heating is assumed not to be a suitable heating alternative.

Electricity-based heating systems have inherent benefits, as the plants can be located outside built-up areas, thereby reducing the local air pollution in densely populated areas, compared with local heating systems. This factor is, however, not considered in this study.

2. Method

It is important to select and define a reference entity for comparisons between energy systems (Schlamadinger et al. 1997). Here, we have defined the reference entity as one unit of heat (1 MWh) consumed in a detached house. This reference is used in all systems compared.

In comparative studies it is also important to select and utilise the same system boundaries (ISO 1997; Schlamadinger et al. 1997). The analyses performed include the entire energy system, from the natural resource to the delivered reference entity, but not end-use efficiency measures, such as improved thermal insulation of the buildings. Neither is the energy contained in the materials and incorporated into the construction of the facilities (e.g. in plant buildings, wires for the electric supply network and the production of trucks) included. The energy embodied in conversion plants is very small compared with the energy content of the fuels used during its lifetime: 1‰ to 1%, according to Brännström-Norberg et al. (1996). The input energy for, and emission from, biomass ash recirculation is not considered, but is expected to be very low.

The heating systems are assumed to supply existing buildings. The cost of internal heat distribution systems in the buildings was therefore excluded in the analyses. Thus, for heating systems based on boilers or heat pumps, the cost of piping and radiators for internal heat distribution has been excluded. For electric resistance heaters, the cost of internal electric wires was excluded. For local fuel-based heating systems, the chimney is assumed to be part of the existing building. Thus, the cost of constructing a chimney was not included. The cost of upgrading an old chimney was calculated for the pellet boiler system to be less than 5% of the total heat cost, assuming that the cost of upgrading the chimney was US$1300.

The CO_2 mitigation cost, M_{cost}, is defined as

$$M_{cost} = \frac{C_x - C_r}{E_r - E_x} \qquad \text{where } E_r - E_x > 0$$

and where C is the heating cost and E is the CO_2 emission resulting from the production of 1 MWh heat in a system. The indices r and x represent the reference system and the system that is the object of comparison, respectively. Hence, the CO_2 mitigation cost of a system x is the increase in cost per unit decrease in CO_2, compared with the reference system. Evidently, switching to a system with higher emission than the reference system is irrelevant when considering CO_2 mitigation.

Investment costs were annualised, using a 6% real discount rate. All costs and prices refer to 1998 when the average exchange rate was US$1 = SEK7.95 (National Bank of Sweden 1999). Domestic Swedish energy taxes, environmental fees and subsidies have been excluded from the analyses. All fuel costs used in the analyses are assumed to include all upstream costs associated with production of the fuel.

Biological carbon stocks may change when wood fuel is harvested. Recovery and combustion of logging residues may lead to a net increase in CO_2 emission compared with the natural decay of the biological material. Based on a study by Zetterberg and Hansén (1998), Börjesson (1999) estimated that the recovery and combustion of logging residues would change the biological carbon stock, increasing the CO_2 emission by about 8 kg C/MWh, compared with natural decay. The indirect effects on the carbon content in the soil not considered by Börjesson may result in smaller changes in the carbon stock. The net changes in biological carbon stocks due to logging residue recovery are, however, mostly reversible in the long-term perspective. As recovery ceases, the accumulation rate of humus returns to its former value, and the decomposition of the remaining residues in the forest will occur naturally.

Compared with the recovery and burning of logging residues instead of natural decay, the changes in carbon stock are different when perennial energy crops replace annual food crops. When *Salix* replaces an annual food crop, an annual carbon accumulation in mineral soils of 0.5 tonne C/ha over a period of about 50 years has been estimated by Börjesson (1997).

In this study, the CO_2 emission has been calculated for the energy systems analysed when the biological systems generate a net increase and a net decrease in CO_2 emission equal to

10 kg C/MWh. This variation probably represents a limit for the change in biological carbon stock when logging residues are recovered and when *Salix* is cultivated on mineral soils instead of annual food crops. These changes, however, will not continue permanently. Results are also shown without any net CO_2 emission, assuming that the CO_2 released in the combustion of biomass is completely balanced by the CO_2 removed from the atmosphere during biomass growth.

3. Energy Systems Analysed

Two types of energy systems, based on various heat production technologies, have been analysed:

- *Local heating systems,* where the fuel is burned locally and the systems are based on boilers utilising split wood, pellets, oil or natural gas, which cover the total heat demand (Figures 1–4). Electricity production in the wood boiler and pellet boiler systems is based on wood chips, whereas in the oil boiler and natural gas boiler systems it is based on natural gas.
- *Electric heating systems* with boilers, resistance heaters or heat pumps. A wood-chips- or natural-gas-fired condensing plant using combined-cycle or steam-turbine technology produces 95% of the electricity used, while the remaining 5% is produced with a light-oil-fired gas-turbine (Figures 5–6).

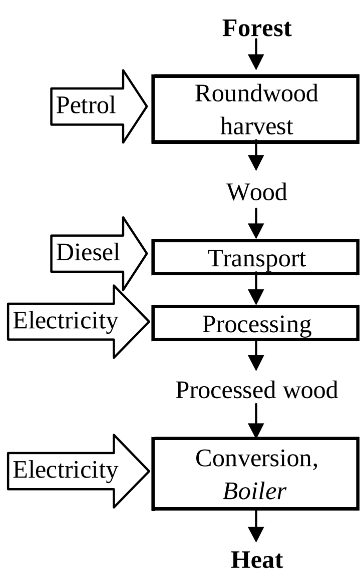

Figure 1. The wood boiler system.

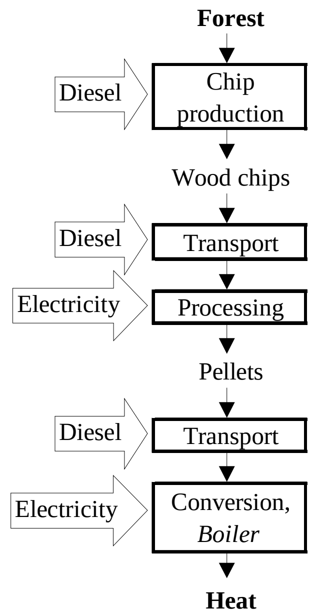

Figure 2. The pellet boiler system. Harvesting and recovery are included in chip production.

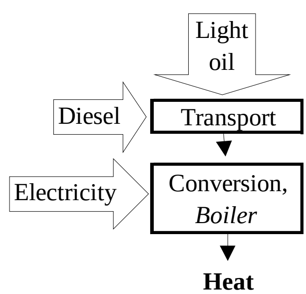

Figure 3. The oil boiler system.

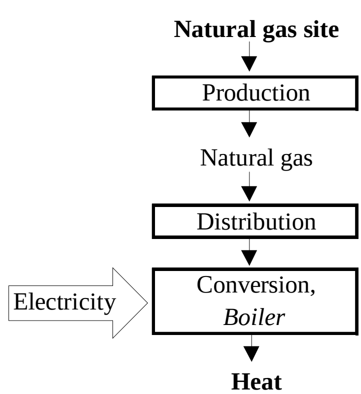

Figure 4. The natural gas boiler system.

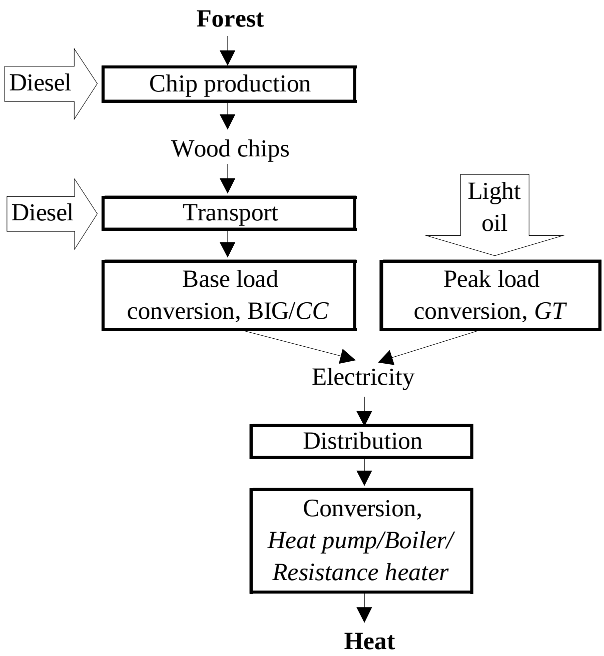

Figure 5. The electric heating system based on biomass. Harvesting and recovery are included in chip production. Figure 6. The electric heating system based on natural gas. GT = gas turbine technology, CC = combined cycle technology.

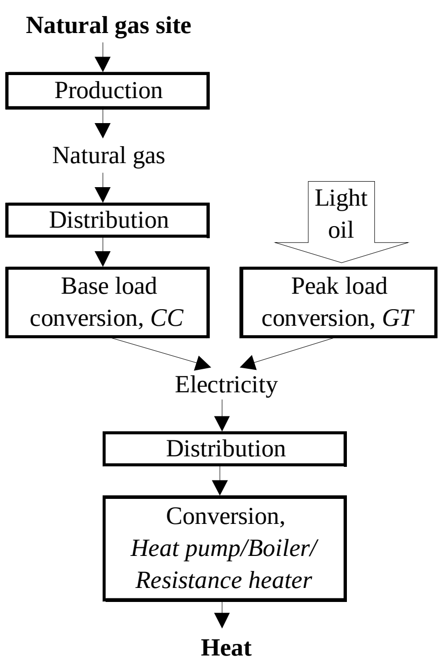

Figure 6. The electric heating system based on natural gas. GT = gas turbine technology, CC = combined cycle technology.

In the systems using water as an internal heat carrier, i.e. all systems except for the resistance heater systems, a circulation pump is included. This pump is assumed to use 8 kWh electricity per distributed MWh of heat [23]. Electricity production is illustrated in Figures 7–8 and the production of diesel, petrol and light oil in Figure 9.

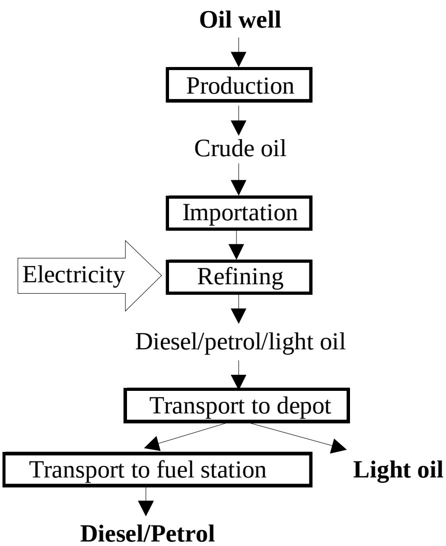

Figure 7. The production and transportation of petrol, diesel oil and light fuel oil.

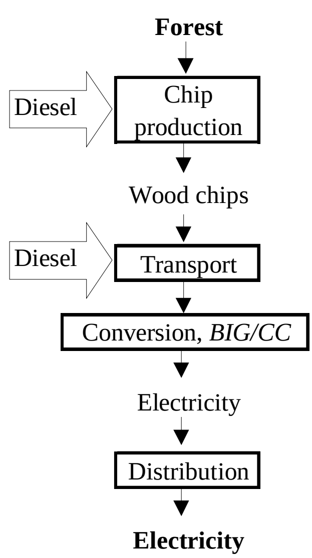

Figure 8. The biomass-based production of electricity. Harvesting and recovery are included in chips production.

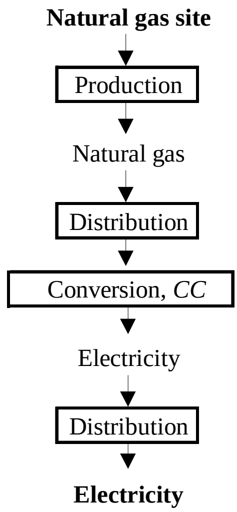

Figure 9. The fossil-fuel-based production of electricity.

The total cost of producing 1 MWh heat in the local heating systems was calculated by estimating the investment, operating and maintenance costs of the end-use conversion, as well as the end-use conversion fuel cost. The corresponding total cost of the electric heating systems was calculated by estimating the cost of producing electricity in the power plants, of distributing the electricity and of the end-use conversion. The cost of electricity production includes investment, operating and maintenance costs, as well as the fuel cost. The cost and loss arising during the distribution of electricity are assumed to be US$27/MWh and 7%, respectively. Both high- and low-voltage transmission is assumed to be required, except for the distribution of electricity to the pellet plant. Here the loss is assumed to be 2%, as only high-voltage is assumed to be required (Statistics Sweden 1997; Gustavsson et al. 1995). The electricity distribution cost has been included in the cost of the pellets and was not calculated separately. The cost of reserve capacity and other costs, such as administration costs associated with the electricity system excluding production, are assumed to be included in the distribution cost.

The removal of CO_2 from the flue gases of fossil-fuel burning and its disposal are assumed to be possible in large condensing plants only, due to the economy of scale. The cost of decarbonization, based on data for a natural-gas-fired, combined-cycle plant of 300 MW_e, has been estimated to be US$260/tonne C avoided (i.e. the cost of electricity production increases by about 50%), reducing the CO_2 emission by about 80% and decreasing the conversion efficiency from 52% to 45% (IPCC 1996). The cost of CO_2 storage onshore in natural gas fields has been estimated to be less than US$11/tonne C (Hendriks 1994). The cost of underground storage depends on local circumstances and may vary from about US$7 to 30/tonne C (Hendriks 1994). We assumed that end-use CO_2 emission could be reduced to 20 kg C/MWh_e in natural-gas-fired condensing plants and that the increased cost of producing this electricity was US$20/$MWh_e$, based on the fuel costs and discount rate assumed here. This results in a total cost of US$220/tonne C avoided. A variation of the fuel cost by ± 25% will change the decarbonization cost by ± 15%.

The production and transportation of petrol, diesel and light fuel oil forms a sub-chain, as is the production of electricity in systems using electricity as energy input (Figures 7–9). These sub-chains have been included in the analyses. As electricity is required for diesel production and diesel is required for electricity production in the biomass-based systems, the diesel production forms a never-ending loop. The secondary sub-chain of this system represents less than 1% of the total energy flow in the system. Therefore, the third sub-chain is neglected as it represents about 1‰ of the total energy flow.

3.1 Production and transportation of fuels

The energy use in and CO_2 emission from the production and transportation of fuels are shown in Tables 1–3. The wood chips are produced from logging residues or *Salix* where motor fuels and energy used to produce fertilisers are the main energy inputs (Börjesson 1996). Diesel fuel is, for example, required for the recovery of logging residues, the cultivation of *Salix* and the transportation of fuels. The logging residues and *Salix* are chipped on site. Here it is assumed that the water content of the chips is 50% during transportation.

Wood chips were assumed to be transported 100 km by diesel truck to the condensing and cogeneration plants and 50 km to the pellet plants. The longer transportation distance of wood chips to condensing plants is assumed not to result in a higher total cost as the larger volume involved in supplying condensing plants is assumed to provide reductions in costs that balance the greater transportation cost. The transport distances of pellets from pellet plants and of split wood to end-use consumers are assumed to be 100 km and 20 km, respectively.

It has been assumed that the split wood is harvested using a chainsaw, which uses petrol as fuel, transported in a diesel truck, processed in an electric cleaving machine and an electric cutting machine, and left to dry. It was also assumed that the wood has a water content of about 50% when transported, which decreases to about 25% after storage.

Petrol, diesel and light fuel oil are produced from crude oil (Figure 7). The extraction of crude oil is assumed to originate from offshore production in Norway from where the oil is shipped by diesel tankers to Sweden, refined, and then transported by coastal tankers to depots. In each of these stages, energy is utilised. The production of diesel and light oil is assumed to lead to equal amounts of energy loss and emission. The transportation distances of diesel and petrol from depots to service stations and residential consumers are not well known. In a study made by Blinge et al. (1997), the distance of transporting petrol and diesel to service stations was assumed to be 85 km on average. We assume that petrol, diesel and light oil are transported 85 km to the service stations and to customers. The light-oil-fired, stand-alone power units are assumed to be located near a depot, therefore the transportation of fuel between the depot and this type of power units is neglected.

The average cost of forest fuels today in Sweden is approximately US$14/MWh (US$3.8/GJ) and includes the cost of recovery, chipping, transport and administration (Lönner et al. 1998; Hillring 1999). The price of forest fuels in Sweden has decreased by about 50% since the mid-1980s (Swedish National Energy Administration 1999a). The current production cost of *Salix* is higher.

In this study, the cost of wood chips was assumed to be US$5.0, 13 or 17/MWh (US$1.4, 3.5 or 4.7/GJ). The highest cost corresponds to chip production from *Salix* with existing technology including a transport distance of about 50 km. Improvements in cultivation methods and plant-breeding may result in a cultivation cost of US$13/MWh, including transportation. This corresponds to the cost of recovering forest fuels today. The lowest cost (or even lower) may be achieved if *Salix* cultivation is designed for multi-functional benefits (Börjesson 1998). The lowest cost may also be achieved for logging residues in some parts of southern Sweden if local environmental benefits are considered (Börjesson 1999). The corresponding cost of pellets produced from wood chips is assumed to be US$30, 38 or 43/MWh. The price of split wood is assumed to be US$14/MWh, with a variation of ±25% (Swedish National Energy Administration 1999b; Löfgren 1999).

Table 1. Primary energy input (MWh/MWh_{fuel}) and associated CO_2 emission ($kg\ C/MWh_{fuel}$) for the production of wood chips from logging residues and *Salix* (Börjesson and Gustavsson 1996), the processing of pellets from wood chips (Dethlefsen and Trenkle 1996; Froste 1998; Bohlin et al. 1995) and wood harvesting (Dethlefsen and Trenkle 1996).

Fuel produced	Energy input		CO_2
Wood chips from logging residues	0.039	(crude oil)	3.1
Wood chips from *Salix*	0.043	(crude oil)	3.0
Pellets[a]	0.13	(wood chips)	0
Wood[b]	0.0054	(petrol)	8.4×10^{-6}

[a] The pellet plant uses about 21 kJ electricity per MJ pellets produced (Dethlefsen and Trenkle 1996). The CO_2 emission is based on sawdust instead of logging residues and *Salix*, as no data were available for logging residues or *Salix*. The additional energy required at the pellet plant is provided by wood fuel. Results are also shown when the internal use of wood fuel and the associated emissions are zero, assuming that the heat produced to dry the fuel has an alternative use.
[b] For roundwood cutting and cleavage, an expenditure of 0.47 kWh electricity per MWh wood is assumed. The wood is assumed to dry to 25% water content subsequent to cleavage and 1% of its energy content is lost due to the evaporation of combustible substances.

Table 2. Primary energy input (MWh/MWh_{fuel}) and associated CO_2 emission ($kg\ C/MWh_{fuel}$) for the production of fossil fuels in the biomass and fossil-fuel-based systems (Egebäck et al. 1997; Alvarez 1990; Blinge et al. 1997).

Fuel produced	Biomass-based systems[a]		Fossil-fuel-based systems	
	Energy input	CO_2	Energy input	CO_2
Petrol[b]	0.088	5.3	0.087	6.3
Diesel[c]	0.056	3.4	0.056	3.7
Light oil[d]	0.054	3.2	0.054	3.6
Natural gas	–	–	0.053	3.1

[a] The water content of the wood chips used in the biomass-based systems has an insignificant effect on the energy input.
[b] Energy inputs of wood chips and natural gas are 0.022 and 0.020 MWh, respectively.
[c] Energy inputs of wood chips and natural gas are 0.0071 and 0.0064 MWh, respectively.
[d] Energy inputs of wood chips and natural gas are 0.0071 and 0.0097 MWh, respectively.

Table 3. Primary energy use (kWh_{diesel}/MWh_{fuel}, km) and associated CO_2 emission ($g\ C/MWh_{fuel}$, km) from the transportation of wood chips, pellets, wood, diesel and petrol by truck (Egebäck et al. 1997).[a]

Fuel transported	Energy input	CO_2
Wood chips (*Salix*, 50% water content)	0.12	8.9
Wood chips (logging residues, 50% water content)	0.11	8.4
Wood chips (logging residues, 35% water content)	0.087	6.4
Pellets	0.046	3.4
Wood	0.095	7.1
Diesel	0.019	1.4
Petrol	0.019	1.4

[a] All trucks are assumed to carry 100% loads to the customer and 0% load on the return trip. 3.9 kWh diesel/km is required (Egebäck et al. 1997; Gustavsson et al. 1995). A truck is assumed to have a capacity of 95 m^3 wood chips and 35 tonne pellets or diesel (Edner 1999). The lower heating values for chips from *Salix* and logging residues are 4.5 and 4.8 MWh/tonne dry content, respectively, and 4.8, 2.3, 12, 12 MWh/tonne for pellets, wood, diesel and petrol, respectively. The chip density is assumed to be 0.30 tonne/m^3.

Oil prices may vary considerably. The price of crude oil increased from an average of US$13/barrel in 1998, which was very low, to US$34/barrel in September 2000, and the price of light fuel oil for residential heating in Sweden rose from US$18 in 1998 to 29/MWh in June 2000 (Aronsson 2000). The average price of crude oil for 1979–1985 and 1986–1998 was US$32 and 18/barrel, respectively (BP Amoco 2000). The price of light oil for domestic customers is assumed to be US$25/MWh with a variation of ±25%. Owners of large power plants usually import the fuel oil themselves, often once a year, which reduces the cost of the fuel. The domestic transportation cost of light fuel oil is also much lower for large consumers than for domestic customers. Therefore, the price of light fuel oil is assumed to be US$20/MWh with a variation of ±25% for electricity production.

The natural gas is assumed to be obtained from offshore production in Norway. The natural gas is compressed using gas turbines on the oilrig. No further compression is needed in the existing distribution system in Sweden. The figures used for the production of natural gas in this study include energy use and emission from extraction, treatment and transport to the Swedish coast. The natural gas is distributed to the end-users in pipes, and the loss is assumed to be 0.2% (Bohlin et al. 1995). The prices of natural gas for electricity production and for residential heating are assumed to be US$14 and 29/MWh, respectively. We have calculated the effect on the heating cost when the natural gas price is varied by ±25%.

3.2 Conversion technologies

The performance of, and the emission from, the energy conversion technologies are given in Table 4 and the investment cost, fixed operating and maintenance costs, and variable maintenance cost are given in Table 5. The scale, and whether commercial or demonstration plants are considered, are important factors when estimating the cost of technologies being developed, such as BIG/CC technology (Faaij et al. 1997; Ståhl and Neergaard 1998; Rensfelt 1997). The costs assumed in this study are for commercial, full-scale plants. The first full-scale plant will involve high engineering costs, which are expected to decrease after a number of similar plants have been built. For a cost comparison between biomass technologies for cogeneration and stand-alone power production (see e.g. Gustavsson and Börjesson, 1998). All other conversion technologies are available commercially.

The combustion of light oil and natural gas is assumed to give rise to CO_2 emissions of 76 and 57 kg C/MWh$_{fuel}$. In the reference case wood fuels are assumed to emit no net amount of CO_2.

For condensing plants and resistance heaters, a 25-year lifetime is assumed, and for all other conversion technologies, a 15-year lifetime. The annual utilisation times were assumed to be 7000, 350 and 2500 hours for the natural-gas- and wood-chips-fired condensing plants, the gas turbine, and the small-scale heaters, respectively.

4. Results

4.1 Heating cost

The natural gas boiler system has the lowest heating cost of the systems compared, but the difference in heating cost between oil, natural gas and wood boilers is small. The heat pump systems have about a 20% higher cost than these boiler systems, and the other systems have even higher cost, Figures 10–11. A variation in fuel prices will not change the situation significantly. Heat pump systems, especially, are insensitive to changes in fuel price due to their high energy efficiency.

The electricity production technology affects the total cost. The cost of decarbonization for electric heat pump systems when the base-load electricity is produced in natural-gas -fired condensing plants is minor, about 7% of the total cost. The corresponding cost of the electric boiler and heater systems is about 20% of the total cost. Biomass-based electric systems are more

Table 4. Capacity and efficiency (η) for various technologies.

Technology	Capacity (MW_{th})	η	Reference
Small heaters			
Electric boiler	0.008	0.95	(Liinanki 1998)
Electric resistance heater	–	0.97	(Gustavsson et al. 1992)
Heat pump	0.0085	3.3	(NUTEK 1997)
Light-oil boiler	0.008	0.85	(Liinanki 1998; Bohlin et al. 1995)
Natural gas boiler	0.008	0.88	(SAME 1999; IPCC 1996)
Pellet boiler	0.011	0.78	(E.K. Teknik 1998)
Wood boiler	0.024	0.75	(Swedish National Energy Administration 1994; Swedish Environmental Protection… 1998; Liinanki 1998; Löfgren 1998)
Condensing plants			
BIG/CC	100	0.47	(Gustavsson and Börjesson 1998)
Steam turbine (biomass)	200	0.40	(Gustavsson and Börjesson 1998)
Combined cycle (natural gas)	300	0.52	(IPCC 1996)
Gas turbine (light oil)	120	0.27	(Bohlin et al. 1995)

Table 5. Investment cost (IC), fixed operating and maintenance cost (FC) and variable maintenance cost (VMC) for various conversion technologies (Dahlström 1999; Berntsson 1999; Sandberg 2000; Röhl 1995; Swedish Environmental Protection… 1998; Gustavsson and Börjesson 1998).

Technology	Capacity (MW)	IC (US$)	FC (US$/yr)	VMC (US$/MWh)
Small heaters				
Electric boiler	0.008	3100	75	–
Electric resistance heater	–	2500	–	–
Heat pump	0.0085	10500	75	–
Light-oil boiler	0.008	6300	130	–
Natural gas boiler	0.008	5000	130	–
Pellet boiler	0.011	7500	110	–
Wood boiler	0.024	6500	310	–
Condensing plants		(US$/kW)	(US$/kW, yr)	
BIG/CC	100	1300	38.0	3.8
Steam turbine (biomass)	200	1400	16.0	3.8
Gas turbine (light oil)[a]	120	400	5.4	0.63
Combined cycle (natural gas)	465	700	11.0	1.3

[a] Assumed to be half of the cost of the natural-gas-fuelled combined cycle.

cost-efficient than the fossil-fuel-based system with decarbonization. Using steam-turbine technology instead of BIG/CC in the electric heating systems increases the cost by less than 3%.

There are several uncertainties, apart from that in fuel prices, in the data used to calculate heating costs. The investment cost depends on local conditions and may vary significantly compared with the average cost of typical plants, used here. The investment cost for new technologies, such as BIG/CC and decarbonization, is especially uncertain since such technologies have not yet been commercialised. The discount rate is another uncertain parameter.

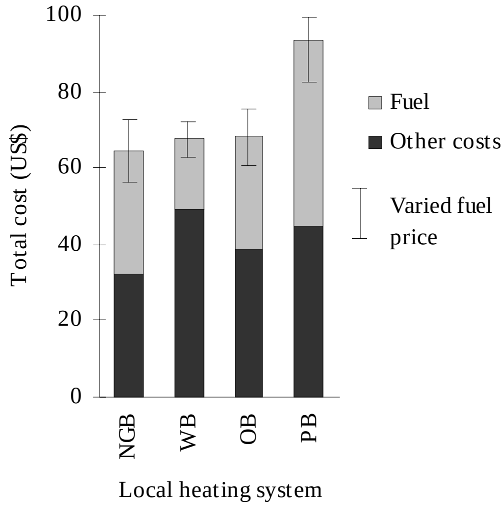

Figure 10. The cost of producing 1 MWh of heat in the local heating systems when producing the reference entity. The error bars show the variation in the cost as the cost of fuel varies. BIG/CC technology is used in the wood-fuel-based systems.

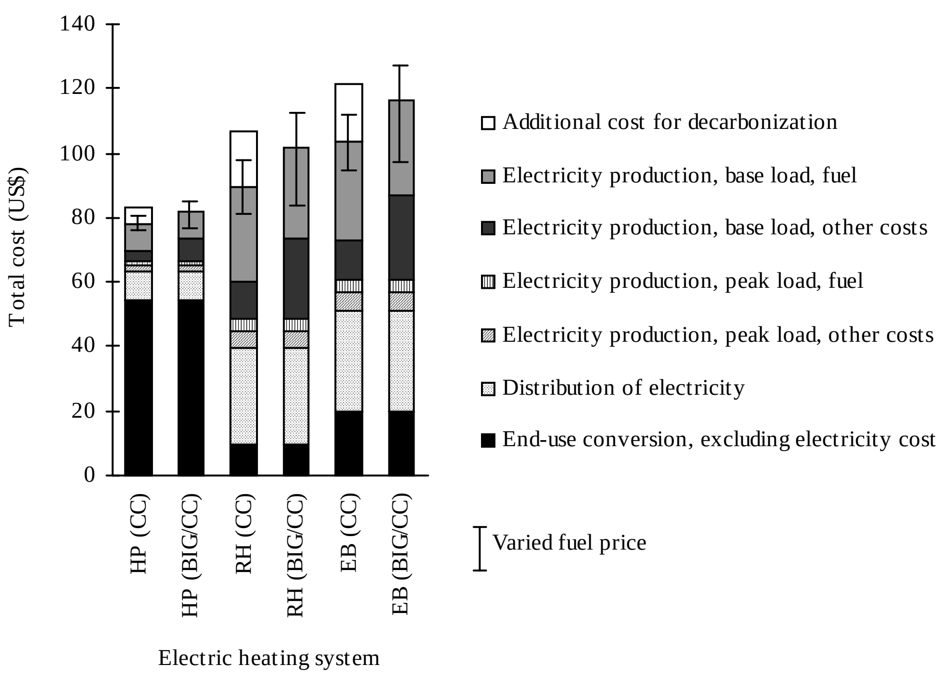

Figure 11. The cost of producing 1 MWh of heat in the electric heating systems when producing the reference entity. The error bars show the variation in the cost as the cost of fuel varies. HP = heat pump, RH = resistance heater, EB = electric boiler. CC (natural gas fuelled combined cycle) and BIG/CC are the technologies used for producing electricity in the systems.

4.2 CO_2 emission

The CO_2 emission varies between the systems analysed when the reference entity of 1 MWh is produced. Generally, the fossil-fuel-based systems emit the greatest amounts (Table 6). The emission of CO_2 is a function of the amount of crude oil used in the biomass-based systems. For the fossil-fuel systems the end-use conversion of the local systems and the electricity production of the electric heating systems emit more than 90% of the total CO_2 emitted.

Table 6. The emission of CO_2 (kg C) from the various stages of the energy systems studied when producing the reference entity.[a]

	System				
	Wood boiler	Pellet boiler[b]		Oil boiler	Natural gas boiler
Production of fuel	0.039	4.4	(3.9)	4.2	3.7
Transport of chips/ Distribution of natural gas	0.50	0.63	(0.56)	0.14	5.9×10^{-4}
Processing of fuel	0.0057	0.23	(0.23)	–	–
Transport of pellets	–	0.46	(0.46)	–	–
End-use conversion	0.27	0.50	(0.57)	94	69
Total	0.81	6.3	(5.7)	98	73

	BIG/CC systems			Combined cycle systems		
	EB	RH	HP	EB	RH	HP
Peak-load production						
Production of fuel	0.48	0.47	0.14	0.53	0.52	0.15
End-use conversion	11	11	3.3	11	11	3.3
Base-load production						
Production of fuel	7.2	6.9	2.0	6.8	6.5	1.9
Transport of chips/ Distribution of natural gas	2.1	2.0	0.58	1.1	1.1	0.31
End-use conversion	0	0	0	120	120	34
Total	21	20	6.0	140	130	40

[a] Abbreviations: EB is electric boiler, RH is resistance heater, HP is heat pump.
[b] Results, when assuming that the internal use of wood fuel at the pellet plant is zero, are shown in parentheses.

The CO_2 emission, considering the changes in the biological carbon stock, is shown in Figure 12. Decarbonization in the natural-gas-based systems does not reduce the CO_2 emission to the low level of the corresponding biomass-based systems. Steam-turbine technology increases the CO_2 emission by 8% compared with BIG/CC.

An energy-effective system gives rise to less emission. The primary energy use is shown in Figure 13 for the systems studied. The most energy-efficient systems are the heat pump systems, followed by the local heating systems, while the remaining electric heating systems are the least efficient.

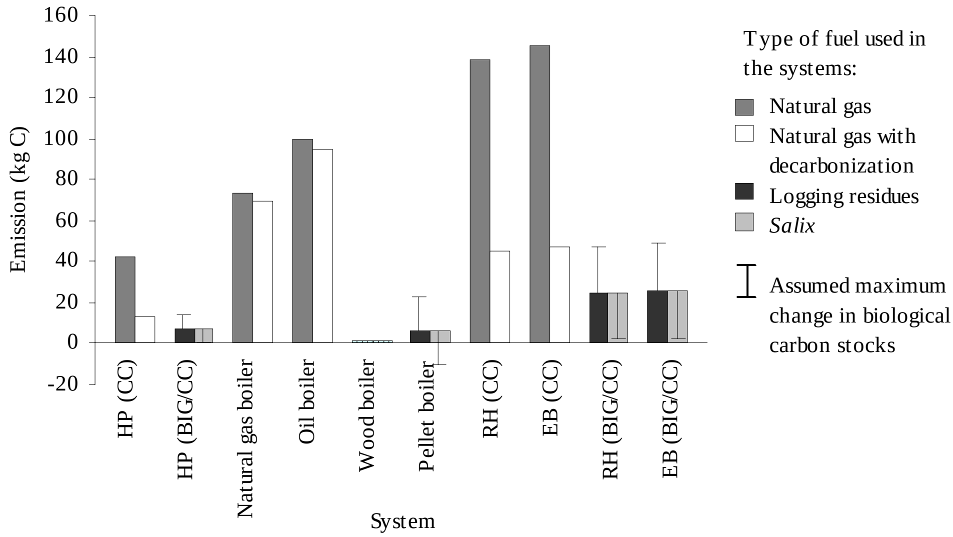

Figure 12. The CO_2 emission from the energy systems studied, in producing the reference entity, when changes in the biological carbon stocks and decarbonization are considered. BIG/CC technology is used in the wood-fuel-based systems. HP = heat pump, RH = resistance heater, EB = electric boiler. CC (natural gas fuelled combined cycle) and BIG/CC are the technologies used for producing electricity in the systems.

4.3 CO_2 mitigation cost

The CO_2 mitigation cost depends on the system used as a reference. The natural gas boiler system has the lowest cost and the lowest CO_2 emission among the fossil-fuel-based systems. An natural gas grid, however, is not always accessible. In such a case, an oil boiler system may be a realistic reference system. Here, we have shown the results when using both the natural gas boiler and the oil boiler systems as reference systems.

The lowest CO_2 mitigation cost is exhibited by the boiler and the heat pump systems (Figure 14–15). Using the natural gas boiler system as the reference system gives a higher CO_2 mitigation cost than using the oil boiler system as the reference, because the total cost of, as well as the CO_2 emission from, the natural gas boiler system is lower. Switching from oil boiler and natural gas boiler systems to fossil-fuel-based electric boiler and fossil-fuel-based resistance heater systems leads to an increase in CO_2 emission. The low CO_2 mitigation cost of the wood boiler system with the natural gas boiler system as a reference is a result of both the small difference in cost and the high difference in emission between the systems (Figure 14). Compared with the oil boiler system, the wood boiler system results in a negative CO_2 mitigation cost, as the wood boiler system is less costly than the oil boiler system. The high CO_2 mitigation cost when switching from an natural gas boiler or oil boiler system to a pellet boiler system is a result of the relatively high cost of the pellet boiler system. The CO_2 mitigation cost of the pellet boiler systems differ insignificantly when it is assumed that the internal use of wood fuel at the pellet plant is zero.

The error bars in these figures represent a variation in fuel price in the systems compared. Three cases of fuel price for the reference system are shown. The price of the fuel used in the reference system, natural gas or oil, is not varied in the system that is the subject of comparison.

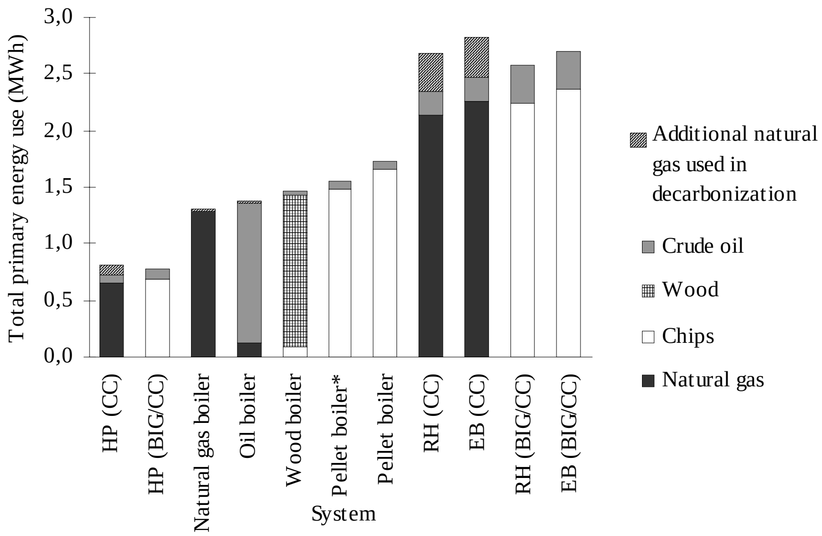

Figure 13. The total primary energy use for the energy systems studied when producing the reference entity. BIG/CC technology is used in the wood fuel based systems. HP = heat pump, RH = resistance heater, EB = electric boiler. CC (natural gas fuelled combined cycle) and BIG/CC are the technologies used for producing electricity in the systems. In the pellet boiler system denoted (*), the internal use of wood fuel is assumed to be zero at the pellet plant.

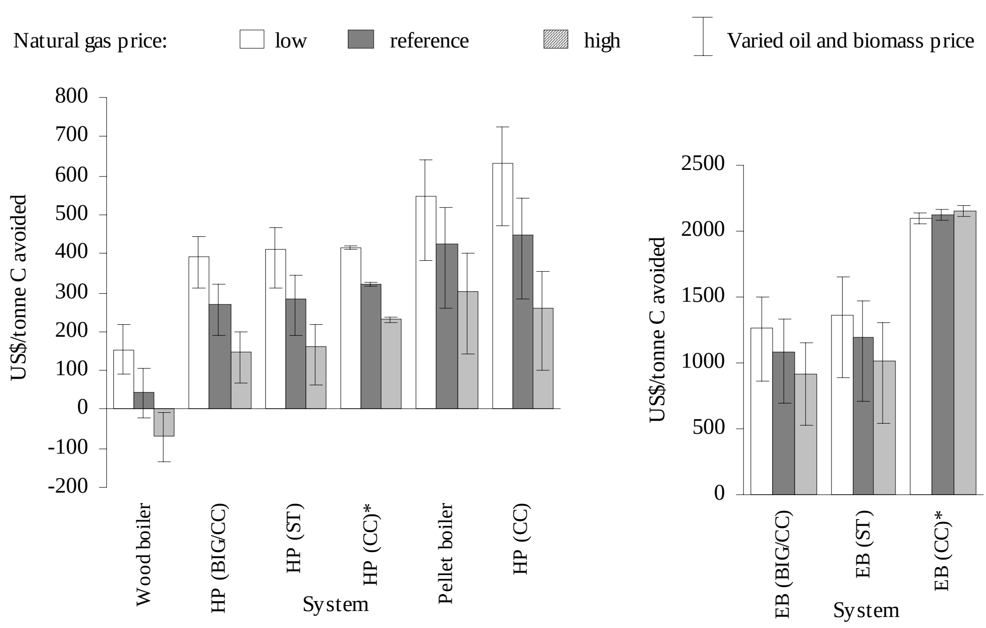

Figure 14. The CO_2 mitigation cost using the natural gas boiler system with three levels of natural gas price as reference system. HP = heat pump, EB = electric boiler. CC (natural gas fuelled combined cycle), ST (steam turbine) and BIG/CC are the technologies used for producing electricity in the systems. Systems denoted (*) include decarbonization of flue gases. BIG/CC technology is used in the wood boiler and pellet boiler systems.

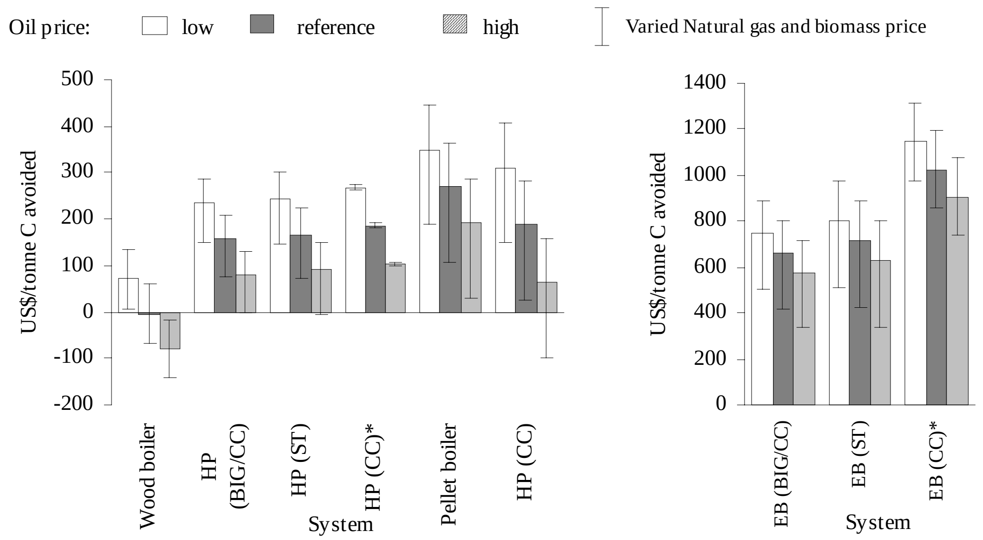

Figure 15. The CO_2 mitigation cost using the oil boiler system as reference. system. HP = heat pump, EB = electric boiler. CC (natural gas fuelled combined cycle), ST (steam turbine) and BIG/CC are the technologies used for producing electricity in the systems. Systems denoted (*) include decarbonization of flue gases. BIG/CC technology is used in the wood boiler and pellet boiler systems.

Using the natural gas boiler system as the reference system results in low cost variations of the fossil-fuel-based systems as natural gas is the fuel used for base-load production and the cost is kept constant in the reference system as well as in the system compared. The relatively high variations in the fossil-fuel-based heat pump system is a result of the large difference in cost between the heat pump system and the natural gas boiler system.

As the heating systems of this study are assumed to supply existing buildings, the cost of internal heat distribution systems in the buildings was excluded. The resistance heater systems use electric radiators, whereas the other systems use water as a heat carrier in the buildings. Therefore, in the cost of switching from a natural gas or oil boiler system to a resistance heater system, the cost of installing a new internal heat distribution system has to be included. This is beyond the scope of this study. However, as the resistance heater system is an ineffective and expensive system, it is of minor interest to switch from a natural gas or oil boiler system to this type of system. Nevertheless, the CO_2 mitigation cost of changing the technology for producing the electricity to the resistance heaters is estimated. This is performed by using a resistance heater system where the electricity is produced with natural-gas-fuelled combined cycle as the reference system. This results in a CO_2 mitigation cost of 110, 130 and 180 US$/tonne C avoided for the resistance heater systems using BIG/CC, steam turbine and combined cycle with decarbonization, respectively. These mitigation costs end up in the lower range of the mitigation costs estimated in this study.

5. Conclusions and Discussion

The choice of energy system for heating detached houses is of importance regarding the CO_2 emission, the heating cost and thus the CO_2 mitigation cost. Not only the end-use technology, but also up-stream technologies could have a considerable effect on these parameters. The analysis performed here included the entire energy system, from the natural resource to the delivered reference entity, but not end-use efficiency measures, such as improved thermal insulation of the houses.

The local boiler systems, excluding the pellet boiler system, exhibited the lowest cost. The cost of electricity-based systems, especially other than heat pump systems, was higher due to a lower end-use efficiency.

The biomass-based systems emitted about one-tenth of the CO_2 emitted by the fossil-fuel systems. Generally, an efficient system emits less than an inefficient one. The removal of CO_2 from the flue gases from large natural-gas-fired condensing plants could reduce the CO_2 emission by about 70%. This will increase the primary energy use and cost, and so these will be higher than for similar biomass-based systems. However, regarding heat pumps, these increases are quite small. The availability of heat sources has not been analysed and hence the potential use of heat pumps has not been estimated.

The changes in the biological carbon stock, mostly temporary, would lead to an increase in the net emission of CO_2 when forest residues are used, and a decrease in emission when *Salix* chips are used. However, electric heating systems based on logging residues still give rise to lower CO_2 emission than systems based on natural gas and decarbonization.

The CO_2 mitigation cost is dependent on the reference system chosen. The CO_2 mitigation cost of replacing an natural gas boiler system with a wood boiler, heat pump or pellet boiler system ranges from US$42 to 430/tonne C avoided. The CO_2 mitigation cost upon replacing an oil boiler system with a heat pump or pellet boiler system is about 40–60% lower. The CO_2 mitigation cost of electric boiler and resistance heater systems is higher due to the relatively low energy efficiency of these. For comparison, the Swedish CO_2 tax today is US$240/tonne C for fossil-fuel based heat production in the residential sector and US$84/tonne C for the industrial sector. In addition, there is an energy tax for fossil fuel heat production in the residential sector. This energy tax is 115 and 46 US$/tonne C for oil and natural gas, respectively. There is no carbon or energy tax for electricity production.

6. Acknowledgements

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Net Greenhouse Gas Emissions Due to Energy Use of Forest Residues – Impact of Soil Carbon Balance

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Abstract

The CO_2 emissions from utilising the harvest residues as energy and the decrease in forest soil carbon stock caused by it was quantified by simulating the decaying of the harvest residues at the forest site. The difference in soil carbon stocks between landscapes where residues are removed and where they are left to decay is considered as an indirect emission to the atmosphere. If the fossil fuels are replaced by utilisation of logging residues about 80–90% of greenhouse gas emissions could be avoided. The effect of the decrease in the soil carbon stock attenuates the avoided emissions by about 10%.

Keywords: logging residues, carbon sinks, soil, greenhouse gas emissions

1. Introduction

The use of renewable energy sources instead of fossil fuels is one of the most important means in the limitation of greenhouse gas emissions. In Finland wood energy is considered to be a very important potential energy source in this sense. The National Technology Agency has launched a new energy technology programme, which has target to increase the use of forest chips from 0.5 million to 2.5 million m^3/yr (Alakangas 2000).

It is generally assumed that biofuels, such as forest residues, do not cause any net CO_2 emissions to the atmosphere. This assumption is based on the reasoning that carbon stored in plants, which is released in burning the fuel, is taken up again by regrowing plants. This consideration, however, disregards the effect of residue removal on forest soil carbon stocks. There are also emissions of other greenhouse gases, for instance direct emissions from burning and indirect emissions from the production chain. Taking these emission sources into

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account it is possible to achieve a more complete greenhouse impact of the energy obtained from logging residues.

In the forests carbon flows from dead biomass to soil, unless there are no disturbances like forest fires or harvests. These disturbances diminish the carbon flow to soil thus decreasing the soil carbon storage (Liski et al. 1998). The use of harvest residues (by which we mean aboveground residues, needles and branches) means a more intensive utilisation of forest biomass. This induces a smaller carbon input to the soil after the harvest, which will correspondingly lead temporarily to smaller carbon storage in soil. Although, the additional impact of utilisation of harvest residues has not been noticed to be very considerable in comparison with the effect of conventional harvesting on soil carbon storage (Olsson et al. 1996; Bengtsson and Wikström 1993).

Carbon is released from removed harvest residues as soon as they are burned. If they were left at the site, they would decay over a period of decades. This means that the effect of utilisation of harvest residues when comparing with the decomposition of the residues at the site will extend over long time periods necessitating time-dependent analysis. For instance, Schlamadinger et al. (1995) have described the decaying of the harvest residues with an exponential decay model and they have studied the carbon neutrality as a time-dependent variable.

The aim of this study was to quantify the effect of the collection of harvest residues to the carbon reservoir in Finnish upland forest soils. We commuted this time-dependent difference in carbon storage to an indirect CO_2 emission, which was compared with other greenhouse gas emissions from forest chips production chain and with emissions from fossil fuels. This gave us an idea of the effectiveness of the replacement of fossil fuels with the harvest residues.

2. Model Simulations

For the analysis we used a dynamic model, which describes the carbon stocks and fluxes of decomposing organic matter in upland forest soils. The model operates on a yearly time step. It consists of three litter compartments describing physical fractionation of forest litter and five compartments describing microbiological decomposition in soil (Figure 1). Each of these compartments has its own fractionation (a_x parameters) or decomposition rate (k_x parameters). These rates represent the fractions that are removed from the contents of the compartments each year. They were determined by adjusting them to observations in the field (Lambert et al. 1980; Berg et al. 1982; Berg et al. 1984). The component leaving a litter compartment is divided into the soluble, cellulose and lignin compartments (c_x parameters) according to its chemical composition (Hakkila 1989; Berg et al. 1982; 1984). A fraction of matter leaving the soluble, the cellulose, the lignin or the first humus compartment (p_x) is transferred to the subsequent compartment as illustrated in Figure 1, while the rest of it ($1-p_x$) leaves the system. From the second humus compartment, output is out of the system only.

Litter production formed the carbon input into the model. We calculated it for the felling moment as residue biomass using allometric biomass functions (Marklund 1988). Fine root biomass was estimated using a constant needle-fine root-ratio (Nikinmaa 1992; Vanninen et al. 1996). At studied spruce (*Picea abies*) sites, harvest residues, i.e. foliage and branches, represented about 50% of all residue biomass and about 20% of the total biomass of a mature stand. Amounts of carbon left at the site in harvests of different intensity can be seen in Figure 2.

Two separate cases were simulated with the model. In the first simulated case the harvest residues were left at the site. In the second simulated case, the harvest residues were removed from the site and burned for the energy production, only roots and stumps were left at the site to decay. All the carbon in the residues was released to the atmosphere once they were burned. We assumed that all the harvest residues were collected. In practice it is usually possible to collect only about 70% of them.

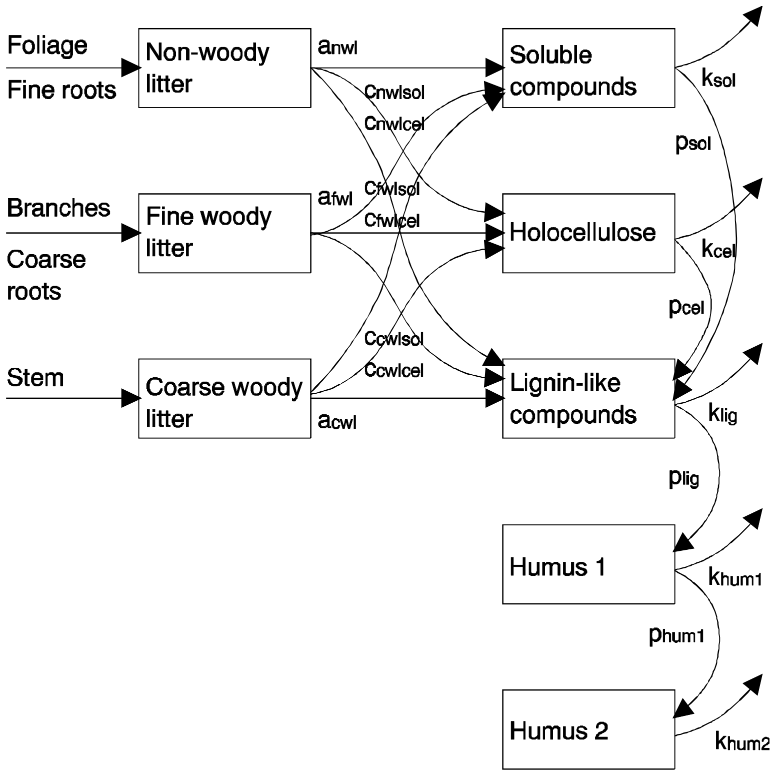

Figure 1. Flow chart of the soil carbon model. The boxes represent carbon compartments, the arrows carbon fluxes, and the text by the arrows parameters controlling the fluxes.

Table 1. Parameter values used in model calculations.

Parameter	Value	Parameter	Value
a_{nwl}	1.0 yr^{-1}	k_{sol}	0.5 yr^{-1}
a_{fwl}	0.5 yr^{-1}	k_{cel}	0.3 yr^{-1}
a_{cwl}	0.05 yr^{-1}	k_{lig}	0.15 yr^{-1}
c_{nwlsol}	0.27	k_{hum1}	0.013 yr^{-1}
c_{nwlcel}	0.51	k_{hum2}	0.0012 yr^{-1}
c_{fwlsol}	0.03	p_{sol}	0.15
c_{fwlcel}	0.65	p_{cel}	0.15
c_{cwlsol}	0.03	p_{lig}	0.18
c_{cwlcel}	0.69	p_{hum1}	0.18

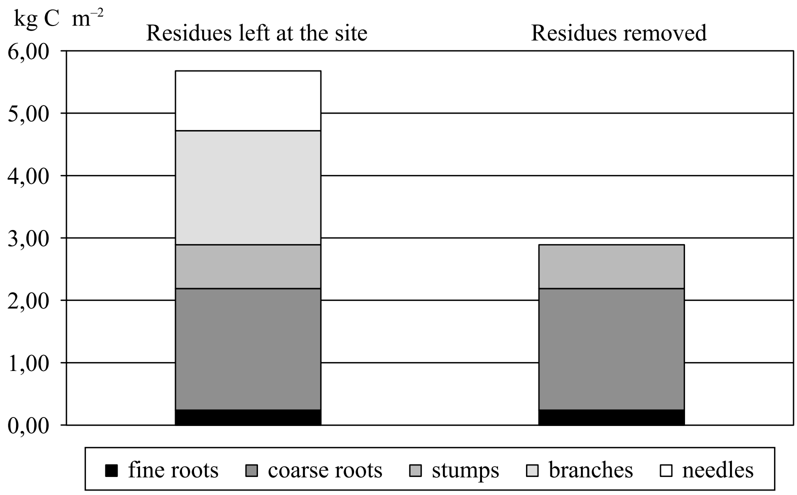

Figure 2. Amounts of carbon left at the spruce site in harvests of different intensity and distribution of the carbon into the biomass compartments.

3. Results

In the first simulated case, the harvest residues were left at the site. At the start they were calculated to decompose quite fast (Figure 3). About 90% of the carbon of the residues was released into the atmosphere within the first 20 years. However, the remaining 10% decomposed very slowly, within hundreds of years. In the second simulation case the harvest residues were removed from the site, only roots and stumps were left there to decay. The difference in soil carbon stocks in our example calculation was at the beginning the amount of carbon in residues, 2.8 kg C/m^2, and after 20 years about 0.2 kg C/m^2. For comparison, the average organic carbon storage in soil of *Myrtillus* type (MT), which can be thought to represent a typical spruce site in Finland, has been measured to be about 10 kg C/m^2 (Liski and Westman 1995).

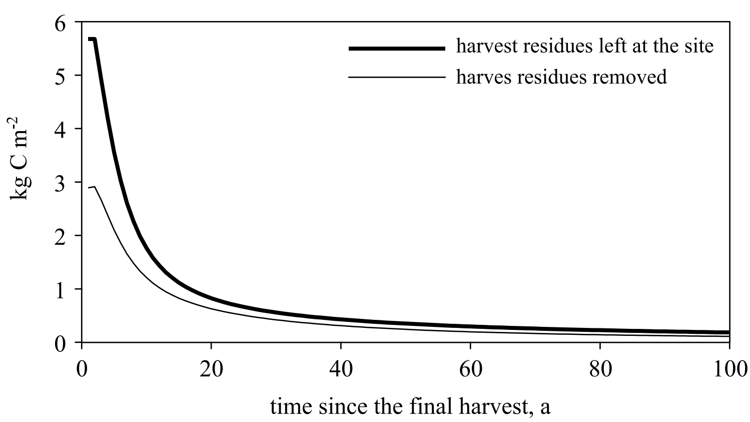

Figure 3. Carbon amounts from the final harvest at the Norway spruce site after harvest of different intensity.

Within the 100-year rotation length the average carbon stock from residues in soil is about 11% of the original amount of carbon in harvest residues (Table 2). After 100 years the carbon storage from the residues is only 3% of the original carbon amount. During the next 100-year periods the carbon storage is 2% (years 101–200), 1% (years 201–300), 1% (years 301–400) and 1% (years 401–500). This means that if the utilisation of the carbon residues was continued in every final harvest, for example, for 500 years, the carbon storage would be 16% of the carbon in residues in one harvest smaller when compared with the case of no residue utilisation (Figure 4).

Table 2. Carbon from harvest residues in forest soil after the final harvest.

Years after final harvest	Residue carbon left in the soil	Average carbon stock during the years
60	4%	15%
80	4%	13%
100	3%	11%
120	3%	9%

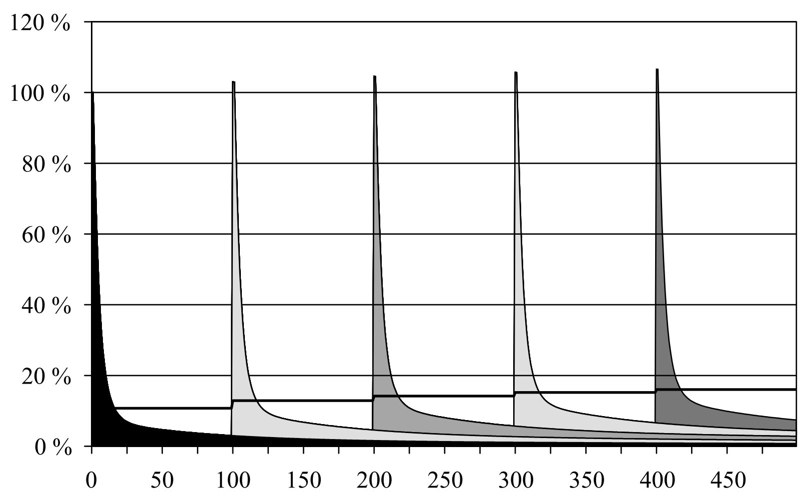

Figure 4. Harvest residues decaying at the site over five 100-year rotations. Average level during 100-year rotation is described with the solid line.

When we consider sufficiently large land area, which can include forest stands in all stages of the cycle from stand establishment to mature stands, the average carbon stock across the landscape may adequately represent the average for each given stand over time. Then considering two landscapes, where 100-year rotation lengths are applied and harvest residues are removed from the other area systematically in each final harvest, average soil carbon stock in this landscape would be smaller than in the other landscape. According to the modelling results, the average carbon stock from residues in soil within the 100-year rotation length is about 11% of the original amount of carbon in harvest residues depending on the content of the decaying material. The difference in carbon stocks between the landscapes is this harvest residue carbon decaying in the other landscape, being thus about 11% of the total carbon amount in residues. For a spruce stand with 200 m^3/ha stemwood volume and 15 Mg C/ha harvest residues, this means a carbon emission of 1.7 Mg C/ha or a CO_2 emission of about 6.1 Mg CO_2/ha.

4. Comparison with Emissions from the Full Fuel Chain

The energy obtained from the residues depends on the moisture of the residues. Assuming that energy achieved is 135 to 150 MWh/ha and a 100-year rotation length is applied, the indirect CO_2 emission from decreasing soil carbon is 40 to 45 kg CO_2/MWh. Adding this indirect emission to the direct greenhouse gas emissions from burning and the other indirect emissions from fuel production and transportation chain we get a more complete greenhouse impact of the energy obtained from logging residues. Greenhouse gas emissions (methane – $CH_{4,}$ and nitrous oxide – N_2O, not carbon dioxide – CO_2) from burning residues in a CHP-plant have measured to be as small as about 2 kg CO_2-ekv/MWh (Wihersaari and Palosuo 2000). The emissions from collecting, chipping and transporting the residues are usually about 4–7 kg CO_2-ekv/MWh (Wihersaari and Palosuo 2000). Granulation and recirculation of ash increase emissions only slightly, about 0.2 kg CO_2-ekv/MWh (Wihersaari and Palosuo 2000). Additional greenhouse gas emissions from nitrogen losses compensated with fertilisation would be about 7 kg CO_2-ekv/MWh (Wihersaari and Palosuo 2000).

Table 3. Greenhouse gas emissions from the final harvest fuel chips production and utilisation.

Emission source	emissions, kg CO_2-ekv/MWh
CH4 and N2O emissions from burning	1–4
Emissions from collecting, chipping and transporting	4–7
Nutrient loss compensation with fertilisation and recirculation of ash	0–7
CO_2 emission from decreasing soil carbon	40–45
Total	45–63
Coal	334–374
Peat	378–382

For the spruce case, the total emissions may be roughly about 50 kg CO_2-ekv/MWh (Table 3). For comparison, CO_2 emissions in Finland from burning coal are about 334 kg CO_2/MWh (IPCC 1997) and CO_2 emissions from combustion of peat about 378 kg CO_2/MWh (Boström 1994). If the emissions from production, transportation and storage of these fuels are taken into account, emissions for coal would be approximately 12% higher and for peat about 1% higher (Wihersaari 1996).

Thus, if the fossil fuels are replaced by utilisation of logging residues the net effect is still very positive. Depending on the emissions being included, about 80–90 % of greenhouse gas emissions could be avoided by utilisation of harvest residues instead of coal or peat. The decrease in the soil carbon stock attenuates the avoided emissions by about 10%.

5. Discussion

Reliability of the model results depends both on the validity of the model structure and accuracy of the model parameters. The sensitivity of the results to the model parameters has been studied in Palosuo and Wihersaari (2000). The average carbon stock in soil during a 100-year rotation length varied between –20% and +39% when different parameters were multiplied by 0.5 or 2. Uncertainties of the soil model concern mostly the fractionation and decomposition rates of the soil compartments, which could be adjusted to even more careful empirical studies.

This study does not account for all the conceivable emissions caused by the utilisation of harvest residues. Final harvest always increases the soil carbon stock first as the biomass compartments move to the litter and soil carbon storage. The real incidence to the total soil carbon stock depends also on the effects the harvest has to yearly litter production of the forest. Energy use of forest residues may cause changes in productivity of forest sites (Kimmins 1977; Jacobson et al. 2000; Egnell et al. 1998), which could lead to smaller carbon accumulation into forests and soils. Also N_2O emissions from forests may change by the utilisation of the harvest residues and this may have significant impact on the greenhouse gas balances of the forests.

It must be also noted that the removal of residues may alter the decay rate of organic compounds left at the site. For example, the temperature and humidity conditions of the sites have been noticed to change after harvest residues have been removed (Egnell et al. 1998) and this type of changes has been demonstrated to alter to the decomposition rates (Bunnell et al. 1976). Decay rates may also change during forest development as the environmental conditions at the site under the growing trees changes. Also the content of the decomposing material has an effect on decay rates.

The carbon neutrality is an essential question when comparing the energy sources, as it is a central argument used for utilising wood energy. The significance of soil as a third carbon pool and the results of this study should be expanded with further studies.

6. Conclusions

Energy from harvest residues is not completely carbon neutral in the sense that it would not cause any net CO_2 emission to the atmosphere. Effect of the soil carbon balance should also be taken into account. There are also greenhouse gas emissions from collecting, chipping and transporting the residues and direct emissions from burning (other than CO_2).

Altogether the emissions from using harvest residues as biofuel are about 50 kg CO_2-ekv/MWh including roughly about 80% effect from decrease in soil carbon. Comparing these emissions with domestic emissions from fossil fuels the net effect, when fossil fuels are replaced by utilisation of logging residues, is still very positive. Over 80% greenhouse gas emissions could be avoided by using energy from harvest residues.

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Production of Woody Biomass for Energy in Post-Mining Landscapes and Nutrient Dynamics

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Abstract

Since the German reunification in 1990 lignite production in the Lusatian mining region has significantly decreased. This development coincides with efforts of the government of the German state of Brandenburg to enhance the production of woody biomass on set-aside arable and post-mining landscape for energy transformation purposes. As part of the reclamation activities in the post-mining landscapes short-rotation plantations have come into focus. Thus, in 1995 a 2.5 ha short-rotation plantation was established on clayey-sandy substrates in order to study the ecological potentials of fast-growing tree species such as balsam poplar clones, aspen progenies and willow clones. Special emphasis was placed on yield aspects, nutrient cycling, chemical characterization of the above-ground biomass and the wood ash to be used as a fertilizer. Even under unfavourable soil conditions increments ranged from 5.3 to 19.6 tons dry matter per hectare at age 4. The 4-year-old above-ground biomass showed low N, Cl and heavy metal concentrations, and a high ash softening temperature and calorific value. Therefore, it is seen as a most favourable biofuel for energy. The wood ash was characterized by high concentrations of macronutrients with the exception of nitrogen and low heavy metal concentration. The utilization of ash for amelioration purposes can be seen as having potential for compensation for nutrient loss by harvesting the biomass.

Keywords: woody biomass, bioenergy, short-rotation plantation, nutrient cycling, wood ash, reclamation, landuse system, post-mining landscape

1. Introduction

Biomass as a renewable resource may present an important alternative for heat and energy supply in rural landscapes, i.e. in areas with decentralised structures. In this context it is

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expected that with the adoption of the Renewable Energy Act by the German Government in April 2000, the growth rates of bioenergy sources will accelerate. The overall objective of the law is to contribute towards increasing the share of renewable energy in the electricity market from 5% to 10% by 2010. The state of Brandenburg in north-eastern Germany offers the unique chance to adopt this strategy into reclamation activities on the large-scale post-mining landscapes of the Lusatian lignite mining region.

Hence, perspectives and potentials of economically and ecologically adapted landuse systems for energy supply purposes are under investigation. Presently in the state of Brandenburg the total of set-aside arable land amounts to 175 000 ha (MELF 1997). The post strip-mining area in the Lusatian lignite mining region is about 77 500 ha (Schiffer and Maaßen 1997).

The intention of the research activities is to determine the effects that biofuel production may have on the water and nutrient fluxes of terrestrial ecosystems to avoid or at least to minimize possible negative impacts (Bungart 1999). Based on profound research findings sustainable landuse systems will be developed for these rural areas. In this respect the Lusatian lignite mining region in the south of Brandenburg may offer a high variety of mining dumps to scientifically test the ecological effects and yield potentials for such cultivation purposes (Hüttl 1997; Bungart 1999; Bungart et al. 2000; Bungart and Hüttl 2001).

Since the German reunification, targets and strategies for recultivation have changed. These now are focused on the establishment of new systems in a way that allows lasting landuse practices in the future. On smaller areas within the post-mining landscapes there are dominating loamy as well as sandy, lignite- and pyrite-free substrates in the upper level of the dumps (Bungart 1999).

2. Changes in Energy Economics and Energy Policy

The Lusatian lignite production declined rapidly due to the dramatic economical and structural changes since the German reunification in 1990. This development parallels the increasing importance of growing biomass for energy purposes in the Lusatian lignite mining region during recent years. This has been encouraged by Brandenburg energy policies. The energy policy strives for the goal of 5% of the total energy consumption supplied by regenerative energy carriers including 3% supplied by biofuels like wood (MELF 1997). Up to now wood and wood-like biofuels from forestry and landscaping have hardly received the attention they should have when considering renewable energy resources and thermal transformation. In this context the production of biofuels is contributing to a higher security of the energy supply. This is especially true for wood and woodlike products which have more favourable energetic properties when compared with lignite.

With regard to the above mentioned aims, short-rotation plantations as a special form of energy forests may well serve for a production of bioenergy or woodfuels on recultivated sites in the future (Bungart and Hüttl 2001a). Actually both, productivity/ecology aspects as well as socio-cultural benefits of this landuse system are presently under study on recultivated loamy substrates in the Lusatian mining region (Bungart 1999).

3. Production of Biomass in Short-Rotation Plantations for Energy

The idea of producing large amounts of woody biomass by cultivation of fast-growing tree species with different rotation periods is well known (Bungart 1998). Research has emphasized the suitability and yield potential of fast-growing tree species such as poplar (of the varieties *Tacamahaca* and *Aigeiros* and their hybrids), aspen (of the variety *Leuce* – hybrids of *Populus tremula* L. and *Populus tremuloides* Michx.) as well as basket willows (*Salix viminalis* L.) in short-rotation plantations on former arable land (Jug et al. 1999; Hofmann-Schielle et al. 1999; Liesebach et al. 1999).

For the first time, the present study investigates the suitability of fast-growing tree species on lignite- and pyrite-free substrates (Bungart 1999; Bungart et al. 2000). In 1995, a 2.5 ha short-rotation plantation was established on clayey-sandy, nitrogen and phosphorus poor substrates in the Lusatian mining region Welzow-Süd in order to study the potentials of fast-growing tree species. Special emphasis was placed on the nutritional and yield aspects taking into consideration the plant-soil interaction (Bungart 1999).

This study focuses especially on the chemical and energetic properties of wood, the nutrient removal and depletion by harvesting, the ash content and the chemical properties of wood ash with regard to its suitability for use as a fertilizer (Bungart 1999). The main site characteristics are summarized in Table 1.

Table 1. Main characteristics of the short-rotation plantation site.

Substrate conditions			
Texture [% wt]	sand	silt	clay
	72.8–76.4	3.9–4.8	19.8–20.9
Field capacity [mm in 1 m soil depth]	242–248		
pH_{KCl}	7.2–7.7		
Total element concentration	C [%]	N [%]	P [mg g^{-1}]
[dry matter DM]	0.47–0.83	0.01–0.04	0.41
Climate conditions*		Mean annual (1961–1990)	
	Temperature [°C]	Precipitation [mm yr^{-1}]	Vegetation period [d yr^{-1}]
	8.8	532.8	166

* DWD Deutscher WetterDienst – German Weather Service

3.1 Experimental sites, plant material and methods

The experimental sites were established in April 1995 with an initial application of N 100/P 100/ K 100 kg ha^{-1}. There were four plots with eight clones of poplar (*Populus* spp. variety *Tacamahaca*) and two clones of basket willow (*Salix viminalis*) with four replications each in a randomized design (planting density about 8333 cuttings per hectare in a planting space of about 2 m x 0.6 m). The aspen progenies are hybrid crosses between *Populus tremula* and *Populus tremuloides*. The planting density was 5555 rooted stems per hectare with a spacing of plants of about 2 m x 1.2 m (Bungart 1999). In order to determine the above-ground biomass after the fourth vegetation period, nine representative stems per clone were harvested in the dormant season for determination of mean height and diameter. Samples were oven-dried at 65°C to calculate the absolute dry weight per hectare. For statistical tests the t-test and variance analysis according to Scheffé ($p<0.05$) were used. Ranges given in the tables are absolute values. Total samples were pulverized by plant rotor mill, model Fritsch Pulverisette 14.

The chemical and energetic properties of the above-ground biomass and of wood ash were determined as follows:

Total nitrogen concentration: C/N-analyser LECO Instruments, model CHN 1000; determination of N by Electronical Conductivity EC. Total sulphur concentration: S-analyser, model SC 432, LECO Instruments. Oxidation at 1350°C; determination of SO_2 by infra-red spectroscopy. Total concentrations of P, K, Mg, Ca, Cd, Pb: HNO_3-digestion under pressure. Element determination of P, Mg, Ca by ICP, model PU 701, Unicam. Determination of K by AAS, model Solar 932, Unicam. Determination of Cd and Pb by GFAAS, model Solar 932, Unicam. Chloride concentration: Water extraction. Determination by IC, model DX 120, Dionex. Wood ash contents after DIN 51719, calorific value after DIN 51900, ash softening temperature after DIN 51730.

3.2 Results and discussion

3.2.1 The above-ground biomass at age 4

The present study shows above-ground biomass increments ranging from 5.3 to 19.6 tons dry matter (DM) per hectare at age 4 years (average 9.2 t ha^{-1}; 2.3 t $ha^{-1}yr^{-1}$). After 4 years growth the mean height of the clones and progenies ranged from 199 cm to 351 cm; the mean diameter of the species ranged from 20 mm to 41 mm (Bungart 1999). The wide range of productivity is related to the different nutrient- and water-use efficiency of the clones (Bungart 1999; Bungart et al. 2001). Based on the definition for fast-growing tree species by Röhrig (1979) the annual increment of above-ground biomass was found to decrease significantly under the threshold value of 5.4 t $ha^{-1}yr^{-1}$. However, since this threshold has been defined for high productivity sites these results cannot simply be applied to disturbed mine sites with marginal fertility. Jug et al. (1999) and Hofmann-Schielle et al. (1999) determined an average above-ground biomass yield of between 5.1 and 5.9 t $ha^{-1}yr^{-1}$ for a five-year rotation period on former agricultural sites with loamy-sandy brown podzolic soils with the same genetic plant material and for similar density and spacing.

3.2.2 Chemical properties of wood and nutrient export at time of harvest

The chemical properties of the 4-year-old above-ground biomass represent the total above-ground nutrient accumulation by a plantation (kg ha^{-1}). It is therefore a measure of the nutrient replacement with regard to the nutrient depletion by harvesting the above-ground biomass (Hansen and Baker 1979). These nutrients should be replaced after harvesting to maintain site productivity and the soil nutrient pool for the further rotation periods. Table 2 shows the element concentrations for macro- and micronutrients and heavy metals on a dry matter basis (DM) for the above-ground biomass. The total accumulated nutrient concentration of phytomass is given in Table 3.

Jug et al. (1999) described nitrogen concentrations in 5-year-old stems in a short-rotation plantation ranging between 3 and 7 mg g^{-1} DM. Hofbauer (1994) discussed general N concentrations of wood of about 1.1 mg g^{-1} DM and bark of about 4.2 mg g^{-1} DM. In the present study the proportion of bark and branches of the total above-ground biomass is relatively high since the diameter of the growing stock is still low. Therefore, the range of N concentrations are within the upper level of data given in literature. At the end of the fourth vegetation period 51.0 kg N ha^{-1} (range 31–88 kg ha^{-1}) have been accumulated in the above-ground biomass and would, therefore, be exported out of the system at time of harvest. Jug et

Table 2. Element concentrations of the 4-year-old above-ground biomass (s.d. = standard deviation).

Dry Matter	N [mg g^{-1}]	Cl [µg g^{-1}]	P [mg g^{-1}]	K [mg g^{-1}]	Mg [mg g^{-1}]	Cd [µg g^{-1}]	Pb [µg g^{-1}]
Mean	4.9	113	0.8	3.6	0.6	0.8	0.5
s.d.	0.99	5.8	0.13	0.66	0.09	0.7	0.17
Min–Max	4.3–6.9	67–194	0.7–1.0	2.7–4.9	0.5–0.8	0.2–2.7	0.2–0.7

Table 3. Element accumulation in the 4-year-old above-ground biomass.

Dry Matter	N [kg ha^{-1}]	P [kg ha^{-1}]	K [kg ha^{-1}]	Mg [kg ha^{-1}]	Ca [kg ha^{-1}]	Cd [g ha^{-1}]	Pb [g ha^{-1}]
Mean	51.0	7.8	35.1	5.7	57.9	7.4	4.6
Min–Max	31–88	4–15	21–70	3–14	34–105	2–25	2–6

al. (1999) presented annual N accumulation rates of between 18 and 26 kg ha^{-1} in the first 5-year rotation period.

A high chloride concentration of woodfuels is well known to cause corrosion and to increase the emission of acidic compounds during the thermal transformation process (PCDD/PCDF). In the present study 113 µg g^{-1} DM of chloride were found in the dry matter. This is similar to other findings (Schriever 1984; Hofbauer 1994).

The phosphorus concentration of the above-ground biomass at age 4 ranged from 0.7 to 1.0 mg g^{-1} DM which is in line with data of Jug et al. (1999) and corresponds with P concentrations found in hay (Hasler and Nussbaumer 1996). In the present study 7.9 kg P ha^{-1} (range 4.1–13.9 kg ha^{-1}) are accumulated in the above-ground biomass after the 4-year rotation period. These values are similar to the findings of Jug et al. (1999) who reported a biomass accumulation of about 9–15 kg ha^{-1}.

Concentrations of potassium in the wood varied between 2.7 and 4.9 mg g^{-1} DM and were similar to those of previous studies (Hofbauer 1994; Jug et al. 1999). Corresponding to the low biomass accumulation of about 20.9–69.7 kg ha^{-1} (mean 35.1 kg ha^{-1}), K accumulation in the above-ground biomass was less than the K removals by harvest. Hansen and Baker (1979) found that the range of K concentrations of low-yielding clones was between 22 and 89 kg $ha^{-1}yr^{-1}$.

In the present study harvesting of 4-year-old biomass caused a removal of about 58 kg Ca ha^{-1} which was significantly lower compared with the findings of Jug et al. (1999) who calculated Ca net accumulation of 30–210 kg ha^{-1}.

Based on a mean magnesium concentration of the wood of 0.6 mg g^{-1} DM an accumulation rate of 5.7 kg Mg ha^{-1} was calculated. The present data are roughly equivalent to those presented by Hasler and Nussbaumer (1996). Jug et al. (1999) reported Mg values in 5-year-old above-ground biomass ranging from 0.4 to 0.6 mg g^{-1} DM. The chemical properties of the 4-year old biomass are in line with the chemical properties of the biomass reported at age 3 years (Bungart et al. 2000).

In the course of the thermal transformation heavy metal concentrations may increase significantly. Therefore, for the utilization of ash from biomass a comprehensive risk analysis is necessary to ensure that threshold values will not be exceeded (Obernberger 1997). According to Hofbauer (1994) the Cd concentration in wood and bark ranges from 0.2 to 2.7 µg g^{-1} DM. This parallels the findings of the present study. For the above-ground biomass a net accumulation of 7.4 g ha^{-1} was calculated. The average Pb concentration of wood is about 1.1 µg g^{-1} DM (Hasler and Nussbaumer (1996). In the present study Pb concentrations of wood was significantly lower (0.5 µg g^{-1} DM) resulting in a Pb accumulation of 4.6 g ha^{-1}.

3.2.3 Energetic properties of the above-ground biomass

Concentrations of Ca, Mg and K in the solid biofuels have an important influence on the ash softening point, which refers to the tendency of ash to turn to slag during the thermal transformation process. Once slag has formed, nutrients are immobilised, and cannot be used for site amelioration. In addition, the current German legislation prohibits the utilization of slag in the open field. Due to a relatively high ash softening temperature (between 1480 and 1640°C), wood and bark are considered to have the most favourable thermal characteristics among the group of solid biofuels (Hofbauer 1994). In the present study an ash softening temperature of the above-ground biomass from the experimental site ranged between 1670 and 1690°C. The ash content influences the logistic conditions of transportation as well as storage of ash (Obernberger 1997). Biomass grown on mining substrates shows an average ash content of about 2.4%. Four years of biomass accumulation equates to an ash production of about 221 kg ha^{-1}. Because of the relatively low diameter of individual trees the relative portion of bark in the total biomass increased on a dry weight basis. In consequence, the ash content is higher than the values presented by Hofbauer (1994) and Obernberger (1997). The calorific value of the solid biofuel analysed after 'DIN 51900' is about 17 000 MJ kg^{-1}. For the biomass accumulated within the 4-year rotation, a calorific value of 42 GJ $ha^{-1}yr^{-1}$ has been calculated (Table 4).

Table 4. Ash content, ash softening temperature and calorific value.

	Ash content [% wt]	Ash softening temperature [°C]	Calorific value [MJ kg^{-1}]	Calorific value [MJ ha^{-1} yr^{-1}]
Mean	2.4	1680	17	42 000
Min–Max	2.0–2.8	1670–1790	16.8–17.2	

3.2.4 Chemical properties of wood ash

During the process of thermal transformation of biomass nitrogen will be completely emitted as N_2 and NO_x. Hence, in the present study the N concentrations of the wood ash did not exceed 0.17 mg g^{-1} DM. Within the group of the macronutrients highest concentrations were recorded for P, K, Mg and Ca. With regard to the Pb and Cd concentrations the present data (Table 5) exceeded those reported by Obernberger (1997), but are still acceptable for thermal utilization.

Table 5. Nutrient and heavy metal concentrations of ash.

DM	N [mg g^{-1}]	P [mg g^{-1}]	K [mg g^{-1}]	Mg [mg g^{-1}]	Ca [mg g^{-1}]	Cd [µg g^{-1}]	Pb [µg g^{-1}]
Mean	0.17	29.9	111.7	21.4	218.3	5.9	42.5
Min–Max	0.1–0.2	23.0–32.1	89.2–139.7	19.6–22.5	186.9–229.8	1.2–13.0	28.7–64.3

3.2.5 Nutrient balance between element re-import by ash replacement and element removal by harvesting

The element concentrations of the ash calculated on an area basis are shown in Table 6. The present data exemplified the potential of ash for amelioration purposes and replacement of nutrients as caused by biomass removal. Especially the macroelements P, K, Ca and Mg balanced the nutrient export by harvesting. A compensatory application of fertilizer is only required for N (atmospheric N-input is about 12 kg ha^{-1} yr^{-1}) to maintain site productivity. Ongoing research work is focusing on the effects of fast-growing tree species on the chemical soil properties as well as on amount and composition of fertilizers and the optimum time for application.

Table 6. Element accumulation in ash (kg ha^{-1}) and balance due to the element import by ash application (I) and element export by harvesting biomass (E) at age 4 years. (s.d. = standard deviation).

DM	N [kg ha^{-1}]	P [kg ha^{-1}]	K [kg ha^{-1}]	Mg [kg ha^{-1}]	Ca [kg ha^{-1}]
Mean (I)	0.04	6.3	23.5	4.5	46.1
Min–Max (I)	0.01–0.07	3.2–12.7	12.4–43.7	3.0–8.8	29.4–95.1
Balance (I)–(E)	–50.8	–1.4	–11.7	–1.2	–11.8
s.d.	20.9	0.2	1.1	8.6	10.9

So far our results indicate that the cultivation of fast growing tree species in short-rotation plantations is an adequate tool to establish sustainable landuse systems in the post-mining landscapes. This landuse system, therefore, can be considered to present an important potential to rehabilitate land resources without any competition to the common agricultural landuse which corresponds to the EU agricultural policy. Especially in the federal state of Brandenburg the availability of wood fuels shows regionally large fluctuations ranging from 2 to 9 MWh per year and capita. The landuse system of short-rotation plantations, therefore, serves to balance regional deficits in rural areas and to provide solid biofuels of high quality and quantity.

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South-Eastern European Biomass Action – A New International Research Co-operation between Slovenia and Croatia

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Abstract

In the Resolution on Efficient Energy Supply and Use in Slovenia (1996), much attention was paid to wood biomass, which is, in fact, the only natural renewable source of energy in which Slovenia abounds (besides water). The current share of woody biomass in primary energy in Slovenia is around 4%. The development strategy anticipates that in the next 10 years this share should rise to 8%. When the national energy programme BIOEN (Biomass Use Programme) was launched in 1997, Croatian bioenergy future took a new image. The BIOEN Programme vision is that by 2030 at least 15% of the Croatian energy needs will be derived from biomass and waste. In the recently published Energy Strategy of the Republic of Croatia, bioenergy, unlike other renewables, has a significant position in all of the analysed scenarios. To achieve these goals, many actions were taken in both countries. One of the important projects is the joint research co-operation action. The overall aim of this international co-operation is to promote efficient use of biomass through achieving a better understanding of the socio-economic impacts of bioenergy systems at the regional (rural development) and national levels (higher share of wood biomass in primary energy).

Keywords: biomass, bioenergy, socio-economic aspects, international research co-operation, Slovenia, Croatia

1. Introduction

Biomass resources are potentially the world's largest and most sustainable energy source – a renewable resource comprising 220 billion oven dry tonnes (about 4500 EJ) of annual primary production. The annual bioenergy potential is about 2900 EJ, although only 270 EJ could be considered available on a sustainable basis and at competitive prices. Most major energy scenarios recognise bioenergy as an important component in the world's future energy. At present, biomass supplies some 10–15% of the energy demanded all over the world. In the 15 countries of the European Union, biomass now provides, on average, 3.5% of the primary energy consumed, but a three-fold increase is forecast by the White Paper of the EU.

Historically, biomass has been used in selected regions in Slovenia and Croatia by local populations mainly for heating and cooking. The other sector with significant biomass utilisation is the wood industry. In Slovenia and Croatia forestry is the most important source of biomass for energy production and previous analyses show that there is a huge unused biomass potential. Introduction of modern, efficient technologies for biomass utilisation (district heating systems, combined heat and power (CHP) plants) should be given priority in all further actions.

Although Slovenia and Croatia were closely connected in the past, there was a significant lack of joint actions and projects after becoming independent states. A number of similarities between both countries make co-operation relatively easy and reasonable. Also, the socio-economic effects of biomass use were never precisely quantified in either Slovenia or Croatia, and subsequently have never taken an important place in the energy policy of both countries.

Realisation of the energy policy of Croatia is planned through a certain number of national energy sector development programs, whose goals include increasing the use of renewable energy sources. There are ten national energy programs and one of them is the Biomass Use Program – BIOEN. The BIOEN program vision is that by 2030 at least 15% of the Croatian energy needs will be derived from biomass and waste. According to various factors (the development of agriculture and forestry, new technologies, etc.), the technical potential of biomass and waste is expected to be between 50 and 80 PJ in 2030. This makes biomass the most significant renewable source of energy. The recently issued Energy Strategy of the Republic of Croatia has considered three different scenarios. Unlike other renewables, bioenergy holds a significant position in all scenarios.

Slovenia is a country poor in fossil fuels, in particular those of high quality. The existing energy system based on hydroelectric stations is largely exploited and, for various reasons, the Krško nuclear power plant is posing problems as well. Due to Slovenia's specific natural conditions in the Alpine and Sub-alpine area, the environment is very vulnerable, which makes the construction of new power plants both a demanding and costly intervention. Slovenia's dependency on imported energy has reached as much as 75%, although it should not exceed 65%. The use of energy per inhabitant is within the average in the EU, while the consumption per unit of GDP is 2.5 times higher, which means that energy is not used as efficiently as in the EU. With respect to this situation, it is understandable that the Resolution on Efficient Energy Supply and Use in Slovenia (1996) gives special emphases to the improvement of efficiency, and to the increase of consumption through renewable energy sources. Among the renewable and alternative sources, special attention is focused on wood biomass, which is, in fact, the only natural source of energy in which Slovenia abounds (apart from water). The important advantages of this energy source are traditional use, general and scattered occurrence, private ownership, as well as the possibility of ecologically acceptable use. Therefore, the Resolution anticipates in its guidelines that its present share of 4–5% in primary energy should double by the year 2010. There are already 55 medium-sized heating installations with a rated power above 1 MW, but they are installed for processing heat for industry. According to our estimates, the major part of wood waste is unexploited. The key components for planning and realising the increased use of wood biomass at different levels are the qualitative and quantitative analyses of the available sources and all social and economic effects for the region and country development.

2. State-of-the-Art of Bioenergy in Slovenia and Croatia

In Croatia, bioenergy contributed 5.1% to the total energy supply in 1998. Heating wood and commercial and non-commercial cutting down woods amounted to 15% of the primary energy consumption in 1970, and in 1990 that part, due to urbanisation and growth of living standards, was 5.3%. In the past, biomass had never taken an important place in the energy policy of Croatia. However, in the course of the last few years the Croatian scientists and engineers have carried out much research and developed different technologies for energy production from biomass. In the area of briquetting, significant results have been achieved, and in some Croatian regions the briquette market is already well established. The research has been conducted on briquetting (wood waste, sawdust and maize stalks), biogas motor development and biomass fired boiler construction.

As almost 44% of the area of Croatia are covered by woods and forests, developed agriculture and wood industry, biomass has a great potential as a source of renewable energy. Total technical energy potential of biomass for energy production in Croatia was estimated at 33.8 PJ/yr in 1995. The most significant source of biomass for energy production is woody biomass from forests (fuel wood, forest residues and wood waste from wood processing industry). However, agricultural residues have a significant energy potential in both eastern Croatia and its coastal zone.

Although Croatia has significant potential for energy production from renewable resources, there are certain difficulties and barriers as far as the increase of this share is concerned. There are two critical barriers to the wider adoption of renewable energy sources in Croatia and especially in community-based project:

1. social barriers; and
2. lack of financing or resources.

Croatia will soon have to face the challenges of energy shortage, and the socio-economic issues. Renewable energy resources could play an important role in the promotion of numerous Croatian objectives. The development of a successful bioenergy sector could in the long term contribute to the:

- energy efficiency improvement;
- diversification of energy production and contribution to security of supply;
- domestic production and decreased import of energy;
- significant reduction of the environmental influences from the energy sector;
- creation of new jobs and investment in rural areas, in areas of special interest of the state, in coastal regions and islands; and
- retention of income within local communities.

The road ahead is full of opportunities and challenges. The new Government will have to recognise the importance of bioenergy use, particularly for agriculture and forestry, but also for development of local communities and rural areas. A full implementation of the proposed Energy Strategy, prepared by leading Croatian experts, should enable wider use of modern biomass technologies with a number of positive effects on the Croatian economy, society and population. The south-eastern European Biomass Action could be an important step in this direction.

Slovenia is one of the most wooded countries in Europe; 56% of its surface area is covered by forests. And the forest area is getting even larger. The problem lies in the abandonment of agricultural land. Many young people are moving from rural to more developed urban areas. The result of this process are completely unused – abandoned – areas. Here two very important questions are raised. How can these areas be developed? And how can new activities be created within them? This is not only a research problem, but one of the very important political issues as well. Production of wood fuel, creation of wood fuel market and the increase use of wood for power production can be one of the possibilities for activities creation, for new sources of income on farms, and for development of rural areas.

Of the total amount of available wood (about 2.1 million m^3/yr), 60% is used in timber and paper industry, 15% for energy and 25% for home consumption. Total technical energy potential of biomass for energy production in Slovenia was estimated at 12.6 PJ/yr in 1996. The wood biomass still is an important energy resource for individual heating. Nowadays, 30% of housekeeping are still using wood or wood waste for heating purposes. The problem is in the old (traditional) technologies of preparing and using wood for heating. The main characteristics of this technologies are: low efficiency (less then 60%), high emissions of CO, preparation of fuel wood is time consuming work, and the quality of living is lower. Due to these characteristics and low prices of fossil fuels in the past, a lot of people, also in rural areas, decided to substitute wood with oil or natural gas. Now the prices of fossil fuels have changed and we have new opportunity for introducing modern technologies using renewable sources of energy, woody biomass being the most important among them.

To change the present situation, some actions for a better future of wood biomass have already been taken in both countries. The most important actions taken in the past are:

1. energy strategies in both countries emphasise the importance of biomass in the future,
2. surveys were carried out in the field of estimation biomass potential (BIOEN in Croatia, GEF project in Slovenia),
3. introduction of pilot projects of modern technologies (PHARE Project: District heating system for Gornji Grad in Slovenia),
4. implementation of an international research co-operation,
5. transfer of knowledge and technologies (know-how), now already in progress.

Nevertheless, the main barriers for more effective and increased use of wood biomass for energy purposes still are:

1. economic barriers: high investment costs (start-up investments in modern technologies are at least 3 times higher than start-up investments in other technologies);
2. social barriers: knowledge and behaviour of end users (lack of information and no system for education).

If we want to overcome these barriers, we should help the decision makers with a tool to support their decisions, with a tool to develop a system for subsidies, and with knowledge transfer to the end users.

3. Cornerstones and Aims of the South-Eastern European Biomass Action

The overall aim of the project, which is being developed between Slovenian and Croatian partners, is to promote efficient use of biomass for energy in joint Croatian-Slovenian actions through achieving a better understanding of the socio-economic impacts of bioenergy systems at the regional and national levels.

Although the project is based at the regional level, full account will be taken of the overall national and international framework, within which the region should work. Regions for the case study (Gorski kotar in Croatia and part of the Notranjska region in Slovenia) were chosen, as they are border regions between Slovenia and Croatia. They are both rural areas, the natural conditions are similar (more than 50% of the region is covered by forests) and they have been traditionally closely connected with the forestry and timber industry.

Because of a number of similarities between other border Slovenian-Croatian regions and the entire South-eastern Europe (transition countries), the potential to apply these results to other areas is very high. Special attention will be given and linkage made to ongoing and proposed activities in both Croatian and Slovenian energy sector restructuring and development as well as EU recommendations and actions in this field. The proposed action will be co-financed from and activities linked with recently launched IEA Bioenergy Task 29 'Socio-economic aspects of bioenergy systems'.

The Task on Socio-Economic Aspects of Bioenergy Systems ('Task 29'; duration 1st Jan 2000 – 31st Dec 2002) is an international collaboration within the IEA Implementing Agreement on Bioenergy. The International Energy Agency (IEA) has been established within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an international energy programme. The objectives of this Task are:

- to determine the economic contribution (e.g. in financial terms, local industry creation, infrastructure developments) resulting from the deployment of bioenergy systems;
- to determine the social impact (e.g., employment, education, health) resulting from the deployment of bioenergy systems; and
- to encourage the exchange of information and Task results between participants and also with countries in transition (Objective 5 of the IEA Bioenergy Strategic Plan).

Currently six countries are participating in Task 29 (Austria, Canada, Croatia, Japan, Sweden and the UK). Slovenia, India and New Zealand have shown interest in participating and act as observers.

Special attention will be given to energy policy education and training through workshops and seminars for targeted groups (policy makers, potential investments and local authority from both countries, scientific experts and students) and interactive use of the internet. Nearly all countries in transition have similar problems:

- high dependence on energy imports;
- problems with reduction of greenhouse gas emission;
- many undeveloped rural areas;
- insufficient utilisation of different renewable sources of energy.

Croatia and Slovenia signed the Framework Convention on Climate Change as well as Annex 1, committing themselves to reduce emissions of greenhouse gases (GHG) by 5% and 8% in comparison with the base year. Due to very low emission, expected development and significant forest area in the base year, both countries may have difficulties with fulfilling this obligation. Biomass utilisation is recognised as an effective option for the reduction of net GHG emission and achieving targets from the Kyoto Protocol.

Today, biomass energy is experiencing a surge in interest in many parts of the world due to: greater recognition of its current role and future potential contribution as a modern fuel in the world's energy supply; its availability, versatility and sustainability; a better understanding of its global and local environmental benefits; perceived potential role in climate stabilisation; the existing and potential development; technological advances and knowledge, which have recently accumulated on many aspects of biomass energy. A systematic approach to biomass use in the selected Croatian and Slovenian region could be of value for approaching a series of issues covered by these actions:

- evaluation of socio-economic aspects of bioenergy systems in national energy policy;

- recognition of contribution of bioenergy systems in regional development (regional employment created, regional activity created, regional economic gain, increased regional incomes, regional return on investment, avoided unemployment, regional public finance receipts, support of related industries);
- developing guidelines for Slovenian-Croatian co-operation in biomass use projects and creation of a possible model for joint actions of other transition countries in this field; and
- energy policy advice education and training for targeted audience with participation of international experts from the IEA Bioenergy Task 29.

There are at least three very good reasons to introduce the regional co-operation in biomass for energy utilisation and to launch this action:

1. utilisation of large biomass potential and contribution to environment protection;
2. energy analysis of socio-economic aspects of bioenergy systems at the regional and national levels and their recognition and evaluation in energy policy of Croatia and Slovenia; and
3. positive aspects of Slovenian-Croatian joint project in renewable energy area.

It is planned that the described action will be carried out in the following phases:

Phase 1: Analysis of current situation and possible future scenarios.
Phase 2: Evaluation of socio-economic aspects of bioenergy use at the regional and national levels.
Phase 3: Identification of possible projects in selected regions and developing guidelines for Croatian-Slovenian co-operation.

4. Expected Results of the Action

The most important result of the joint research action should be the answer to the decision makers' question introduced in Figure 1.

The expected results can be divided into four groups:

1. estimate of all socio-economic aspects of wood biomass systems in selected region;
2. model (modified for situation in both countries) for quantification of all socio-economic aspects;
3. selection of economic methods for the evaluation of costs and benefits of use of wood biomass for the region; and
4. developing a method for gathering public opinion about wood biomass projects (possibilities for developing a market for wood biomass, participation, willingness to pay, etc.).

In the selected regions we would like to collect all the necessary data on:

- present use of different fuels;
- wood biomass potential; and
- economic data for the region.

We would also like to carry out a public opinion survey and a wood biomass flow survey. Very important are data on plans for the future (for example, data on bio-energy plant). Using different methods, we would like to estimate all socio-economic aspects of the increased use of wood biomass and estimate all costs and benefits of this use.

By comparing different methods, we would like to propose a method for efficient collecting of the necessary data, a method to estimate all socio-economic aspects, and a method to assess public opinion.

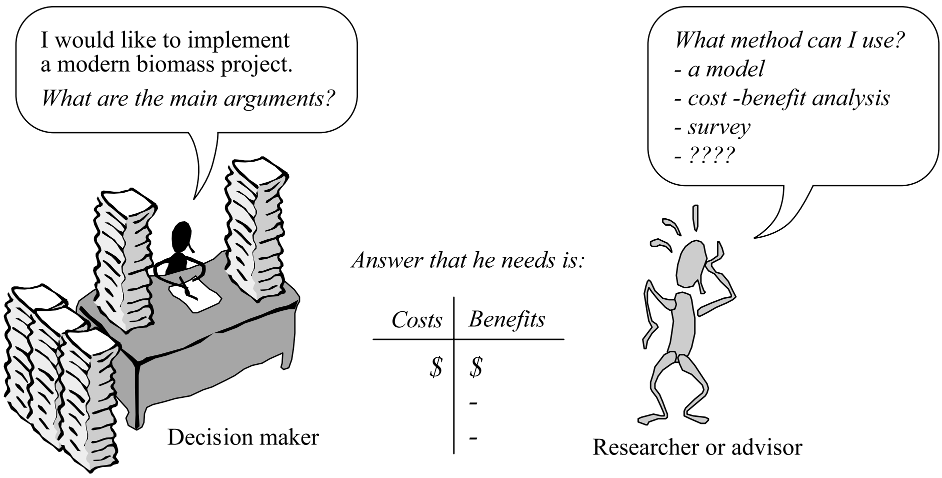

Figure 1. Relationship between decision makers and researchers.

5. Conclusion

The overall aim of the joint action – research co-operation between Croatia and Slovenia is to get better understanding of all aspects of the increased use of wood biomass at the regional level. The challenge is not only to review of possible impacts of the increased use of wood biomass, but also to gauge public opinion.

In general we can say that biomass is not very ‘popular’ among people. They are clearly sceptical about new technologies. The main reason for this situation is lack of information. This situation is similar in both countries.

To overcome this barrier, we should develop a tool to estimate all aspects of the increased use of wood biomass. With clear presentation of all direct and indirect costs and benefits (employment, displaced agricultural activities, developing a market for wood fuel, activity created) public opinion could be affected. We could also possibly have an impact on wood biomass policy.

For example, Slovenia plans to: build 50 new district heating biomass plants (each with more than 2 MW) in the next 10 years; build 100 modern biomass power plants in industry; and install 5000 modern individual heating systems (with the capacity of up to 50 kW). This plan can have a great impact on rural development, job creation, wood fuel market and all forests in Slovenia. Will there be enough wood fuel? Will there be enough money in the budget for subsidies? The answer for all these questions is NO, and this is one of the main reasons why we need a tool to estimate all aspects. Estimates of costs and benefits should be the most important criterion for state subsidies and state policy.

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Biomass for the Post-Industrial Landscape

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Abstract

This paper considers the use of biomass for heat and power as a means to help regenerate the post-industrial landscape of Lanarkshire in Scotland's Central Belt. It examines the changing policy framework and the impetus this has created to find environmentally attractive and sustainable solutions to regeneration. It explores the economic case and the role of the public sector in achieving commercial and public benefits. It concludes that the case for developing biomass in the area is strong and that the public sector should act as a catalyst to establish a viable biomass business in Lanarkshire.

Keywords: biomass, Scotland, Lanarkshire, industrial regeneration, renewable energy

1. Introduction – the Landscape and People

Lanarkshire is located in Scotland's Central Belt, lying to the south and east of Glasgow. It has a wealth of mineral resources, including coal, which led to its great industrial boom in the 19th century – canals, railways, steelworks, mines and mills transformed the landscape. Lanarkshire was at the heart of the Victorian Industrial Revolution and that process has heavily scarred its landscape – it is not a place of mountains and lochs, but of former pits and steel works.

However, Lanarkshire is now emerging from a period of sustained landscape change caused by social and economic forces arising from de-industrialisation including the closure of deep mines and the loss of the area's steel works. A key indicator of this change is the Scottish Vacant and Derelict Land Survey (SVDLS) which shows that Lanarkshire has over one third of all Scotland's derelict land amounting to some 2800 ha spread over 1400 sites.

Furthermore the land in the area is generally poorly suited to agriculture. Small farm units are heavily subsidised with incomes forecast to fall again in the coming year. Large mixed

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estates that pre-date the industrial revolution have been gradually broken up and the many small estate and farm woodlands, originally planted for amenity, timber and domestic use, have fallen into neglect.

The communities in the area are culturally linked to the area's industrial past and, as a result of the decline in industry, have suffered a range of social and economic stresses. Indicators include high unemployment, a high proportion of government subsidised housing, low car ownership and poor health compared to the Scottish average. There is a lack of any real cultural association between the people and the land.

In recent years there has been substantial progress in the regeneration of the area. For example, the new towns of Cumbernauld and Livingston have been successful in attracting technology and service-based industries, and Enterprise Zones, with simplified planning procedures and financial incentives, have been successful in attracting inward investment. However, the enthusiastic promotion of economic development has supported a permissive development culture, and 'hope value' around the city fringes has contributed to under-management of land.

In late-1998 several organisations began thinking about the concept of woody biomass to help continue the physical regeneration process. They intuitively recognised that a variety of local factors – the prevalence of derelict land, a lack of land management, agricultural decline and an increasing priority attached to environmental and social issues by policy makers – seemed to combine and that the concept might help address these in a holistic manner.

The key partners in this process were Central Scotland Countryside Trust, a Government funded agency seeking to deliver the Central Scotland Forest, Scottish Enterprise Lanarkshire, the local economic development agency and North Lanarkshire Council, one of the two Local Authorities covering Lanarkshire.

This paper describes the process we went through, firstly by setting out the policy framework and strategic responses to environmental regeneration. It then explains how we intend to deliver the concept and the costs, benefits and delivery mechanisms.

2. Policy Framework and Strategic Responses to Environmental Regeneration

2.1 National framework

The Scottish Parliament was set up in November 1998 and the new government was elected in May 1999, with 'New Labour' as the dominant party. Since the election, the issue of 'social inclusion' has dominated the agenda. Priority has been given to employment and training, health, education, rural issues and community engagement. In the current climate, new initiatives are more likely to succeed if they relate to these key policy agendas.

2.2 Climate change and renewable energy

Climate change and renewable energy have also had a place on the policy agenda following the 1997 Kyoto commitment to reduce greenhouse gasses. With its large hydro electric programme, Scotland already achieves a target of 10% energy from renewables and has recently consulted on increasing this to 17.5% by 2010. A recent draft Planning Guideline on Renewable Energy (Scottish Executive Development Department 2000) sets out an expectation that much of the new capacity will come from onshore wind and to a lesser extent, hydro, waste to energy and biomass. Also very helpful to our initiative, this document suggests that it may be easier to accommodate renewable energy developments in the central belt and southern Scotland, including semi-urban and brown field land. This is due to limitations in the transmission grid in the north.

2.3 The regional planning and policy framework

The land use planning policy framework for regeneration is, at best, unfocused and there is a conspicuous lack of a serious government policy statement on regeneration. Structure Plans are the highest level of spatial planning in Scotland, but since Local Government reorganisation in 1996, strategic planning has become fragmented with problems of gaps in coverage, different scales of working and the teething troubles of new Structure Planning mechanisms. The many Local Plans that cover the area vary widely in their approach to regeneration resulting in many cross boundary inconsistencies.

In 1997 Scottish Enterprise Lanarkshire (SEL) produced a co-ordinated 10-year strategic plan for economic development. This plan recognised the need to transform the environment of Lanarkshire, it also acknowledged that this could only happen if the public and private sectors worked in partnership to agreed goals. It did not, however, detail all the mechanisms that would actually deliver these aspirations.

In 1997, SEL went on to produce a Derelict Land Strategy to help reduce the amount of derelict land. It focussed on seeking to promote private sector development on derelict land by offering financial incentives. This has reduced the recorded problem by some 30% between 1997 and 2000. This success is a firm foundation and is being built upon as more sites are regenerated by development. The Strategy also identified the need to develop a ‘greening framework’ as a mechanism to regenerate land less suited for built development. Our initiative is now one of its 7 themes.

An emerging rural strategy for the area is also seeking to address some of problems associated with agricultural decline. It specifically recognises the potential of biomass.

2.4 The Central Scotland Forest

The Central Scotland Forest is a government initiative for the strategic regeneration of the area most affected by industrial decline. It covers an area of over 1500 km^2 between Glasgow and Edinburgh. It has a population of 750 000, with many more people close by in the two cities. It is a partnership initiative led by the Central Scotland Countryside Trust. Partners include central government, local authorities and government agencies. Initiated in 1989, its purpose is to regenerate the environment as a spur to attracting employment and to improve the quality of life for people in the area. A target has been set of doubling woodland cover over 20 years to create an attractive and ‘well wooded’ landscape linked to a range of social and economic benefits.

With the focus primarily of tree planting for the first decade (some 5000 ha of new woodland has been planted – around 25% of the target), the focus has now turned to securing the downstream benefits of the Forest. These include opportunities for employment, leisure and healthy lifestyles, biodiversity improvements and community and educational development. It is clear that woody biomass can help meet some of these objectives.

2.5 Waste policy and management

Other specific policies also provide relevant support to the initiative. The wish to improve waste management in the UK led to the recent establishment of the ‘Landfill Tax’ which provides an enhanced incentive to recycle and reuse waste including for example, forestry waste. Perhaps even more important for the project, funds raised under this scheme are available to support a wide range of environmental projects including, for example, renewable energy projects.

The recent ban in Scotland on the dumping of sewage sludge at sea is also relevant. With new arrangements still being developed, recycling to forestry land (and biomass crops in particular) is an attractive option.

2.6 Agriculture

The major change underway in agricultural support is likely to increase the rate of farm restructuring, opening the way to a range of alternative uses with the opportunity for diversion of some land into energy crops. The Scottish Rural Development Plan, at the time of writing, had not yet been approved in Brussels. It is hoped that increased support for non-agricultural rural development will be available for a range of diversification and 'capacity building' programmes including renewable energy initiatives. Forestry grants continue to be available through the Woodland Grant Scheme although grants for short-rotation coppice (SRC) are less than generous.

2.7 Local energy context

At present, mains electricity and gas are the main sources of energy in Central Scotland although some of the more remote villages and properties are not on mains gas. Coal fired heating has almost disappeared from the area and there is little culture of collecting and burning wood on open fires or in stoves. Wind farms are beginning to appear in the landscape. In addition, a new biomass fired electricity generating station is being built in Carlisle just across the border in England that is expected to open in 2003. Lanarkshire is just within the catchment area for fuel supply.

3. Introduction to the Lanarkshire Biomass Project and its Potential Benefits

In 1999/2000, as the biomass debate in Lanarkshire gained focus it extended from its original three partners to include other prospective partners, including: South Lanarkshire Council, Scottish Homes, the Scottish Executive, the Forestry Commission, Scottish Enterprise National, and the private sector (including, for example, Scottish Coal and privatised water companies).

As a result a study was commissioned highlighting the viability of developing various biomass business opportunities. This enabled the benefits and rationale for developing the initiative to be articulated.

Clearly, the wider strategic justification for developing a local biomass business relates to its contribution to the climate change agenda. However, there are a number of potential local benefits that have been identified by the project stakeholders that meet many of the policy objectives described and provide a clear rationale for developing the concept:

- It will provide a long-term and beneficial use for derelict, vacant, abandoned, under-used and marginal agricultural land.
- It will create a new business activity in the local economy providing new jobs. This will be significant in socially excluded areas affected by a decline in the mineral extraction industries.

- It will generate a commercial use for forestry waste and so encourage the management of derelict woodlands.
- It will diversify farmers' income.
- It will improve the character and recreational use of the landscape, particularly in the urban fringe.

Econometric studies have not been undertaken to quantify the benefits that are specific to biomass development in Lanarkshire. However, a cost benefit study of the Central Scotland Forest in 1996 indicated that by far the greatest values of woodland establishment in this area arise from landscape and recreation benefits (£68 million and £25 000 million, respectively) and that these benefits are far beyond any market value for timber products. Similarly high levels of landscape and recreation values are likely to arise from biomass establishment in this post-industrial area and design issues will need to be borne in mind to ensure that this significant benefit can be fully realised.

4. The Economics of Biomass in Lanarkshire

In order to determine the viability of the production of heat/energy from biomass in Lanarkshire, we assessed the cost of producing fuel from a range of land types, and the value of fuel to the user under different conversion systems (Table 1). The selection of both land types and conversion options took into account our wish to deliver multiple benefits to assist the overall regeneration of the area and to address some of the key policy agendas.

Table 1 shows that the cost of producing fuel ranges from £0/o.d.t. to £85/o.d.t. This takes account of establishment costs, yield, and rent of land, interest rates, annual management,

Table 1. Summary of biomass market options (o.d.t. = oven dried tonne).

Cost of Producing Fuel	
Land/Biomass Type	**Fuel Cost (£/o.d.t.)**
Short-rotation coppice (SRC) on agricultural land	46
Trees on agricultural land	0
SRC on under-utilised agricultural land	50
Trees on under-utilised agricultural land	70
SRC on opencast sites (reclaimed)	50
Trees on opencast sites (reclaimed)	85
SRC on contaminated sites	29
SRC in urban fringe	27
Existing woodland	12
Value of Fuel To User	
Conversion Option	**Price that can be paid for wood fuel (£/o.d.t.)**
Supply of electricity to the grid through a local generation plant.	30
Generation of electricity via Carlisle Power Plant	26–30
Room heating with logs	50
Wood chip boiler for heat – 200kW upwards	Fuel price integral part of business plan
Village district heating for villages off mains gas	40–45

harvesting and transport to a local store. It also takes account of grants from the Forestry Commission that will offset these costs.

It excludes extraordinary 'ground condition costs' and any 'social costs' relating to planting in urban fringe areas. It also excludes the infrastructure costs of supply.

The major discrepancies in costs for apparently similar options are largely the result of the grant system where very different grant rates are available for different types of land and planting systems.

The table also shows that the price that can be paid for wood fuel (value of fuel to user) ranges from £26–30/o.d.t. to around £50/o.d.t., under the different conversion options that were considered.

In addition, there will be minimum transport cost of £5/o.d.t., assuming a large articulated tipper with a 20 tonne load on a journey of less than 40 kilometers.

By comparing these figures, it is clear that some of combinations of fuel and conversion system are technically 'viable'. However, some of the fuel sources (including, for example, trees on opencast sites and trees on under-utilised land) are too expensive for any of the conversion options although these would be highly desirable from the point of view of helping to regenerate the area. At the other extreme, the highly favourable cost of £12/o.d.t. for producing fuel from existing woodland would suggest this as the obvious economic option. However, while valuable for encouraging more woodland management, this option would not, alone, address the wider agenda for regeneration.

This analysis revealed that a biomass business was unlikely to deliver all the perceived benefits without some form of public sector assistance. It also enabled us to consider the best approaches in terms of the kind of biomass business we should be promoting. Two scenarios have been identified.

1. *Wood fuel supply to Carlisle* – Under this scenario a contract is negotiated for a fuel supply to the Carlisle plant at a price of £26–30/o.d.t. An organisation is set up to co-ordinate the supply of wood fuel from the region from many different sources, deal with contract and quality control issues and to assist in crop planning. If set up with some public funding it could also cross subsidise fuel sources so that some of the more expensive, but beneficial, fuel options can be included.
2. *Wood heat concept* – Under this scenario a wood heat company would purchase, install and maintain woodchip boilers to provide heat for institutional buildings such as schools, colleges, prisons or leisure centres. It would also co-ordinate and secure fuel for suppliers. The company would offer competitive 10-year heat supply contracts to the institutions, which would service a capital loan to purchase the boilers. Once again cross subsidisation of different fuel sources would maximise the benefits. This scenario has the added local benefit of retaining the value adding activities involved in conversion within the local economy.

5. The Case for Public Sector Intervention in the 'Market'

An important component of our thinking was to be clear why we, as a public sector agency, should intervene.

The primary justification for involvement is to ensure cross subsidisation between the potentially profitable sale of forestry wastes and the more economically marginal activity of establishing biomass plantations. Beyond this, there are three other reasons for public sector intervention:

1. To remove some of the constraints to private sector involvement. The time-scales, complexities and uncertainties of the agri-environment and forestry grants may deter the private sector from developing biomass plantations and acting alone at this stage. The UK's biomass market is also immature with relatively undeveloped technology. This produces high, up-front development costs that currently prevent companies from exploiting potential markets and developing business.
2. The public sector is in an excellent position to develop both the supply of land for biomass and the wood heat markets that would use this supply. It owns much of the derelict and other land suitable for biomass. It is familiar with land assembly (identifying the owner, negotiating with them, putting in place legal agreements and getting planning permission). It also owns or controls many of the buildings that could use the energy source.
3. To maximise and retain the benefits. The public sector can help ensure that biomass plantations are well located and designed in order to maximise landscape benefits, and respond to the local issues of derelict land and recreational use. They can also focus biomass business activity on areas of social exclusion, helping to deliver the economic and environmental benefits to areas of greatest need.

6. Future Directions

We propose that Lanarkshire's public sector partners establish a formal partnership organisation. It will include public bodies and private companies expressing an interest in being involved. The organisation could be part of, or separate from, the current partners. The options with regard to its precise status will need to be investigated. Once in place, the partnership organisation will have an overall objective of setting up a viable stand-alone biomass business within two years.

To achieve its overall objective, the partnership organisation will have a number of development tasks, for example:

- Determining the current extent of existing biomass plantations in the Lanarkshire and Central Scotland Forest area.
- Creating a partnership with existing woodland management contractors and finding out scale, costs and mechanisms necessary to provide forest wastes as a wood fuel.
- Identifying and negotiating of land for new biomass cropping.
- Exploring options for a biomass-processing depot.
- Preparing a viable business plan for the new organisation.

Completing these development tasks should remove current barriers to business development and highlight the precise nature of the benefits. A clear and costed business plan will be developed that can then be used to secure the finance to meet the capital investment costs. These tasks are complex, time consuming and specialist in nature. The partnership organisation will need a dedicated member of staff to undertake, co-ordinate and manage the process. It will also need to buy in external consultancy services. An expenditure of £250 000 to meet these costs is anticipated.

Our initial consideration of how we can meet these development costs has identified three potential sources:

- The Shell Foundation – Sustainable Energy Programme.
- European Regional Development Fund Objective 2, Measure 1.1. (Develop a Competitive and Innovative Business Base).
- Landfill Tax Credits.

We also expect the partnership organisation will need to provide the new business entity with ‘seed corn’ funding to enable it to build up its business case and prepare funding bids. This will also give the partnership organisation a greater level of credibility and avoid a time lag while seeking external funding.

7. Conclusions

Following the international conference on the environment in Kyoto in 1997, the UK accepted a legally binding target on CO_2 emissions as part of the climate change programme. The wider strategic justification for developing a local biomass business therefore relates to its contribution to the climate change agenda. However, there are a number of potential local benefits that provide a clear rationale for developing the concept, relating to the post-industrial transformation of the landscape:

- Beneficial use for derelict land.
- New business activity in the local economy.
- Commercial use for forestry waste and so encourage the management of derelict woodlands.
- Diversify farmers’ income.
- Improve the character and recreational use of the landscape, particularly in the urban fringe.

We can only realise the full benefits of a biomass business using the cross subsidisation approach, including public sector intervention. The establishment of a supply contract with the Carlisle plant would allow the relatively straightforward establishment of a business based on existing market. The development of a local ‘wood heat’ market is more complex to establish, but would increase the range and scale of benefits to the area. We propose that Lanarkshire’s public sector partners establish a formal partnership organisation. Once in place, the partnership organisation will have an overall objective of setting up a viable stand-alone biomass business within two years.

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Driving Forces and Inhibitors of Wood Fuel Utilization in Northern Areas: a Case Study in Kainuu County

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Abstract

In this paper, the driving forces and inhibitors of wood energy utilization are discussed. The aim is to obtain a practical view by analysing Kainuu County in a case study. The wood energy resources and the use of wood in existing boilers are discussed. It appears that wood energy in the case area competes with fuel peat and wood residue from mechanical wood processing in large boilers. In institutions and family houses, there is mostly price competition with light fuel oil and electrical heating. The most dominant factor in decision-making concerning the adoption of energy wood is the price compared with the closest alternative fuel. The image of renewing energy is also an important factor in the use of energy wood. Moreover, the employment opportunities and the benefits derivable by forestry similarly favour the use of energy wood as fuel. The possibility to use mixed solid fuels in existing boilers seems to be of primary importance for the growth of energy wood use in the case area, and obviously also elsewhere.

Keywords: wood fuel, heating, decision-making, environmental effects

1. Introduction

The use of different wood-based fuels is generally considered positive mainly because of the obvious environmental advantages it involves compared to fossil fuels. This is the globally valid driving force for using renewable wood fuels.

Wood fuels have, however, a certain techno-economic position that is determined by more regional and even local factors. Such factors include:

1. sustainable availability of wood fuels in the long term;
2. cost structure of the locally operating wood fuel production chains;

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3. price of available alternative fuels or forms of energy;
4. possibility to modify the existing boilers to use wood fuel;
5. the existing combustion technology and the need to rebuild plant facilities for wood fuel; and
6. societal consequences, such as employment in the utilization chains.

In this paper these factors are discussed mainly based on experiences from the Kainuu area in northern Finland. The following two types of wood fuel are discussed: production of wood fuel as wood chips from forestry, and production and utilization of wood pellets as a more refined wood fuel. The use of these wood fuels can be relatively easily automated and these wood fuels are in practice available.

Both cases show that the utilization of wood fuel inevitably requires local and regionally adapted planning for many reasons: all of the above factors should be properly analysed concerning each wood fuel production chain before a larger wood fuel system can be safely started. The production of forest chips can also be integrated into commercial forestry, which would improve the cost-efficiency of forest management. When using an integrated production chain for commercial timber and energy wood production, energy wood adds to the overall volume of production, and therefore, has a positive effect on the cost-efficiency of the production.

From the point of view of decision-making, the utilization of wood energy is also quite complicated because there are several different decision-makers involved: public sector communities and various private organizations, including power companies and fuel producers. Companies also have their own decision-making strategies, which are naturally shaped by business factors.

2. Kainuu as a Regional Case of Wood Fuel Utilization

It is assumed that a regional case would clearly show the current status of wood fuel utilization, including the limiting potential of resources, the feasible level of utilization for each wood fuel type and the alternative energy production methods, which cause economic constraints. The driving forces and inhibitors may be detectable in a regional case, but the corresponding global effects must be discussed separately.

The Kainuu region is situated in Eastern Finland (Figure 1). Its population in 1999 was about 92 000, and it consists of ten municipalities, of which Kajaani and Kuhmo are cities. The region is sparsely populated, with an average of four persons per square kilometer. Estates number 18 000, and 1800 of them are combined forestry and agriculture operations. About 46% of the forests are privately owned, while 40% are state-owned and 14% belong to different companies.

The total practical energy wood potential in Kainuu has been calculated to be about 0.5 million m^3. The theoretical potential in Kainuu is almost double (Karjalainen 1999). This figure is based on the planned cuttings and includes all forest owner groups.

Table 1 shows the wood energy potential in each community. Most of the energy wood comes from commercial final cuttings, and consequently, the cost structure of the energy wood thus produced is determined by the corresponding technology.

In the case area, the total energy wood potential is 494 020 m^3/yr, which corresponds to 1.25 million m^3 of chipped wood fuel or about 1 million MWh of energy. Calculated per forest hectare, this corresponds to an energy wood potential of about 0.25 m^3. Thus, energy wood is a product whose potential amount can be roughly predicted by the forest area, taking into account the northern geographical location. The theoretical amount of energy potential in Kainuu is 0.9 million m^3/yr and after adjustments to take inaccurate harvesting, very small sites, poor soils and low density into account, the practical energy wood potential is 0.5 million m^3/yr.

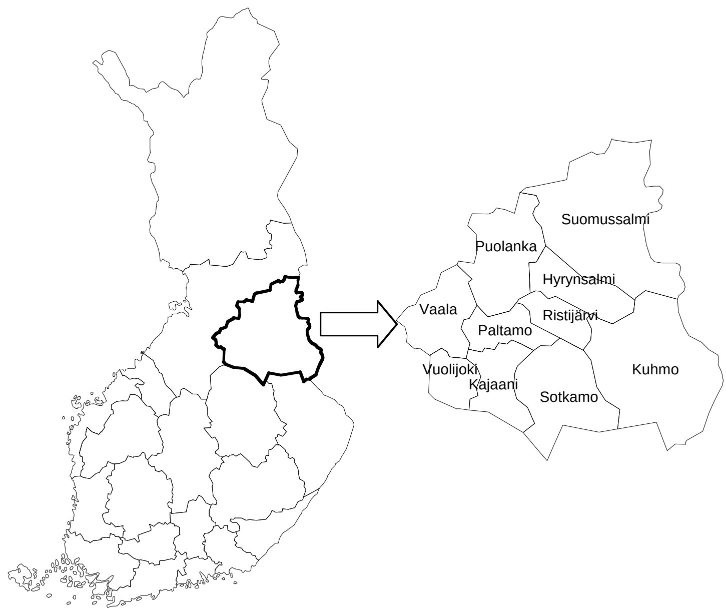

Figure 1. County of Kainuu and its ten municipalities.

Table 1. Potential energy wood resources in Kainuu (solid m^3/yr).

Municipality	Final cuttings		Thinnings	Total
	Pine m^3/yr	Spruce m^3/yr	m^3/yr	m^3/yr
Hyrynsalmi	9 500	12 100	8 400	30 000
Kajaani	8 960	8 960	16 240	34 160
Kuhmo	45 700	29 120	40 320	115 140
Paltamo	5 910	12 100	14 560	32 570
Puolanka	15 680	16 800	17 920	50 400
Ristijärvi	4 930	12 320	10 300	27 550
Sotkamo	16 130	40 320	28 000	84 450
Suomussalmi	29 570	20 160	26 880	76 610
Vaala	8 330	2 020	12 880	23 230
Vuolijoki	5 910	2 240	11 760	19 910
Total	150 620	156 140	187 260	494 020

3. Possible Additional Wood Fuel Potential in Kainuu Region

As with any case area, Kainuu also has a certain imbalance between the resource potential and the possible additional use. In this case, the resources are larger than the feasible additional use. In Kainuu, there are three types of additional energy wood users: industry, district heating systems and households.

The total fuel use in power stations and district heating plants in Kainuu in 1998 was 2 168 000 MWh (Figure 2). The fuels competing with forest chips are milled peat and sawmill residue.

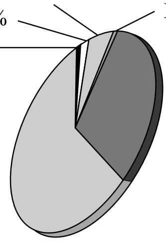

Figure 2. Use of fuels in district heating plants and power stations in Kainuu (1998). Overall use 2 168 000 MWh (Karjalainen 1999).

The potential for growth in forest chip use lies in power station use and district heating (Table 2).

Table 2. The use of forest chip in district heating and the potential for use in Kainuu. (Karjalainen 1999).

Municipality	Use of forest chip MWh/yr	Potential use MWh/yr
Hyrynsalmi		
- District heating plant	2 950	4 000
Kajaani		
- Kainuun Voima power company	0	180 000
- Seppälä Acriculture School	3 200	3 200
Kuhmo		
- Kuhmon Lämpö company	0	0
Paltamo		
- District heating plant	2 000	14 000
Puolanka		
- District heating plant	7 500	9 500
Ristijärvi		
- District heating plant	2 100	4 300
Sotkamo		
- District heating plant of Vuokatti	2 000	6 000
- District heating plant of Sotkamo	0	80 000
Suomussalmi		
- District heating plant of Siikaranta	0	12 000
Vaala		
- District heating plant	0	1 500
Vuolijoki		
- District heating plant in Otanmaki	0	9 000
Total MWh	19 750	323 500
chip-m^3	26 000	430 000

It must be underlined that, in each case of additional fuel use, the decision must be economically sound. If there is already equipment for solid fuel combustion – which is the case in most municipalities – the price of energy must be competitive with the best alternative fuel. If there is no equipment available for solid fuel combustion, the additional investment must also be paid back by the more economical fuel. These are the main problems faced by the local decision-makers.

In the case of Kainuu, there is a possibility to use about 300 000 MWh more wood chips for district heating and power production than is used currently. This is about 30% of the total energy wood potential. Thus, only the most profitable part of energy wood will be utilized. The main competitors are, in practice, milled peat and wood fuel from sawmill residue.

Thus, we can conclude our discussion of forest wood chips by pointing out that there is a major regional need to develop cost-efficient energy wood production chains. In order to compete with milled peat and sawmill residue, forest chips should be produced at a price level of 30–40 FIM/MWh. Closest to this target is energy wood from final cutting areas, especially dense spruce forest stands. It has been shown (Saksa 1996) that cutting residue for boiler plants can be produced by commercial harvesters operating within a distance of 60 kilometers at the price of 39–42 FIM/MWh.

In Finland, energy wood has no environmental protection taxes, while fossil fuels and peat are subject to such taxes. For example, the tax for peat is 9 FIM/MWh. In the production of electricity, power stations can get a tax rebate for electricity produced from wood. Such subsidies make energy wood more competitive.

In addition to ‘large boilers’, there is also some potential in Kainuu for institutions, farms and houses, which use a certain amount of energy wood. The form of energy wood may be wood chip, logs or even pellets. The use of energy wood is traditional on farms and as an additional heating source even in family houses with electrical heating. However, it is quite difficult to estimate the amount of energy wood to be utilized in these applications. As a rough estimate, we could say that there are 30–40 large public buildings in Kainuu which could annually use energy wood to produce 36 000 MWh of energy. At least the same amount could be used on farms and in family houses by replacing light fuel oil. The new developing wood pellet technology may offer new alternatives in the future (Karjalainen 1999).

To summarize the energy wood situation in Kainuu, we can state the following:

- utilization is growing, and there is a major energy wood potential;
- only the most profitable portion of energy wood is sufficiently competitive with the best regional fuel alternatives; and
- farm and house technologies of wood fuel utilization also deserve attention from the developers.

Further important technical questions include co-combustion of wood chips with peat in larger and smaller plants and automatic and reliable chip and possibly pellet combustion systems.

The main obstacle for the development of energy wood systems in Kainuu has been economic comparison with alternative fuels rather than resources and availability.

4. Special Cases of Cutting Residue and Wood Pellets

In order to look at two specific wood fuels more closely, the energy price structures of cutting residue wood fuel from final cuttings and wood pellets are discussed separately. Their cost structure is presented and compared to the closest alternatives.

Oijala et al. (1999) compared different methods of producing cutting residue. Their discussion shows that, depending on the chipping method, the resulting price structure varies, but the resulting total price is roughly similar to the price of milled peat (Figure 3).

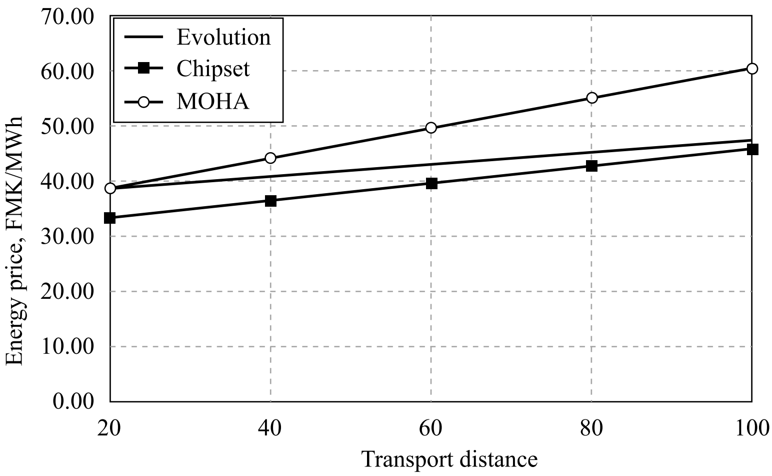

Figure 3. Energy prices of cutting residue (Oijala et al. 1999).

For both biofuels, any further reduction of the price of energy seems very hard to attain and requires essential developments in the process of fuel production. As far as the cutting residue fuel is concerned, we may state that co-combustion with peat, which is quite similar in total costs, is a natural direction to develop energy wood use in large boilers. In Kainuu, efficient utilization of final cutting residue is producing energy wood for the Kainuun Voima power company.

Wood pellets are an example of wood fuel which has different price references because of its different energy price level. Pellet use is often compared with light fuel oil heating systems, electrical heating systems and conventional wood heating or with some combination of these systems.

The choice of the heating system is based on a comparison of the annual heating costs to find the most feasible alternative. Environmental factors are also gaining additional weight. Heating systems for separate households constitute a separate topic of study, which is relevant for the development of energy wood utilization.

The general trend is that the houses built in the 1960s and 1970s were mostly heated with oil, but in the 1980s and 1990s, electrical heating and partly wood heating systems were installed in about 90% of the new houses.

In the special case of wood pellets, it can be assumed that the development of automatic feeding systems and automatic reliable operation will be a decisive factor contributing to increased use of wood pellets.

5. The global and local driving forces of wood fuel application

As the global driving force for wood fuel development, we would like to mention the well known renewing rate of wood fuel. This can be clearly seen from the figure given by Schlamadinger and Marland (1996).

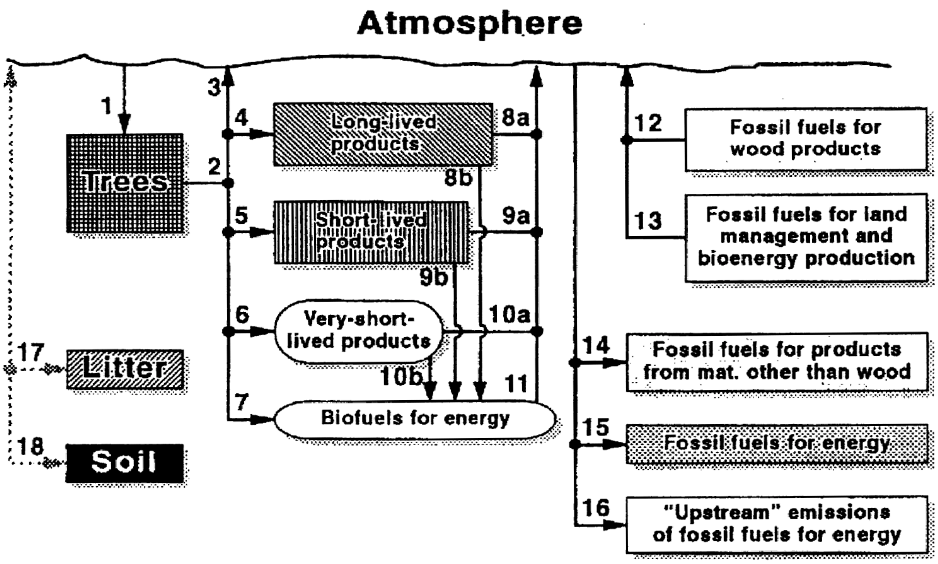

Figure 4. Coal circulation between the atmosphere and fuels (Schlamadinger and Marland 1996).

In terms of global energy consumption, many countries have a share of their total energy produced from wood. There is no environmental factor to prevent the growth of this share. The obstacles are mainly economic, such as the price competition, and, to a certain extent, technical, including the availability of co-combustion facilities. Also, a group of more or less effective barriers for increased wood fuel use have been identified (Finnish Forest Research Institute, 1998).

It can be expected that, in the long term, the use of renewable wood fuel will approach the limit of sustainable production. This would be one practical way to minimize the use of fossil fuels. The wood material is converted into CO_2 in a natural process; therefore, it is an environmentally demanding task to develop energy wood utilizing combustion cycles both for large and smaller boilers.

There are also local driving forces for the use of wood fuel. The availability of local fuel alternatives and the employment effects are important. Environmental factors can also be regarded as a local driving force for energy wood utilization. However, these driving forces are strictly controlled by competition with alternative fuels.

6. Conclusions

In terms of energy wood production, Kainuu is a typical Finnish region as far as energy wood utilization is concerned: the local forest resources would offer an opportunity for many times larger energy wood production than is economically feasible. However, development is going to increase the use of energy wood as fuel from final cuttings and thinnings. Energy wood is used as wood chips in a large power plant and several district heating plants. The form utilized is mixed fuel with peat in FB (Fluidized Bed) combustion in most cases.

In smaller households, energy wood is used the form of firewood, wood chips or possibly pellets.

In each application, the economic competition with the closest available fuel alternatives is surprisingly dominant in the local decision-making concerning boiler plants. The good environmental properties of energy wood are known, and they are a definite benefit for the additional use of this fuel in future.

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Summary of Workshop Session on 28th September 2000[1] – Land Use, Land-Use change and Forestry: the Road to COP6

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This workshop session on Thursday 28 September was organised by IEA Bioenergy Task25 (http://www.joanneum.at/iea-bioenergy-task25) in collaboration with COST E21 (Contribution of Forests and Forestry to Mitigate Greenhouse Effects – http://www.bib.fsagx.ac.be/coste21/), the European Forest Institute (http://www.efi.fi) and the University of Joensuu (http://www.joensuu.fi). Other meetings took place during the same week:

- Conference: Woody Biomass as an Energy Source – Challenges in Europe (25–27 September)
- COST E21 meeting (continued on 29 and 30 September).

The purpose of the session summarised here was to provide a discussion forum for issues concerning the land use, land-use change and forestry (LULUCF) sector that are currently subject to negotiations under the United Framework Convention on Climate Change (UNFCCC). In December of 1997 the Kyoto Protocol was adopted which allows land use and forestry activities to be used in meeting emission reduction commitments. Particularly, afforestation, reforestation and deforestation, if they occurred since 1990 and are direct human induced, are included. The Kyoto Protocol also sets forth that additional human induced activities in the LULUCF sector may be agreed to in the future. However, many details, such as definitions, accounting rules, and decisions on eligibility of activities, have been left open and subject to further negotiations leading up to the Sixth Conference of the Parties to the UNFCCC (COP6) at The Hague, 13th to 24th November 2000, where important decisions are to be made so that the Kyoto Protocol can be ratified by Parties thereafter.

It was only three months after the conclusion of the Kyoto negotiations that IEA Bioenergy Task 25 organised a workshop on LULUCF issues in Rotorua, New Zealand (March, 1998). The proceedings of that workshop can be downloaded at http://www.joanneum.at/iea-bioenergy-

1 This summary has been based on, with permission, the IEA Bioenergy Task 25 Publication (ISBN 3-9500847). The full report can be found at http://www.joanneum.at/iea-bioenergy-task38/workshop/joensuu.pdf

Paavo Pelkonen, Pentti Hakkila, Timo Karjalainen, Bernhard Schlamadinger (eds.)
Woody Biomass as an Energy Source – Challenges in Europe
EFI Proceedings No. 39, 2001

task25. Many of the issues negotiated now were raised for the first time at this workshop. This workshop session summarised below constitutes a continuation of the work by Task 25 researchers on the issues of LULUCF, bioenergy, and global climate change.

Session 1: Overview of IPCC Special Report on Land Use, Land-Use Change and Forestry

The Intergovernmental Panel on Climate Change (IPCC) had been requested by SBSTA (Subsidiary Body for Scientific and Technological Advice under the UNFCCC) to prepare a Special Report on Land Use, Land-Use Change and Forestry (LULUCF), to provide a basis for the negotiations now under way. The report was prepared under enormous time pressure and subject to intensive expert and government review. It was accepted by governments at a plenary session of the IPCC in Montreal in May of 2000. The Summary for Policymakers of the report can be downloaded at http://www.ipcc.ch, and the full report (Watson, R.T. et al. 2000. Land Use, Land-Use Change and Forestry) is available from Cambridge University Press (http://www.cup.org, search for keyword ‘land use’).

Gert-Jan Nabuurs of ALTERRA Green World Research, Netherlands, gave an overview of Chapter 2 of the report: Implications of different definitions and generic issues. There are over 240 different definitions of a ‘forest’, some of these are very country specific and reflect national circumstances. They can be grouped into 3 categories, administrative, land-use and land cover definitions. Land cover definitions of forest do not always include all wooded land, for example if the cover threshold is low (20%) then countries with high cover forest will be able to deforest to the threshold level without this being accounted for. Conversely if the forest cover threshold is high, forested land in some countries will never reach this threshold, some types of savannah with tree cover for example. Therefore this ‘forest’ could be deforested without it being accounted for; there are also no incentives for increasing the area of this type of ecosystem.

There are many issues, which are affected by definitions, such as consistency of methodologies, comparability, transparency, verifiability, accuracy, and cost effectiveness. Should LULUCF activities be accounted for based on activities or land units? Land based accounting would involve identifying the land, then accounting for all C stock changes on that land in the commitment period. Activity based accounting involves first identifying the activity and counting the carbon stock changes directly associated with that activity. Which activities should be accounted for under Kyoto Protocol Article 3.4? Other accounting issues include baselines, system boundaries and leakage.

There is no one ideal method for monitoring and verifying the stock changes on ARD land, but perhaps the best is a combination of forest inventory, soil sampling and remote sensing, while models could be used for verification. ‘Kyoto’ projects may have side impacts including sustainability, biodiversity, employment, water quality, soil erosion; and impacts on harvested wood products and the forest industry.

The overview of Chapter 3 on Afforestation, reforestation and deforestation (ARD) was given by Bernhard Schlamadinger of Joanneum Research, Austria. Chapter 3 focuses on Article 3.3 of the Kyoto protocol, ARD activities and how to account for them. Accounting methodologies also depend on the definitions of ARD and the implications of several definitional scenarios (combinations of definitions of ARD and ‘forest’) are given in the chapter. ARD could be accounted for using land-based or activity-based accounting. Using the land-based accounting, the FAO definition of reforestation could lead to net debits in the first commitment period. With activity-based accounting, which excludes debits from harvest that precedes reforestation, overall net carbon credits would accrue for regrowing trees after harvest. Globally carbon debits from deforestation are likely to exceed credits from afforestation in the first commitment period (CP1), if a 'land-use change' definition of reforestation is used (also referred to as 'IPCC definition' because it is used in the IPCC Guidelines for National Greenhouse Gas Inventories). For example afforestation will be credited for the carbon stock change in the commitment period (5 years carbon increase) and only for those stands established since 1990, while deforestation will be debited for the carbon losses on ALL stands deforested. Chapter 3 also deals with the possible 'perverse incentive' to deforest stands after 1990, put them into an alternative land use for a few years and then reforest to gain carbon credits, and proposes some options to address this. Finally, the presentation suggested that carbon credits could be given for landscape average carbon stock rather than following the ups and downs of afforestation, thinning, harvesting, and regeneration.

The overview of Chapter 4: Additional human induced activities – Article 3.4 was presented by Gregg Marland of Oak Ridge National Laboratory, USA. The chapter contains many ideas, with much focus on soil science and which activities could be included under this article. The 'how' to account for carbon stock changes due to additional human-induced activities is less discussed. There are two ways in which activities could be defined. If defined in a broad way, activities could be land management within a land-use category (forest management, cropland management, pasture land management) or land-use changes between these categories (afforestation, deforestation, etc.). This definition of activities would require minimum monitoring and verification costs, and potentially yield large amounts of carbon credits, perhaps even with no change in management practices. A narrow definition of activities to be included could result in a long list of practices to be considered. This approach would increase accounting requirements and the associated costs but could be used to closely limit the extent to which the LULUCF sector is included in the Kyoto Protocol.

It is important to note that the admittance of activities under Article 3.4 would affect the ability to meet already-set emission reduction targets, in most cases making the targets easier to achieve. The 'modalities, rules, and guidelines' for accounting for activities under Article 3.4 need to consider several issues including; whether only additional activities undertaken since 1990 should be accounted, whether credits should be limited to cases above 'business as usual', whether they should be accounted for as changes in carbon stocks, whether the banking of carbon credits is allowed, whether credits under Article 3.4 should be limited, and whether carbon credits should decrease as a function of uncertainty.

Although biofuels are not included under Article 3.4, it was thought important that something be said about them: Biofuels are included in the Kyoto Protocol as part of the renewable energy portfolio that can help reduce emissions from fossil fuels. Biofuels can, however, yield a double gain if they come from newly established plantations for which carbon stocks are accounted in the LULUCF provisions of the Kyoto Protocol. The chapter looks at the tradeoffs between biofuels production, carbon sequestration, direct and indirect materials substitution, and food production.

Chapter 5: 'Project based activities' was presented by Omar Masera, University of Mexico, Mexico. There has been significant experience at the project level but few projects that deal specifically with greenhouse gas mitigation. To date experience has been gathered in 30 projects, covering 3.5 Mha. These projects include carbon sequestration, avoidance of degradation or deforestation, and multi component projects.

Some of the key concerns about GHG accounting at the project level include:

- the setting of baselines to ensure additionality. There is currently no agreed upon standard method for calculating baselines;

- leakage – this can be addressed by using buffer zones, claiming only some components of the carbon sequestration, for example, only claiming for above ground carbon not soil and litter carbon;
- measuring and monitoring;
- permanence (risks), these could be addressed by: debiting when carbon is released, replacement with a new project, claiming only partial credit at beginning of project, or the creation of buffer zones at the project outset;
- sustainability – extent and effectiveness of local people participation, technology transfer and adoption, capacity to develop and implement guidelines

Justin Ford-Robertson of Forest Research, New Zealand presented chapter 6: Implications of the Kyoto Protocol for the reporting guidelines. The aim of the guidelines is to provide a basis for estimating and reporting greenhouse gas emissions and removals, and to ensure comparability between country data. They were not designed with the Kyoto Protocol in mind, however they could be adapted to provide a framework for reporting required by the Protocol. The guidelines are specified in the Kyoto Protocol for reporting national inventories. Some of the issues to be addressed include:

- the application of the ‘since 1990’ clause,
- lack of consistency between country data because of the flexibility of definitions
- a methodology for accounting for harvested wood products, currently it is assumed that the stock of wood products does not change. It was noted that the issue of how harvested wood products can be accounted for will be considered by the UNFCCC in 2001 (submissions on this issue are due by March 15).

The session was concluded with questions from the audience, which were mainly intended for clarification of the details in the IPCC Special Report.

Session 2: Carbon Accounting Methodologies

Kim Pingoud of VTT Energy, Finland presented an evaluation of the ton-year index as a basis for carbon accounting of forestation projects under the Climate Convention. Several carbon sequestration scenarios are explored including afforestation, afforestation followed by later deforestation, and afforestation with bioenergy use. The results show that: tonne-year crediting can give permanent carbon credits even if deforestation occurs and the C stock decreases; temporary sequestration can increase the atmospheric CO_2 concentration in the long term and be in contradiction with the ultimate objectives of the UNFCCC. The conclusion reached is that tonne-year indices may result in inappropriate allocation of resources to meet its objectives.

Annette Cowie of State Forests New South Wales, Australia presented a paper by Miko Kirschbaum et al. on an alternative accounting procedure for land-use change and forestry activities under the Kyoto Protocol. The proposed accounting system takes into account that management of terrestrial carbon stocks can only have a lasting impact by replacing low carbon-storage potential land-use types with types with higher carbon-storage potential, and that only anthropogenic factors should earn credits or debits. The accounting system divides the biosphere into land use types that each has a characteristic average carbon storage potential. Credits or debits are then allocated based on a change in land use type and human induced change in carbon storage potential within a land-use type. The potential for carbon storage is calculated based on an equilibrium carbon density (carbon storage potential of native forest) multiplied by a land-use factor. Most debits and credits are likely to accrue due to land-use change for which only the area undergoing land-use change would need to be monitored. The area undergoing a change then simply needs to be multiplied by the difference in carbon stocks (according to the difference in land-use factor). The proposed accounting method is simpler and has less data requirements than current methods. The full paper is available from http://www.ffp.csiro.au/publicat/pdfs/alternative_kyoto.pdf

Several issues were raised by the audience regarding the proposed system including:

- Land productivity varies across a region, and land use tends to be determined by productivity, so equilibrium carbon density should be different for each land use type, as a certain land use may not have the potential to reach the equilibrium carbon density based on native forest. Response: the region could be further subdivided to accommodate levels of land productivity.
- This method of accounting seems to require high advance data needs, for instance the equilibrium c stocks and the land use factor. This can be seen as an advantage because once the equilibrium carbon stocks and the land use factor are known the system does not require continual monitoring of the carbon stock changes but only the area changes.
- How would the carbon stock changes be verified and the uncertainties assessed? Verification could be carried out using standard statistical or inventory methods. There are huge uncertainties in the current system, and this system should reduce them but uncertainty has not been assessed to date. It must also be acknowledged that whatever system is used, management of the biosphere will be difficult, and uncertainties will remain. The proposed scheme has the potential to carry fewer difficulties and uncertainties than other schemes, but even with this scheme, management of the biosphere will still be difficult.
- How does this method fit with the wording of the Kyoto Protocol? If a broad interpretation of the wording in the Kyoto Protocol is taken then this method can be used.
- How is permanence dealt with, for example if fire or insects reduce the carbon stock? If the disturbance is part of the normal forest cycle then this effect is included in the average carbon density. If the disturbance is not part of the normal system then the disturbance would result in a change in land use or equilibrium carbon stock.
- The monitoring system will also require periodic ground based verification and the use of remote sensing.
- It was suggested that the equilibrium carbon density may not be needed as there is no standard forest C stock.
- Is the carbon accounting methodology as described in Kirschbaum et al. wishful thinking? It depends on how entrenched negotiators are in particular positions some countries oppose sinks. This method can be used without over stating the role of sinks

Justin Ford-Robertson of Forest Research, New Zealand presented a comparison of real-time, tonne years and carbon density accounting approaches. ‘Real time carbon accounting’ reflects reality and usually produces a saw tooth pattern associated with the growing and harvesting of a forest stand. This method would allow a credit/debit for every change in carbon stocks. Measurements are required annually, or every five years, therefore the measurement/ transaction costs are high and could extend indefinitely into the distant future, eroding the benefits of carbon credits,

‘Tonne-year accounting’ has been developed to make it easier to trade carbon at the project level. Tonne-years combines the quantity of carbon sequestered in a project with the longevity of the project. This method is based on the removal of carbon from the atmosphere for a time equivalent to that which would allow those sinks to restore atmospheric concentrations to their former level. Calculations based on this premise suggest that between 42 and 150 tonne-years are equivalent to one tonne of emission reductions. There are several difficulties with the tonne year approach including the use of a reservoir to counteract a source, that it provides a disincentive for afforestation and that it is incompatible with the Kyoto Protocol.

The benefit to the atmosphere of afforestation/reforestation lies in the initial decision to convert from a low carbon density land use to a land use with higher long-term average carbon density. With 'carbon-density accounting' approaches, carbon credits could be a one-off payment made to a land owner who has increased the long-term average carbon density of a piece of land. No further transactions would be required unless the landowner makes land use/cover decisions, which will change the long-term carbon density again. Debits will occur if the long term average carbon density decreases. The long-term benefit of trading in carbon sinks may be to stimulate planting and thereby permit the formation of a sustainable biomass resource.

One question concerned the treatment of LULUCF carbon stock increases that are only temporary: If deforestation occurs a debit is received. The issue of permanence is more relevant to the CDM. An alternative system for accounting for LUCF projects in the CDM has been proposed by Columbia, which regards all LUCF projects as potentially non-permanent and a temporary credit is issued. After the end of the LULUCF project the credit has to be replaced with a credit from another project (either in the energy or LULUCF sector).

The carbon density accounting method is simple and evens out changes. Is there a danger of a country being more interested in increasing C density in forest rather than increasing harvest for increasing bioenergy? In New Zealand the forest industry is generally not in favour of C distorting. C credits may not change industry decisions, may extend rotation but not reduce harvest levels, therefore will not decrease harvesting and processing residues availability.

Robert Matthews (UK Forest Research) and Rebecca Heaton (Cardiff University, UK) investigated the effectiveness of different LULUCF carbon accounting methodologies in achieving the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol; and the impact of different accounting methodologies on a range of hypothetical countries with different characteristics of fossil fuel emissions and LULUCF sinks/sources. Final results will be available by COP6. First conclusions are that:

- If LULUCF is to be included in the Kyoto Protocol, the accounting procedures can, indeed must, be kept as simple as possible, otherwise anomalous results and perverse incentives are very likely to arise.
- Many examples of accounting procedures give undue weight to carbon sequestration through LULUCF projects compared to projects aimed at direct emissions reduction involving use of bioenergy. Care must therefore be taken in formulating accounting rules and indices to safeguard the potential contribution to emissions reduction that can be made by bioenergy.
- Carbon sequestration in wood products appears not to be important at a global level, but can be of marginal importance for some countries.

The model used in this evaluation was CARBINE (originally developed by UK Forest Research in 1989) and it includes wood products, bioenergy and substitution effects and is similar to other carbon sequestration models.

It was asked by a participant that given an increasing world population and increasing housing stock, why is the carbon stock in wood products not increasing? The presenters responded that available information, although limited, indicates that wood products are not important globally but could be important for individual countries. Evidence from country-level analyses and global-level simulations suggests that the global carbon stock in wood products is increasing, but at an insignificant level compared to stock changes in forests and fossil fuel reserves.

During discussion it was commented that the presentations on analyses of accounting indices and rules did not seem to address potential impacts on societies and local communities, both within and outside the Kyoto process – how could such issues be addressed? The response from presenters was that, ultimately, the Kyoto process is a political one. Scientists could only provide evidence, estimates and analyses on which the political negotiations could be based, and evaluate whether accounting systems would support the ultimate objective of the UNFCCC.

One presenter also commented that the method of Kirschbaum et al. seemed to meet such aspirations in a number of important ways. Firstly, it provided a simple, transparent and scientifically derived framework that could be applied consistently by different nations. Secondly the method had the potential to avoid excessive monitoring costs, enabling wide involvement of communities and countries with varying resources to commit to the Kyoto process. Thirdly arguments over the details of land classification and carbon densities at the national level were, rightly, left ultimately to the Parties to negotiate and agree, and this process could be viewed and understood by stakeholders both inside and outside the process. Finally the method met the requirement for monitoring to be verifiable, and this was a potential continuing role for scientists, acting as commentators and referees during the deliberations of the negotiators, as well as during implementation of the methodology. The scientists could ‘verify’ approaches to land classification, attribution of carbon density values and discounting assumptions. When scientists evaluated proposals and schemes, it was important not to be unduly concerned about whether the methodology was correct as a detailed geographical, physical and biological representation, but rather to evaluate whether it would support the ultimate objective of the UNFCCC if implemented.

Session 3: Land Use, Land-Use Change and Forestry Activities Under Articles 3.3 and 3.4.

Timo Karjalainen of EFI presented a study on carbon sinks and sources in the European Union (Liski et al. 2000). The analysis is to demonstrate the relative impact of different definitions on carbon stock estimates for EU countries, and a uniform data set was gathered and the same methods applied to the entire region so there is some consistency in results. Results were presented for all forests and ARD (afforestation, reforestation and deforestation) lands under Article 3.3 using FAO and IPCC definitions of ARD. In the EU as a whole ARD lands account for 2–9% of total forest area. Applying either definitions of ARD, the carbon stock changes under Article 3.3 were negligible (–5.4 Tg/yr for FAO, and 0.1 Tg/yr for IPCC definitions) when compared with the carbon sink in all forests (63 Tg/yr). However for individual countries ARD lands can represent a considerable carbon sink or source. The majority of forestlands in the EU are not covered by Article 3.3 but may be accounted for under Article 3.4 at a later date.

Doug Bradley of Domtar Inc, Canada gave a presentation on the ‘Domestic Options for Carbon Management’. There are a range of forest management projects that could increase the long-term carbon stocks including pest and disease control, fire control, juvenile spacing and tree improvement. Carbon stock increases for a juvenile spacing trial were presented as an example. The results showed that juvenile spacing or pre commercial thinning decreases carbon stocks in the short-term but in the long-term can enhance tree growth and increase the average carbon stocks on high productivity sites. The issue of possible ‘early crediting’ by governments was also discussed. Early crediting could provide: the incentive needed to implement more ‘enhanced carbon sequestration’ projects than would otherwise occur; provide a wider range of options for meeting Kyoto net emission reduction targets and allow least cost solutions. There are also risks with early crediting such as issuing credits when the carbon sequestration is overestimated or never occurs.

The presenter was asked whether people/companies will react if given some early credit? Bradley replied that ‘yes’, currently electricity utilities and energy companies are interested in obtaining carbon credits from such projects because they cost less than other greenhouse gas reduction measures. What is the motivation for establishing such a system when the government owns the forest estate? Bradley explained that much of the forest land in Canada is owned by the government (93%) but forest product companies manage the forest and own the trees therefore it is contested that they own the carbon in the trees.

Susan Subak, a fellow of the American Association for the Advancement of Science, based at the US Environmental Protection Agency gave a presentation on agricultural soil carbon accumulation and decisions to be made at COP6. In the US, carbon sequestration in agricultural soils is not as controversial as in forests because credits for soils would be of relatively small scale. In addition, many members of the U.S. Congress are supportive of the prospect of providing farmers with financial benefits related to carbon sequestration activities. The potential for agricultural soil C sequestration is estimated to be about 50 Mt/yr for the US, 43 Mt/yr for Europe and 340 Mt/yr for the Former Soviet Union. In the US, activities considered to have positive environmental and carbon impacts are no-till and cover crop systems. There are several issues on soil C to be addressed to enable accounting under the Kyoto Protocol, these include additionality, verifiability, reversibility and indirect effects. The Kyoto Protocol requires a decision whether or not agricultural soils are included, taking into account uncertainties, transparency and verification. This may not be possible because sufficient evidence may not be available to meet these requirements.

It was pointed out in the discussion that some countries are close to achieving saturation levels of carbon in their soils. Should credits then be given to countries that have a significant potential for sequestration because they have mismanaged their soils in the past? Subak stated that some countries have so little sequestration potential that investing in a expensive monitoring program may not be justified. The developing world has large areas of degraded soils, so in the long run it would be constructive to develop soil carbon sequestration incentive programs.

Annette Cowie of State Forests New South Wales, Australia, gave a presentation on measuring and marketing of carbon sequestered in planted forests. The issue of who owns the carbon has been addressed by the State government and separated from the ownership of trees. Several carbon trades have already been made by State Forest New South Wales, and a standard carbon credit product is being developed. Carbon measuring and modelling is linked to existing stem production management systems, expansion factors are then used to estimate other carbon pools. The carbon accounting system must be robust, cost-effective and transparent and stand up to international scrutiny. Once carbon is measured, independently verified and certified it will be available for trading at three levels (40, 60 and 80% of estimated carbon stock changes), the number depending on the measurement uncertainty. Management of a carbon pool that includes a number of forests or stands was also discussed. The advent of carbon trading provides a challenge to integrate forest management for wood and carbon values.

Replying to questions from the audience, Cowie said that the potential for C sequestration projects to cause social conflict in the Australian situation is not seen as significant, it is thought that they will have social and environmental benefits. In Australia forests can provide multiple benefits, such as addressing soil salinity and biodiversity issues while C sequestration is seen as an additional benefit.

The driving force for a carbon trading market in Australia is the requirement for national utilities to reduce emissions, and internationally because some people/companies are anticipating ratification of the Kyoto Protocol and emission reduction requirements.

In the discussion one participant pointed out that under Article 3.7 of the Kyoto Protocol there is the possibility of double crediting of the same unit of land. E.g. land deforested in or before 1990 would first increase the 1990 base year emissions and thus the assigned amount, and then could receive credits if reforested since 1990. The issue of reforestation credits following deforestation is discussed in the Special Report on LULUCF. One possibility to address it is to only give credits under Article 3.3 for land that was not forest in 1990. However, the 'double crediting' would still partly remain for stands deforested just before 1990, due to their continued release of carbon in 1990.

Session 4: Current State of Negotiations

Heikki Granholm from the Finnish Ministry of Agriculture and Forestry presented an overview of the current status of negotiations on LULUCF. Several key decisions are to be taken at COP6 in the Hague (Nov 2000) such as the inclusion of sinks, the flexibility mechanisms (JI, CDM and ET), compliance and the role of developing countries in the Protocol There are high expectations that the Kyoto Protocol will be ratified by 2002 (Rio +10). Decisions made at COP6 will be confirmed by the first Meeting of the Parties (MOP1). While decisions at COP6 will be made at a political level, this would be facilitated by the agreement of technical solutions in the early stages of the negotiations.

The IPCC Special Report on LULUCF thoroughly explores Art 3.3, 3.4, and 3.7. helps policy makers for upcoming negotiations and has facilitated the policy process. Country specific data on Article 3.3 and 3.4 will also facilitate negotiations, because policy makers will be aware of the implication of these articles on country emission reduction targets.

Key decisions to be made at COP6 can not be postponed any longer if countries hope to meet their emission reduction targets. To ensure emission reduction targets for the first commitment period (overall, –5% of 1990 emissions) is met the Kyoto Protocol should be ratifiable, with some flexibility in how to meet emission reduction targets, retain its environmental effectiveness and provide a balanced treatment of all greenhouse gas sources and sinks. However there is still a need for intensive further research and methodological work in the next few years. Sinks were seen by some as the fourth flexibility mechanism agreed to in Kyoto, and therefore sinks should not have the opposite effect for countries that meet certain land-management related criteria. Finally, there should be a balanced treatment of all items

Andreas Fischlin (ETH Zurich) of the Swiss delegation provided his perspective on where the Kyoto Protocol is heading. Currently greenhouse gas (GHG) emissions are still increasing and are likely to grow further. The ultimate objective of the UNFCCC is the stabilisation of atmospheric GHG concentrations at safe levels. The Kyoto Protocol has to serve this objective. He gave an overview of three possible outcomes of the Kyoto Protocol including 1) the Protocol is abandoned at COP6 or COP7 because of the difficulties associated with sinks or other issues such as compliance, flexible mechanisms, or equity (Article 4.8, 4.9); 2) the protocol is ratified and becomes effective but because of the manner by which sinks are included net emission reduction targets are not met; and 3) the protocol is ratified, becomes effective and sinks conform to the ultimate objective of the UNFCCC. Major outstanding issues that still need to be addressed are the definitions of forest, the definition of ARD under Article 3.3, the eligibility of additional activities under Article 3.4, and the accounting framework, in particular with respect to factoring out certain effects like CO2-fertilization, N-deposition, and beneficial climatic change effects. The inclusion of sinks is expected to affect many countries emission reduction requirements significantly. Fischlin pointed out that already in the first commitment period sinks, under Article 3.3 and 3.4 with land-based full carbon accounting, could exceed Annex I countries' emission reduction targets of minus 5% with respect to 1990 levels and in fact could allow even more than a 5% increase in fossil fuel emissions relative to 1990. He expects that the Kyoto Protocol negotiations will not be abandoned, but not all countries might be happy with the end result, not the least due to the inclusion of sinks.

In the following discussion one participant asked about the inclusion of soil carbon under Article 3.3: Some Parties are pushing for the inclusion of soil carbon, while others oppose this. Fischlin suggested they should be included, but doubts that they should be accounted as frequently as every five years (length of a commitment period), since measuring C uptake in soils after such short time might be difficult. He emphasised that the Kyoto Protocol would have only a minor impact on the climate system, but was nevertheless of utmost importance as the foundation of a process towards climate protection and it would be important not to delay the process.

Lorenzo Ciccarese from the Italian Environmental Protection Agency presented an overview of issues surrounding the inclusion of sinks in the Clean Development Mechanism (CDM). He noted the most important issues to be addressed are: the type of projects to be included, how the baselines will be set, leakage, additionality, and whether CDM projects also meet countries sustainable development objectives. In an overview of the benefits of inclusion of sinks in the CDM the following were highlighted: promotion of 'early action'; promotion of (re)afforestation programmes; and sinks projects could also have other benefits, such as increased biodiversity and rural development. However there are issues and risks involved in including sinks in the CDM, that need to be addressed, such as the methodological and technical problems; how 'leakage' is to be accounted for; ensuring additionality; and permanence. The CDM could also represent a risk to the environmental integrity of the Kyoto Protocol because of the high potential for sinks resulting in a lot of LULUCF projects instead of projects that enhance clean energy development. One way of addressing some concerns is to put a cap on the percentage of LULUCF in the total CDM volume that a country can use to offset emissions. Concerns about livelihood impacts should not prevent carbon forestry projects' inclusion in the CDM. In this regard, the use of Social Impact Assessment standards, already used in other contexts, could ensure that no activities are carried out that reduce local population rights to land access and discourage sustainable development. Finally, in order to avoid conditions of discrimination for small-scale projects, it is important to define guidelines for project design and standardised contracts and to introduce other elements that reduce transaction costs.

In the discussion it was pointed out that some countries have so far played an active role about sinks and the CDM (especially South American countries); others have expressed their opposition to the inclusion on sinks in the CDM (Eastern European countries and China). Some African countries tend to think of forestry as part of adaptation measures and not of direct use of carbon forestry projects in the CDM

Assuming sinks are included to some extent in CDM, should all projects be admitted or the same as for Annex 1 projects? Ciccarese responded that it is counter productive to assume very open inclusion of sinks in the CDM, their inclusion will probably be conditional, e.g. a 'positive list', and it may be important to view CDM credits as part of group of benefits, including sustainability, rural development.

Final Discussion

To frame the final discussion, the question was posed to the presenters and to the audience: "If you had a choice, what would be your wish-list, and in your opinion a positive outcome from COP6 in The Hague?

Responses by participants were:

- The Protocol should still lead to a 5% reduction in GHG emissions between 1990 and the first commitment period, so that the atmosphere is not experiencing more emissions than originally intended by the Kyoto Protocol. A fear of 'do-nothing-sinks' credits was expressed. Genetically modified species may pose another threat.
- Inclusion of sinks but with strict boundaries and simple carbon accounting methodology, so that the role of sinks is not overstated. LULUCF rules should be applied consistently across countries, i.e., a generic system but nations decide how much and what to spend on monitoring sinks, if they think they are important. Sinks included in CDM, but hard to implement in a way that does not distort KP.
- Could include sinks in 3.4 and CDM. However, only a fraction (e.g. 5%) of the carbon on the site should be tradable, to cope with uncertainty, and long term maintenance costs of terrestrial carbon stocks.
- Delegations go into the process based on good science and concern for the well being of ecosystems, the Kyoto Protocol is a door to pass through and not the final objective.
- One participant would not like to see an outcome in Hague that takes another 3 years to explain what has been agreed to. A simplified and robust approach to accounting for sinks is preferred, because a detailed approach may rather cause damage to the process. The outcome should reflect what the atmosphere sees (i.e., consider more than only stock changes on 2% of the land), and be consistent with sustainable forest management objectives. The credibility of the Protocol will be improved if sustainable forest management and stock increases lead to credits rather than debits. It is important to have decisions at the Hague on sinks, and to know what sinks mean for different countries.
- Another participant argued for the inclusion of sinks, but that clear and strict guidelines for projects are needed. He saw carbon as the by-product to strengthen other social and environmental objectives. He sought a limit on the percent reduction that can be met by CDM, and limit on the percentage of sinks share in the CDM. Start simple and slowly. Should not just include new plantations or other specific land-uses, because this would give the wrong signal, and could provide incentive to deforest old growth and other forests.
- One participant feared that people involved in the negotiating process may not all be aware of the subtleties between different definitions and processes in terrestrial ecosystems (e.g., GPP vs. NBP etc.). There is the danger of looking at too much detail, simple systems should prevail. For instance, using the pig example, he suggested that one should rather weigh the pig (measuring stocks) than to look at the flows in and out (fluxes). The pig eats a lot relative to the weight gain! One should strive for an accounting system which reflects 'what the atmosphere sees', and not get lost in nitty-gritty details and overlook the major effects of relevance to the climate. On the other hand, the factoring out of some aspects such as so-called natural effects, (CO2-fertilization, nitrogen deposition, beneficial climate change effects) is of outmost importance. If they are not separated from other effects, net emissions will actually not decrease relative to a business-as-usual scenario without the Kyoto Protocol. Of course, many questions remain, whether certain disturbances such as fires, insect outbreak, negative impacts of climate change etc. will all have to be factored out as well?

Again the need for a decision on the inclusion of sinks was stressed. The world community needed to move forward.

Finally, it was said that some certainty for future investments is needed. For example, countries setting up accounting systems need more information now in order to proceed.

Much attention has been given to carbon sequestration, and less to substitution options (bioenergy, materials substitution). The desire was articulated to recognise the complexity of the problem, and to yield a better balance between carbon sequestration and substitution options. In any case, measuring and monitoring must be possible.

Woody Biomass as an Energy Source – Challenges in Europe

Joensuu, Finland • 25–28 September 2000

Monday 25 September

Moderator: Fergal Mulloy, European Forest Institute
Rapporteur: Eero Forss, University of Joensuu, Faculty of Forestry, Joensuu

9.00 Official Welcome and Opening of the Conference
Conference Chairman: *Paavo Pelkonen, University of Joensuu, Faculty of Forestry, Finland*

9.20 The Current Woody Energy Use in Europe
Miguel Trossero, Forest Energy Initiatives, Forestry Department, FAO

10.05 EU Energy Policy Impacts on European Forest Industries
Johan Stolp, Institute for Forest and Forest Products, the Netherlands

11.20 Bioenergy Production in the Nordic Countries
Pentti Hakkila, Technical Research Centre in Finland

12.05 The Role of Bioenergy in the Global Carbon Cycle
Bernhard Schlamadinger, Joanneum Research, Austria

12.50 System Perspectives on Bioenergy, External Effects and Power Utilization in Europe
Björn G. Karlsson, Univeristy of Linköping, Sweden

15.00 Panel Discussion
Moderator: Paavo Pelkonen, Univerity of Joensuu, Faculty of Forestry, Finland
Rapporteur: Eero Forss, University of Joensuu, Faculty of Forestry, Finland

16.30 Poster session

Tuesday 26 September

Moderator: Paavo Pelkonen, University of Joensuu, Faculty of Forestry, Finland
Rapporteur: Eero Forss, University of Joensuu, Faculty of Forestry, Finland

9.00 Challenges for Bioenergy Use in North-West Russia
Alexander Titov, Academy of Sciences, Russia

9.30 Discussion

3 Parallel Sessions

Session 1: Wood Fuel Production and Wood Fuel Harvesting
Moderator: Pentti Hakkila, VTT Energy, Finland
Rapporteur: Mark Richmond, University of Joensuu, Faculty of Forestry, Finland

10.00 Prospects on Utilization of Wood Wastes
Pekka Alhojärvi, World Bank

10.30 Large Scale Forest Fuel Procurement
Antti Asikainen, University of Joensuu, Finland

11.30 Future Primary Forests Fuel Resources in Sweden
Stefan Holm, Swedish National Energy Administration, Sweden

12.00 The Effects of Species and Varietal Mixtures on Yield and Disease of Willows *(Salix)* Grown as a Short Rotation Coppice for Energy
W.M. Dawson, NIHPBS, Ireland

Session 2: Use of Bioenergy and Implications to Greenhouse Effect
Moderator: Bernhard Schlamadinger, Joanneum Research, Austria
Rapporteur: Eero Forss, University of Joensuu, Finland

10.00 CO2 Mitigation Cost: A System Perspective on the Heating of Detached Houses with Bioenergy of Fossil Fuels
Leif Gustavsson and Åsa Karlsson, Lund University, Sweden

10.30 Net Greenhouse Gas Emissions Due to Energy Use of Forest Residues – Impact of Soil Carbon Balance
Taru Palosuo, Technical Research Centre in Finland

11.30 Obtaining of a Charcoal and Energy from Wood Waste in kiln “Polycor”
Vladimir I. Yagodin and Yury D. Yudkevitch, St. Petersburg Federal Forest Technical Academy, Russia

12.00 Discussion

Session 3: Bioenergy and Rural Development
Moderator: Liisa Saarenmaa, Ministry of Agriculture and Forestry, Finland
Rapporteur: Aki Villa, University of Joensuu, Faculty of Forestry, Finland

10.00 Production of Woody Biomass for Energy in Post-Mining Landscapes and Plant Nutrient Dynamics
R. Bungart, OSTWIND Verwaltungsgesellschaft mbH, Germany
R.F Hüttl, Brandenburg University of Technology, Germany

10.30 South-eastern European Biomass Action – A New International Research Cooperation between Slovenia and Croatia
Nike Pogacnik, Slovenian Forestry Institute, Slovenia

11.30 Biomass for the Post Industrial Landscape
Penny Edwards, Central Scotland Countryside Trust (CSCT), UK
Steve Luker, Scottish Enterprise Lanarkshire (SEL), UK

12.00 Driving Foreces and Inhibitors of Woody Fuel Utilization in Northern Areas
Eino Kiukaanniemi, Thule Institute, Research and Development Centre of Kajaani, Finland

3 Working Groups

14.00 WG1: Challenges for Research Towards 3rd Millennium?
WG2: Woody Biomass – A Threat or an Opportunity?
WG3: Policy Making and Research: The Effects of Woody Biomass in the Changing World, e.g. National Forest Policies and Woody Biomass

16.30 Plenary Session
Moderator: Paavo Pelkonen, University of Joensuu, Faculty of Forestry, Finland
Rapporteur: Eero Forss, University of Joensuu, Faculty of Forestry, Finland

Wednesday 27 September, 2000 (excursion)

The excursion will take place in the most eastern part of the European Union, North Karelia. The tour will go through several small Finnish munincipalities where a variety of wood-based heating plants will be visited. Also production of one type of wood energy will be demonstrated.

9.00 Start from hotel Kimmel, Joensuu

9.15 Greenfire 300kW, a heating plant with a new kind of wood combustion solution, Pyhäselkä

10.45 Energy wood harvesting and chipping: a field demonstration by Biowatti Oy

Presentation during the journey to Tuupovaara:
Specialities of living near the Russian border

14.30 A distict heating plant 600kW, a co-operative as a heating entrepreneur, Tuupovaara

A farm-size heating centre based on wood chips

Thursday 28 September, 2000

Organised by: IEA Bioenergy Task 25 ‘Greenhouse Gas Balances of Bioenergy Systems’
Co-organised by: COST E21 ‘Contribution of Forests and Forestry to the Mitigation of Greenhouse Effects’; Joanneum Research, European Forest Institute (EFI); University of Joensuu, Faculty of Forestry.

Session: Land-use, Land-Use Change and Forestry: the Road to COP6
Moderator: Bernhard Schlamadinger, Joanneum Research, Austria

8.15 Introduction

Session 1: Overview of the IPCC Special Report

8.30 Chapter 2, Implications of Different Definitions and Generic Issues
Presented by Gert-Jan Nabuurs, ALTERRA Green World Research, The Netherlands

8.50 Chapter 3, Afforestation, Reforestation, and Deforestation (ARD) Activities
Presented by Bernhard Schlamadinger, Joanneum Research, Austria

9.10 Chapter 4, Additional Human-induced Activities – Article 3.4
Presented by Gregg Marland, Oak-Ridge National Laboratory, USA

9.30 Chapter 5, Project Based Activities
Presented by Omar Masera, University of Mexico, Mexico

9.50 Chapter 6, Implications of the Kyoto Protocol for the Reporting Guidelines
Presented by Justin Ford-Robertson, Forest Research, New-Zealand

Session 2: Carbon Accounting Methodologies
Moderator: Justin Ford-Robertson, Forest Research, New Zealand

11.00 Effectiveness of LULUCF Carbon Accounting Methodologies in Supporting Climate-conscious Policy Measures
Robert Matthews, Forestry Commission Research Agency, Wrecclesham, United Kingdom
Rebecca Heaton, The Salix Project, University of South Wales, United Kingdom

11.20 The Ton-Year Index as a Basis for Carbon Accounting of Forestation Projects Under the Climate Convention
Kim Pingoud, VTT Energy, Finland

11.40 A Practical Procedure of Accounting for LUCF Activities under the Kyoto Protocol
Miko Kirschbaum et al., CSIRO Forestry and Forest Products, Australia
Presented by Anette Cowie, State Forests New South Wales, Australia

12.00 Carbon Accounting Methodologies – A Comparison of Real-time, Tonne Years and One-offstock Change Approaches
Piers Maclaren, Forest Research, New Zealand
Presented by Justin Ford-Robertson, Forest Research, New Zealand

12.20 Discussion

Session 3: Land Use, Land-Use Change and Forestry Activities under Articles 3.3 and 3.4
Moderator: Timo Karjalainen, European Forest Institute

13.40 Trees as C Sinks and Sources in the EU
Jari Liski, European Forest Institute

14.00 Domestic Options for Carbon Management
Doug Bradley, Domtar Inc., Canada

14.20 Adressing COP6 Decisions on Agricultural Soil Carbon Accumulation
Susan Subak, Environmental Protection Agency, USA

14.40 Measuring and Marketing of C Sequestration in Planted Forests
Annette Cowie, State Forests New South Wales, Australia

15.00 Discussion; elaboration of innovative ideas in light of the negotiations

Session 4: Current State of Negotiations

16.00 Status of the Negotiations on LULUCF
Heikki Granholm, Ministry of Agriculture and Forestry, Finland

16.20 To Agree or Not to Agree: Perspectives for LULUCF Negotiations
Andreas Fischlin, ETH Zurich, Switzerland

16.40 Sinks and the CDM: Status fo Negotiations and the Outlook to COP6
Lorenzo Ciccarese, National Envrionmental Protection Agency, Italy
Davide Pettenella, University of Padova, Italy

17.00 Discussion, elaboration of innovative ideas in light of the negotiations
COST E21 Management Committee Meeting

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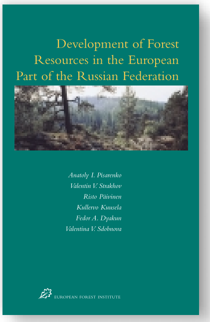

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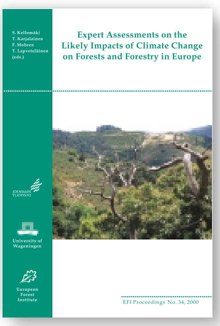

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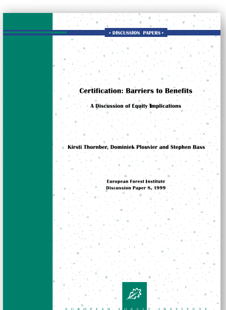

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Research reports

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No 12. Guidelines for Establishing Farm Forestry Accountancy Networks. MOSEFA (Monitoring the Socio-Economic Situation of European Farm Forestry). A. Niskanen and W. Sekot (eds.). Brill: Leiden, Boston, Köln, 2000. ISBN 90-04-12289-3. 126 p.

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