Dissertationes Forestales 35

Fuel switching, energy saving and carbon trading – three ways to control carbon dioxide emissions in the Finnish forest industry

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Academic dissertation

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ABSTRACT

This study consists of three parts, namely: 1) an integrated harvesting of residual forest biomass and industrial roundwood for the three mills of a multinational Finnish based corporation, 2) energy saving linked with the energy conversion of these mills, and 3) the knowledge and understanding of non-specialists (represented by undergraduate students) of the coupling of energy saving and carbon trading in forest industry using procedures of experimental economics. The aim was to analyze CO_2 mitigation alternatives on the basis of a case study and to provide opportunities to generalize the results in Finland and elsewhere under similar conditions.

The data base of final felling stands was used to calculate the production cost of residues at different mills using two optional harvesting methods, the roadside chipping (RC) and the residue log (RL). The production costs of the RL method were a little bit more competitive than the RC. Also a uniform recovery model for the integrated harvesting at the maximum radius of 100 kilometres from the mill was developed.

The energy saving reports of the mills were used to calculate the costs of different energy saving investments and saved CO_2 emissions as a result of decreased use of main mill fuels. When the production costs of residues were compared with the costs of energy saving at different mills, the economic possibilities of integrated harvesting were more promising. However, both two elements are required to mitigate global CO_2 emissions.

The alternative economic decisions of carbon trading experiments - either to make an energy saving investment at their own mill and sell surplus emission allowances to other mills, or to buy lacking allowances up to the emission constraint - was not easy to enforce profitably for most non-specialists. However, as a training tool to educate people on the economic aspects of global warming, experiments are justified.

Keywords: emissions trading, energy efficiency, experimental economics, integrated harvesting, pulp and paper industry, residual forest biomass

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ABBREVIATIONS, UNITS AND CONVERSION FACTORS

a = per annum = per year
1 € = 1 euro (EUR) = 5.94573 FIM (Finnish marks), a unit of money
1 h = 1 hour = 3 600 sec, a unit of time
1 ha = 1 hectare = 10^4 m^2 = 10^{-2} km^2, a unit of area
1 J = 1 joule = $2.78*10^{-7}$ kWh, a unit of energy
1 K = 1 Kelvin, K = ºC + 273.15, a basic unit of temperature
1 kg = 1 kilogramme = 10^3 g, a basic unit of mass
1 km = 1 kilometre = 10^3 m, a unit of length
1 kWh = 1 kilowatt-hour = $3.6*10^6$ J, a unit of energy (1 W = 1 J s^{-1})
1 m^3 = 1 cubic metre = 10^3 l = 264 U.S. gal = 6.2832 barrels of oil, a unit of volume
1 ppb = 1 part in 10^9, parts per billion, a unit of concentration
1 ppm = 1 part in 10^6, parts per million, a unit of concentration
1 t = 1 tonne = 10^3 kg, a unit of mass
1 toe = 1 ton of oil equivalent = 11 630 kWh = $41.868*10^9$ J, a unit of energy

PREFIXS

k = kilo = 10^3 = 1000
M = mega = 10^6 = 1 000 000
G = giga = 10^9 = 1 000 000 000
T = tera = 10^{12} = 1 000 000 000 000
P = peta = 10^{15} = 1 000 000 000 000 000

CONVERSION COEFFICIENTS, toe – MWh – GJ

	toe	**MWh**	**GJ**
toe	1	11.630	41.868
MWh	0.08598	1	3.6
GJ	0.02388	0.2778	1

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1. INTRODUCTION

1.1 Mitigation of climate change through controlling of energy consumption in the Finnish forest industry

1.1.1 Linkages between CO_2 emissions and energy and wood processing industry

The atmospheric concentrations of key anthropogenic greenhouse gases (GHGs), namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and tropospheric ozone (O_3), reached their highest recorded levels in the 1990s since the pre-industrial era. For example, the atmospheric concentration of CO_2 has increased from 280 ppm for the period 1000-1750 to 368 ppm in the year 2000, i.e. an increase of 31±4 %. The rise for CH_4 has been 151±25 % (700 ppb for the period 1000-1750 to 1 750 ppb in the year 2000) and for N_2O 17±5 % (from 270 ppb to 316 ppb) (IPCC 2001). The rise of atmospheric concentrations of the above mentioned gases has lead to the rise in the surface temperatures of the globe due to an excess heat radiation on lower levels of the atmosphere. Human activities, such as the combustion of fossil fuels (especially coal and oil), agriculture, and land use changes, have caused the rise of atmospheric concentrations of CO_2, CH_4, N_2O and O_3. This climate change will have both beneficial and adverse effects on environmental and socio-economic systems, but due to uncertainty and inadequate information, the precise magnitude of the effects still remains unknown. However, according to the available information we have (IPCC 2001), the bigger the changes and rate of change in climate, the more adverse the effects would be. The most severe effects, such as losses in human health, ecological productivity, biodiversity and water reserves, are estimated to be concentrated on those countries and socio-economic groups, whose capacity to adaptation with adverse climatic change is the lowest, i.e. on developing countries and the poor people in all countries (IPCC 2001). In order to adapt these large and complex effects illustrated above, an endeavour of controlling GHGs emissions to the atmosphere is needed.

In Finland, like in economies everywhere, the energy sector has a key role in the mitigation of climate change. Above all, the energy sector is the most important emitter of greenhouse gases due to the combustion of fossil fuels and peat for energy conversion. For example, in Finland in 2004, the amount of fossil CO_2 emissions (including peat) from energy sector and fuel combustion in industrial processes were 51.7 million tonnes, which covered 77 % of all CO_2 emissions from energy conversion and consumption including traffic (Energy Statistics 2004). The Finnish energy sector has been characterized to produce a high amount of energy due to country’s energy intensive industries and its northern location. An inadequate self-sufficiency in energy supply has also characterized the Finnish energy sector. Since the 1980s, the self-sufficiency of energy in Finland has been quite steady at about 40 %, and about 50 % after its joining with EU-15, whereas the other OECD (Organisation for Economic Co-operation and Development) countries were generally over 60 % self-sufficient during the same time period (Energy visions 2030). Thus, energy imports from abroad have been important in order to secure an energy supply. Especially imports from the Nordic countries, namely Norway and Sweden, and from Russia have compensated the low self-sufficiency of energy in Finland. The share of imports from Russia has been remarkably high, nearly 500 PJ of the total consumption of about 1 300 PJ. A liberalization of the Finnish electricity market in 1995 and the formation of a common electricity market area with Sweden, Norway and Denmark through the Nordpool stock have led to a restructuring of energy companies through merging and acquisitions. This progress may still continue in the future because the number of small and individual community-owned energy companies exceeds 100.

The forest industry as a branch and, especially the pulp and paper production, is the single biggest user of energy in Finland. For example in 2004, the pulp and paper industry consumed 281 800 TJ of fuels at mills, which was 60 % of all fuel consumption in industry (Energy Statistics 2004, Finnish Statistical Yearbook of Forestry 2005). Furthermore, in 2004 in Finland, industry as a whole consumed 51 % of all energy by sector, 1 486 900 TJ (Energy Statistics 2004). Concerning electricity consumption in 2004, industry consumed 54 % (46 795 GWh) of all electricity, and from the industry's share, the pulp and paper industry consumed 55 % (25 811 GWh) (Energy Statistics 2004). Particularly, the production of mechanical pulp, and paper and board manufacturing consumed a lot of electricity: the consumption was approximately 17 900 GWh (Energia Suomessa 1999, Vasara et al. 2001, Metsäteollisuus ry 2006). As an example, seven large pulp and paper mills in Finland, namely UPM Rauma, UPM Jämsänkoski, UPM Kajaani, UPM Kaipola, UPM Kaukas, Storaenso Imatra and Anjalankoski, consume, on average, 10 300 GWh electricity per year (Rissa 2003).

A typical feature of the Finnish forest industry is the large share of renewable fuels in energy conversion. The present situation has not always been valid. After the increases of oil price in the 1970s, oil was replaced by wood in energy conversion at mills. Bark and black liquor (mainly lignin in wood) from the recovery of chemicals in chemical pulping were introduced in a large scale for energy conversion at mills. As a result, nowadays, wood or wood based fuels capture a share of 70% of all fuels consumed at mills in Finland. Thus, for example from 1975 to 2000, an annual wood fuel consumption increased from 62.1 PJ to 186.5 PJ and an annual oil consumption at mills decreased from 55.1 PJ to 15.3 PJ (Energy visions 2030). However, when oil was replaced with wood fuels, the consumption of electricity increased as a result of the introduction of new wood containing paper grades. These paper grades contain a large proportion of mechanical pulps, such as groundwood or pressure groundwood and thermomechanical pulps. For example, in order to produce one tonne of fine thermomechanical pulp, 2400 kWh of electricity is needed whereas only 680 kWh of electricity, on an average, is enough for the production of equal amount of softwood chemical pulp (Energia Suomessa 1999). As a result, during 1975-2000, the annual power consumption of the Finnish pulp and paper industry increased from 9.1 TWh to 24.4 TWh (Energy visions 2030). The generation of power at mills was inadequate to cover the increased power consumption which led to a situation where electricity had to be purchased from external power producers. After this the price of electricity started to play an important role in energy procurement of forest companies.

In Finland, partnership energy companies have covered the big share of the electricity conversion of energy-intensive industries, such as the forest and metal industry (Kara 2004). By investing into a new power generation capacity, a single company receives its share of the investment as produced electricity. The company pays its share of the total fixed costs, i.e. investment costs, and receives electricity according to its ownership in the company at the price of the plant's variable costs. Thus, a large power purchaser can decrease its dependence on big power producers, when it does not need to be a single investor carrying alone a financial burden of a large power plant investment. A share owner of the partnership company may not get the best possible profit for his investment, but more secured information on power procurement costs in the future and on an overall energy supply compensate these losses. This type of partnership model has been utilized in major parts of big power plant investments in Finland, such as in those investments of recent and earlier nuclear power plants. The previous model has also been utilized in some partnership companies owned by a forest company and a communal energy company in order to produce steam and electricity for the forest company and district heat and electricity for the communal energy company.

1.1.2 Energy saving and renewable energy in the control of climate change

As mentioned above, human activities, such as the combustion of fossil fuels and the climate change have been connected to each other. The increased use of fossil fuels for energy conversion has led to rising GHG emissions. Saving energy inputs, i.e. improved energy efficiency, means less fuels for energy conversion, and thus less emissions will be discharged. According to examples by von Weizsäcker et al. (1999), the amount of wealth extracted from one unit of natural resources can be quadrupled globally by using energy more efficiently than on average today. This means that energy inputs can be reduced to only one fourth of the present use without jeopardizing society’s present welfare. Often the costs of these efficiency improvements are even negative. In other words, they are very profitable from an economical point of view. In Finland, according to the national energy saving programme for the years 2003-2006, it is possible to save about 4-6 % of the present primary energy consumption until 2010. This means a reduction in CO_2 emissions of 4-6 million tonnes, depending on the fuel to be replaced, in comparison with the basic scenario for 2010 (Energiansäästöohjelma 2003-2006, 2003).

Besides energy saving, switching to renewable fuel energy sources prevents the negative impacts of the climate change. According to previous studies (Hall et al. 1991, Houghton 1996, Obersteiner et al. 2001), the use of biomass, rather than fossil fuels in energy conversion, stabilizes the atmospheric concentrations of GHGs more effectively than merely sequestering carbon into terrestrial sinks, namely into living biomass. With an active management of biomass for energy, it is possible, in conjunction with a low consumption of fossil fuels, to reach a net removal of carbon from the atmosphere (negative emissions) before the end of this century. This biomass energy can be used to produce carbon neutral energy carriers, e.g. electricity and hydrogen, and at the same time, it offers a permanent CO_2 sink by capturing carbon at the conversion facility and permanently storing it in geological formations (Kraxner et al. 2003). By-products from chemical pulping processes, such as methanol, ethanol and bio-oils, offer ways to increase the share of renewable liquid fuels for transport and heating purposes in conjunction with electricity conversion from wood. By the year 2030, a gasification of black liquor may yield more electricity from renewable energy sources than power generation technologies used today in the Finnish forest industry (Energy visions 2030).

The control of GHG emissions is an international task due to the even distribution of sources emitting GHGs throughout the globe and also due to the free circulation of these gases in the atmosphere. The Kyoto protocol of the United Nations Framework Convention on Climate Change was agreed upon in 1997 as a goal to reduce GHG emissions in the atmosphere. This protocol includes different mechanisms, such as a joint implementation (JI), a clean development mechanism (CDM), and an emissions trading, all of which aim at softening the economic adjustment of industrialized countries (in the protocol, Annex 1 countries) in reducing their greenhouse gas emissions (Grubb et al. 2001).

1.2 Development of energy wood procurement

The demand for energy wood has considerably followed the development of global energy markets. An explosive interest in the use of wood for energy increased after the worldwide energy crisis in 1973. Due to the increase of oil prices at the end of 1970s, the development work for production and processing of wood for energy was initiated. The research on energy wood procurement was initiated not only in the Nordic countries – Finland, Sweden, Norway and Denmark, but also in the United States and Canada. In Finland and in Sweden, where both large forest resources with an advanced wood processing industry and exceptionally high per-capita fossil fuels consumptions exist, attention has been paid to the development of energy wood procurement due to marginal reserves of fossil fuels (Hakkila 1989).

Through different research projects in Finland, such as the PERA-project (Hakkila 1985), the Bioenergy Research Programme in 1993-1998 (Nikku 1998) and the Wood Energy Technology Programme in 1999-2003 (Hakkila 2004), the technology of energy wood procurement has been developed to provide commercially important solutions for Finland and abroad. The goals of these programmes, especially the two latter ones, were to decrease the high production costs of forest chips, introduce reliable chip procurement organizations, and produce wood fuel with a satisfactory quality (Hakkila 2004). As a result, a forest chip production technology from regeneration areas succeeded as the cheapest and the most abundant source of wood energy. The above research programmes were made successful due to the rapid development of chip production organizations, such as Biowatti and UPM, which both produced 0.5 million m^3 (1 TWh) of forest chips in 2003. A goal of the Finnish energy and climate strategies is to use 5 million m^3 (0.9 Mtoe, 10 TWh) of chips annually by 2010. This goal has led to the use of new, additional biomass sources, such as whole-tree material from early thinnings, stumps and roots wood from regeneration areas. Two major procurement technologies of regeneration areas, namely a chipping at landing called roadside chipping and a baling of forest residues called residue log, will be discussed in more detail in Chapters 2.1.1 and 2.1.2. These two technologies proved to be the most inexpensive according to the study of Asikainen et al. (2001). They are also suitable for large scale operations, where residues are collected simultaneously with commercial roundwood, logs and pulpwood. This, so called integrated harvesting method, combines the best advantages of industrial roundwood procurement for energy wood procurement and aims at low production costs.

1.3 The emissions trading scheme of the European Union and steering elements inside this scheme for the mitigation of GHGs

1.3.1 Emissions trading in the European Union under the Kyoto Protocol

The European Union (EU) decided to establish a Community-wide emissions trading scheme by 2005. The aim of this programme is to be prepared for 8 % reduction in emissions of greenhouse gases (GHGs) by the Kyoto Protocol during the period of 2008-

2012. In the longer term, global emissions of GHGs will need to be reduced by approximately 70 % compared to the levels of GHGs in 1990, which is the base year for GHG emissions in the Kyoto Protocol (Directive 2003/87/EC). Greenhouse gases listed under the trading scheme are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Within the first three-year period (2005-2007), only CO_2 emissions are included, but for the next period 2008-2012, other greenhouse gases will also be included. The Community and its member states will fulfill their commitments to reduce anthropogenic greenhouse gas emissions under the Kyoto Protocol jointly, in accordance with Decision 2002/358/EC. In order to achieve their international commitments more effectively, the European market in greenhouse gas emission allowances started in the beginning of 2005 within the EU, with the least possible diminution of economic development and employment.

Project-based mechanisms of the Kyoto Protocol (see Grubb et al. 2001), the Joint Implementation (JI) in the economies of transition in countries of Eastern Europe, and the Clean Development Mechanism (CDM) in developing countries linked to the Community-wide emissions trading scheme, are linked to emissions trading. JI and CDM mechanisms are important in achieving the goals of both reducing global greenhouse gas emissions and increasing the cost-effective functioning of the Community scheme. Emission reductions carried out in the JI and CDM countries by some EU countries can be listed with the emission quota of these EU countries. The above mentioned project-based mechanisms are part of the Kyoto Protocol and are thus valid for the period 2008-2012. The Directive of greenhouse gas emission allowance trading should also encourage the use of more energy-efficient technologies, including combined heat and power technology, producing less GHG emissions per unit of output (Directive 2003/87/EC).

The emissions trading scheme has interconnections to other policy sectors within the EU, such as energy, forestry and agriculture. In the Constitution for Europe (Treaty establishing a Constitution for Europe, 2004), energy is mentioned in the contexts of energy efficiency and energy saving, and as a need to develop new and renewable forms of energy. Although the European Union has no common energy policy, renewable energy has been promoted throughout the Union by the European Commission in the white paper (Commission of the European Communities 1997) and in the green paper (Commission of the European Communities 2000). The targets mentioned in the white paper are to increase the share of new and renewable energy sources in the EU by 2010 to 12 % of gross domestic energy consumption and the share of electricity produced from renewable energy sources to 22.1 %. In addition to the above targets, the biofuels directive (Directive 2003/30/EC) sets reference values of a 2 % market share for biofuels in 2005 and 5.75 % in 2010. In the green paper, the aim is to increase energy self-sufficiency within the EU by promoting, for example, more renewable energy sources to a supply sector. An environmental policy has also been adopted as a part of the EU’s energy policy, in order to correct some weaknesses in it, which for example the directive on electricity produced from renewable energy sources (Directive 2001/77/EC) shows. Linkages to a common agricultural policy are formed through support schemes, which enable a financial support to energy crops cultivated on agricultural lands for energy conversion (Council Regulation 2003/1782/EC). The support of energy crops cultivated on agricultural lands is indirectly connected to forestry, because pulpwood from natural forests has been partly directed to energy conversion. By promoting more renewable energy sources from agriculture, it is possible to reduce the pressure to exploit more pulpwood for energy conversion instead of more profitable pulping for paper making.

In Finland during 2005–2007, like in other major EU countries, emission allowances will be delivered to activities producing GHGs free of charge. According to the Directive (Directive 2003/87/EC) for the above period, the member state shall allocate at least 95 % of the allowances free of charge and for the period 2008-2012, at least 90 % of the allowances free of charge. In this so-called grandfathering system, the amount of deliverable emission allowances for a certain time period, here for the period 2005-2007, shall be determined according to past emissions of certain years. In Finland, these years will be mainly 1998-2002 or even 2000-2003 (condensing power conversion) (Hiilidioksidipäästöjen päästöoikeuksien jakoperusteet…2004). The specific emission coefficient factor based on the past emissions of 1998-2002 or 2000-2003 is calculated as a mean of the years mentioned above, such that the best and the worst factors are ignored and from the remaining ones, an arithmetic mean is calculated. If the amount of delivered allowances to an installation is less than the amount of emissions from this installation at that particular year, the operator, i.e. any person who operates or controls an installation, must purchase lacking allowances from emission markets. In the opposite situation, the operator can sell surplus allowances to the market or save them for the future use. A failure of returning enough allowances will lead the penalty of 100 EUR for each tonne carbon dioxide equivalent emitted by the installation for which the operator has not surrendered enough allowances. However, during the three-year period which was initiated on 1 January 2005, the penalty for not returning enough allowances will be, to a member state, 40 EUR for each tonne carbon dioxide equivalent emitted. In addition to penalty payments, the operator has to purchase allowances for excess emissions from the emissions trading markets.

1.3.2 Guidelines for emissions trading in the European Union

The idea of greenhouse gas emission allowance trading is based on the fact that each economical unit has its own marginal costs for the GHG emissions reduction. Those units with low marginal costs for emissions abatement can sell allowances cost-effectively to units with high marginal costs. Furthermore, units with high marginal costs can buy emission allowances at a cheaper cost than the cost at which abatement would have been paid to these units, if they had reduced their emissions themselves without trading. Results from the tradable permit system in the United States in the 1990s with sulphur dioxide (SO_2) with the so called U.S. Acid Rain Program (see Ellerman et al. 2000, Joskow and Schmalensee 1998, Montero 1999) showed that SO_2 emission reduction was cheaper than it was predicted due to flexibility of permit systems and new innovations that program encouraged. The U.S. Acid Rain Program has offered practical experience on emissions trading and thus affected the formation of the greenhouse gas emission allowance trading scheme within the European Union (see Solomon 1995, Sorrell and Skea 1999). However, the theoretical advantages of emissions trading can be minimized or even lost. This happens if national allocation plans for delivering emission allowances to different activities ignore possibilities of different activities to decrease their emissions, costs of these emission reductions and the nature of markets among different activities (Hiilidioksidipäästöjen päästöoikeuksien jakoperusteet…2004). That holds true for the activities under the emission trading scheme and activities outside the scheme, because the burden of emissions reductions is shared among the whole national economy responsible for reducing their emissions.

The trading of emission allowances will not decrease GHG emissions itself, but real measures to save energy and increase the use of non-polluting renewable energy resources will reduce the emissions. The trading is a way to promote reductions of GHG emissions in a cost-effective and an economically efficient manner. According to the Directive (Directive 2003/87/EC), activities under the EU's emission trading scheme are energy conversion, the production and processing of ferrous metals, mineral industry and pulp, paper and board production. Installations of the activities mentioned above participate in the trading scheme when the installed capacity of power and heat generators is 20 MW or higher. Industries above and their installations under the scheme are responsible to return, by 30 April each year at the latest, a number of allowances equal to the total emissions from that installation during the preceding calendar year, after which these allowances will be cancelled.

In the emissions trading scheme, carbon emissions are calculated according to the carbon content of each fuel. This CO_2-coefficient factor is typical for each fuel, varying from 56.1 g CO_2/MJ with natural gas to 106 g CO_2/MJ with fuel peat (IPCC 1996). The CO_2-coefficient factor for biofuels is 0 g CO_2/MJ, because CO_2 released in combustion is assumed to be absorbed into new renewable biomass. Biofuels include the following types (Hiilidioksidipäästöjen päästöoikeuksien jakoperusteet…2004):

- Forest chips, bark and sawdust
- Wood waste from mechanical forest industry
- Processed, wood-based fuel products (pellets and briquettes)
- Biofuels and biosludges from pulp and paper industry (e.g. black liquor)
- Other wastewood
- Biomass on arable land: willows (*Salix sp.*), straw, reed canary grass (*Phalaris arundinacea*)
- Harvestable natural vegetation from waterfronts and water systems
- Biogas and biosludges from sewage treatment plants, landfills and waste treatment plants
- Biogas from cultivated plants: flax (*Linum*), clover (*Trifolium*), *Phalaris arundinacea*
- Animal based products (e.g. meatbone meal).

1.3.3 Experimental economics and emissions trading

The approach of emissions trading to mitigate global GHG emissions is a new challenge to societies under the trading scheme. The effects of the trading are not always easy to foresee. In order to gain experience on complex economical connections, laboratory experiments have been introduced. In these experiments, the economic behaviour of human subjects can be examined in controlled circumstances. A complex phenomenon, such as emissions trading, can be separated into experiments. Thus experience can be achieved and people can be educated for this new market oriented form of the GHG emissions reduction. Although the actual trading of emission allowances is conducted by professionals, there are many interest groups and professional fields whose professions touch the mitigation of GHGs. These professions, such as environmental officers in public organizations, general managers working in the businesses of energy, wood processing and metal etc. industry under current emissions trading scheme, need education and practical training on issues of emissions trading. It is important to extend this education over the whole society due to the diverse effects of the trading. For example, private consumers in paying their electricity bill indirectly meet the consequences of emissions trading, because electricity producers are duty-bound to participate in the emissions trading scheme.

Laboratory experiments in economics are conducted with human subjects, usually university undergraduates (Muller & Mestelman 1998, Davis & Holt 1993). Typically, about 8-12 subjects are recruited for each market session. Before each trading session, participants are instructed about the rules of the experiment and assigned roles as buyers, sellers or traders. Quite often a market instrument is used an abstract product called a token, but real monetary units are also possible. Before actual gaming, participants are informed on how their profit is calculated and according to which performance their possible earnings are paid. Trading occurs for a number of market periods under the rules specified by the experimenter. Trading may be carried out orally with manual record keeping or it may be mediated by computer programs of a different sophistication.

One basic principle in experimental economics is to pay subjects sufficiently to ensure their motivation for an experiment (Muller & Mestelman 1998, Davis & Holt 1993). This is a main reason for using university students as subjects; the opportunity costs of employed professionals, especially senior ones, would be much higher. A second basic principle is never to deceive the subjects. All the rules of an experiment are informed in advance and are strictly followed. However, an interpretation of the data may differ from the subjects. This is true, e.g. in a case, where subjects are not told that the tokens they are trading represent permits to emit pollutants. In this way, it may possible to avoid biases linked to the commodity being traded. However, using real life monetary units and examples based on circumstances mimicking true situations may motivate the subjects to perform the experiment more efficiently.

Laboratory trading institutions differ from each in the following aspects: the number of seller and buyer subjects, who proposes prices, decisions and timing (either simultaneous or sequential decision) and how contracts are confirmed (Davis & Holt 1993, Kagel & Roth 1995). Those institutions where subjects make key decisions on trades sequentially and in real time are closer to the institutional rules of many financial, commodities and producer goods markets. The former connection to real markets rationalizes the use of trading institutions with sequential decisions, although it is more difficult to analyze them than institutions with simultaneous decisions. Especially institutions with sequential decisions where both sellers and buyers propose prices and both sides may also confirm contracts, diversify an actual experiment and increase the motivation of all participating subjects. Examples on these types of institutions are e.g. a double auction and a decentralized negotiation.

In order to simulate the effects of trading on GHG emissions and abatement costs, carbon trading experiments offer a way to achieve those goals (Hizen & Saijo 2001). The trading experiment also provides valuable experience to participants seeking real world trading opportunities. Trading requires information on energy conversion facilities, used fuels, the legislation of emissions trading, the market development of emission allowances etc. Thus emission trading experiments are a way to educate interest groups into an operational environment of the emissions trading. In the trading experiment, the active participants are those who need to decrease their carbon emissions, such as the individual countries responsible for the implementation of the Kyoto protocol or the companies emitting CO_2 and thus meeting national requirements for the abatement of GHGs.

1.4 The aims of the study

The main aim of the study was to investigate, how the harvesting of residual forest biomass for energy conversion and saving energy at three mills affected the CO_2 emissions originating from the energy conversion of these mills and what the price of CO_2 abatement in these two above alternatives was. In addition, the coupling of energy saving and carbon trading was studied as an elementary part of a value chain of the pulp and paper production for today and especially for the future. The analysis of interconnectedness was carried out for three elements in the value chain, namely societal (carbon trade), technical (logging and transportation operations) and refinery (energy conversion at the wood processing mills) processes (Figure 1.1). Basically, the societal process sets provisions for technical and refinery processes to modify their operations to meet expectations of the society facing the rise of GHG emissions.

This study consists of three parts, namely: 1) a harvesting of residual forest biomass in connection with industrial roundwood of three mills of a forest consolidated corporation, 2) energy saving linked to energy conversion of the three mills and 3) the knowledge and understanding of undergraduate students (representing non-specialists) with respect to the coupling of energy saving and carbon trading with procedures of experimental economics in the context of forest industry. The aim was to carry out the analysis on the basis of a case study and provide opportunities to generalize the results in Finland in general and also elsewhere. Especially with the same wood harvesting, energy conversion and pulp and paper production techniques, the results can be generalized for Sweden and Norway and other countries with same conditions.

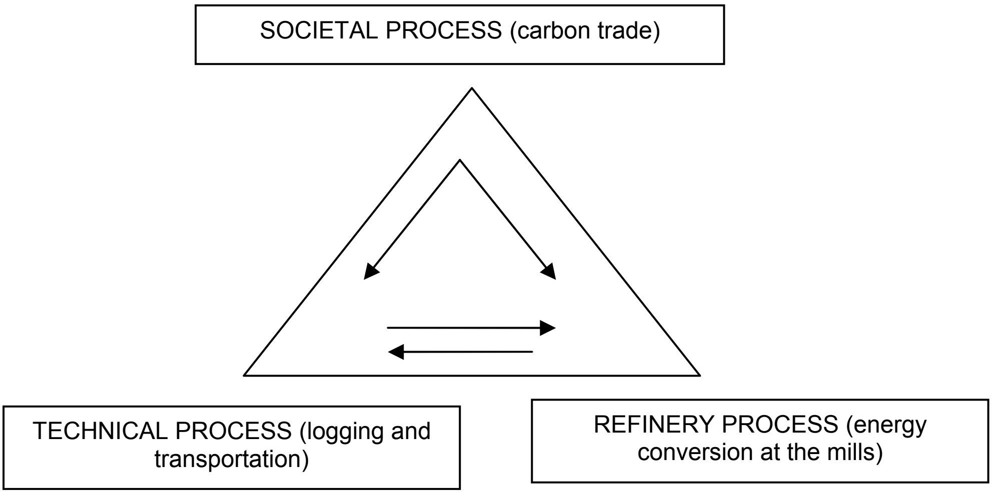

Figure 1.1. Three different processes, namely societal, technical and refinery and their interdependences according to the framework of this study.

The fundamental research topics cover the following issues:

- How much residual forest biomass is it possible to harvest from the timber purchasing area of three individual mills? What is the price of the biomass at each mill after all procurement operations using two alternative harvesting methods, namely the roadside chipping and the residue log? What share can this residual forest biomass cover from all energy conversion of these mills?
- How are energy saving and CO_2 emissions at the mills connected to each other? How are investments to save energy linked to reductions of fossil carbon emissions originating from energy conversion of the mills and from a conversion of purchased electricity?
- Comparison of CO_2 abatement costs related to energy wood procurement and energy saving in the context of the three mills of a consolidated corporation.
- Demonstration of energy saving and carbon trading between three mills producing several forest products in order to illustrate connections between energy saving investments and a trading of emission allowances. How was the idea of coupling energy saving and carbon trading understood among different students representing non-specialists and participating in trading experiments?
- How did the amount of available trading information affect the gaming performance of each participant?
- The carbon trading experiments as a training tool to educate students to understand the economic phenomena of the GHG, especially CO_2, mitigation and improve their knowledge and skills on the issue.

2. MATERIAL AND METHODS

2.1 The energy wood harvesting technologies used

In this study, two harvesting technologies were used as a basis of cost and recovery calculations of energy wood, namely the roadside chipping (RC) and the residue log (RL). It is important to notice that the technologies were used as optional, not replacing each other. This means that all calculations were carried out with the same stand information data for both the RC and the RL technologies in order to compare the two technologies and their performance. In Chapters 2.1.1 and 2.1.2, the RC and the RL methods are presented in detail.

2.1.1 The roadside chipping method

The roadside chipping (RC) method is a major technology used when the chipping of logging residues or whole trees is not possible at the processing plant. It is common for most plants owned by communes or private energy companies. The roadside chipping technology consists of a harvester which cuts trees into piles of roundwood and forest residues, a forwarder which forwards saw logs, pulp wood and logging residues to the side of the forest road into separate piles, and a chipper which chips the residue material for a long-distance transportation with a chip truck (Figure 2.1).

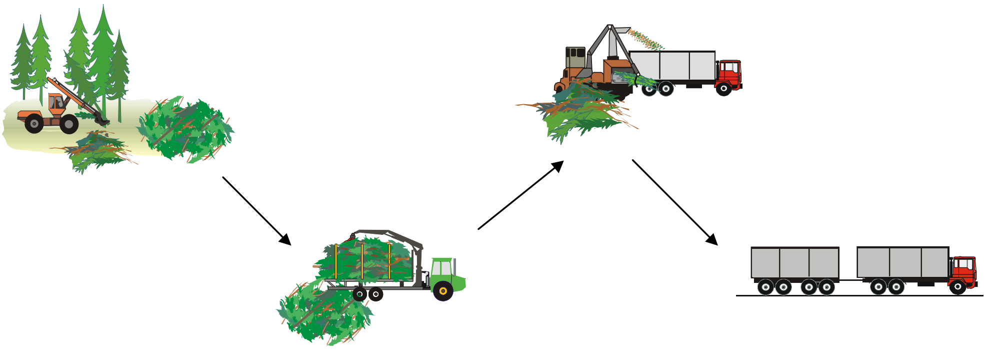

Figure 2.1. The roadside chipping –method. From left to right: harvester, forwarder, chipping unit, chip truck. The arrows describe the various operations following each other, not the paths of certain residue piles (Figure: VTT Energy, E. Alakangas, Jyväskylä, Finland).

A roadside chipping or a crushing is typically carried out with vehicle-based drum chippers and hammer or rotor crushers (Ranta 2002). Before chipping, logging residues from a roadside pile must be loaded into the feeder of a chipper with a chipper grapple and feeder rolls. Drum chippers produce chip material which is due to its homogeneity more often suitable for chipping residues than chips produced by disc chippers. They also tolerate impurities better than disc chippers. Drum chippers' knife pockets easily trap and pulverize thin branches of logging residues, whereas flexible branches pass through disc chipper´s disc slots easily yielding high sliver content. In order to produce a more homogenous particle-size distribution of chips, both a drum chipper and a crusher can be equipped with an internal sieve (Ranta 2002).

Road-based chipping allows a higher chipping capacity per time unit than terrain chipping, where a chipper has been installed on a forwarder capable of operating on a logging site (Ranta 2002). Comparing crushers and chippers, the weight and the mobility are two separating factors. Crushers are heavy and difficult to transport, whereas chippers can easily be installed on a truck or a forwarder chassis. The chipping can then be done on a road-side landing, where the soil is firm and the landing area is straight. Truck-mounted chippers have high operational mobility, and thus move rapidly between sites. On the other hand, crushers tolerate small-sized impurities, such as stones, better and their productivity is higher if the crushed material contains impurities (Ranta 2002). The maintenance of blades and knives, which is typical for chippers, can then be omitted. However, at a power plant, a system feeding fuel into a boiler must be adapted to tolerate an uneven particle size of residues as the result of crushing.

2.1.2 The residue log method

The residue log (RL) method is used at harvesting sites where chipping or crushing can be carried out at the processing plant, commonly at a power plant integrated with a wood processing industry. In this method residues are first delimbed into separate piles in conjunction with industrial wood harvesting, and after that residues are bundled into cylindrical bales using a bundler machine installed on the base of a normal forwarder body (Figure 2.2). Residue bales are forwarded with a forwarder into piles next to a trucking route, where a normal timber truck can load bales into a load space and transport them to the landing of an energy plant. For combustion, forest residues are crushed into smaller particles suitable for conveying into a boiler.

The bundling method for residue log is divided into three stages (Ranta 2002). In the first stage, collected logging residues are pressed by feeder rolls, in the next stage they are further compressed in a rectangular presser, and in the last stage the compaction is ended with the roping of the pulse-fed logging residue bundle. In the end, the bundle is cut into desired lengths with the chainsaw of a bundling machine. The bundles are wrapped with string at about every 40 cm, and their length can be selected in order to attain optimal transport economy. Normally, the length of a bundle is 3.2 m and the diameter about 700 mm (Poikola 2002). The weight of one bundle is 450-550 kg (Ranta 2002).

After bundling, residue bundles are transported to a roadside landing with a normal forwarder. At landing, they can be handled like any other timber assortments which can be unloaded to stacks, such as logs and pulpwood. About 20 residue logs can be forwarded in a forwarder’s load space at the same time to a road-side landing, if two bundles are loaded sequentially. In order to secure full employment, the bundling machine should work at logging sites with 2-3 harvesters.

The long-distance transport of residue logs is carried out with a normal timber truck of a length of 22 m, width of 2.6 m and a gross truck weight of 60 tons (Ranta 2002). In the truck and trailer system, normally used nowadays, there is a load space of 65-70 residue bundles and a weight capacity allowance for the 35-38 ton load (Korpilahti & Suuriniemi 2001). At the end-user site, the unloading of residue bundles is carried out with similar equipment as used for pulpwood, straight from the truck to the feeding table of the crusher. Slow or high-speed crushers and high power chippers are used for processing bundles into a combustible form. After crushing or chipping, the processed residue material is suitable to be fed into the boiler. The productivity of crushing varies in a large scale according to the

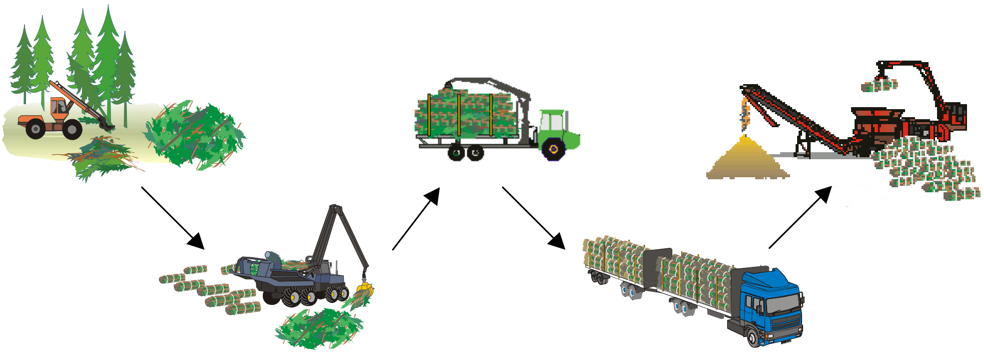

Figure 2.2. The residue log –method. From left to right: harvester, bundling machine, forwarder, timber truck, chipping or crushing unit. The arrows describe again the operations following each other, not the path of an individual residue pile (Figure: VTT Energy, E. Alakangas, Jyväskylä, Finland).

crushing type: from 25-40 m^3 (solid)/h with slow-speed crushers to 80-120 m^3/h with high-speed crushers (Asikainen et al. 2001). Also, the feeding efficiency affects the productivity, so that the higher the feeding efficiency is, the higher is the productivity. For example, wood residue bundles can be fed into the feeding table of the crusher quicker than loose, unwrapped residues.

The residue log method has some advantages compared to the roadside chipping. In the residue log method bundles can be forwarded by normal forwarders from the forest, and long-distance transportation can be carried out by normal timber trucks (Ranta 2002). As a result, harvesting and transportation costs can be minimized in this method while those costs are higher in the RC method. There are several circumstances, such as the flatness and firmness of terrain, enough space for piles of residues and the high yield of residues at the site which favour bundling so that the total yield of residues at the site is increased. Another benefit of this method is that storing of residue bundles is more convenient than storing chips. Bundles can be stored on a logging site, at a road-side landing or at a terminal of an energy conversion unit, without major losses of biomass. Besides, the fuel quality of bundles is superior to that of stored chips (Lehtikangas and Jirjis 1998, Thörnqvist 1984). However, according to Jirjis and Lehtikangas (1993), better results are probably achieved by storing residues in windrows rather than in bales.

2.2 Procurement area of three mills

The procurement area for each mill was formed from individual stands marked for cutting from the data base of the wood procurement organisation of the forest corporation. In this study, a specific procurement area is used for each mill (symbolized by the names Mill A, Mill B and Mill C), although a specific mill may not use all the timber assortments listed in the stand records. For example, Mill A does not use spruce logs, although stands with spruce logs can be found in the stand records of Mill A. So it was assumed that energy material from these stands (branches and non-merchantable stemwood, tops) was procured to Mill A and spruce logs were transported to a mill suitable for using the material. In stands records both thinnings and final fellings were executed. In this study only stands marked for final felling were accepted, because the harvesting methods used here for stands with an adequate amount of forest residues were economically viable. Thus predefined thinnings are out of the scope of this study. In this study, five different final felling options were used, namely:

- removal of dominant trees,
- strip felling,
- clear felling,
- seeding felling and
- special-purpose felling.

Each stand's data contained information on area (unit hectares, ha), haulage distance in forest (unit metres, m), number of tree species and assortments (pine, spruce, birch and other hardwoods, mainly aspen; both logs and pulp wood; unit: solid cubic metres, m^3), co-ordinates of each stand (meridian and parallel circles, unit: kilometres, km) and long-distance transportation with timber trucks (unit kilometres, km). For this study, the stands located within a radius of approximately 100 km from the mills studied were selected for further analysis. The road transport distance of approximately 100 km from the mill was selected according to the information gathered from the Bioenergy Research Programme in 1993-1998 (Nikku 1998) and from the Wood Energy Technology Programme in 1999-2003 (Hakkila 2004). From stand data, a real transport distance from the stand to the mill was based on the public road network. In cases where this distance information was missing from some stands, existing information from other stands was used to estimate the missing distance to the mill (see Asikainen et al. 2001, Ranta 2002). Using the computer program Mapinfo 7.0 Professional, a straight line distance from a stand to the mill using coordinates of the mill and the stand was specified. After that, the winding coefficient (WC) for one individual stand marked for final felling with an existing distance was calculated using the formula

$$WC_{ij} = RD_{ij} / SLD_{ij} \qquad (1)$$

Where,
i = stand, i = 1,…, m; j = Mill, j = 1…3
WC_{ij} = winding coefficient for stand i and the mill j
RD_{ij} = real distance from stand i to the mill j,
SLD_{ij} = straight-line distance from stand i to the mill j.

When WC had been calculated for each stand with the distance information, the general winding coefficient (GWC) was defined as a mean of the calculated winding coefficients (WC_{ij}) for each three mill and the year in 1999-2002. GWC was used to define the estimate of the real distance (ED) from a stand to the mill for those stands with missing distance information. The estimate was calculated using the formula:

$$ED_{ij} = GWC_{j} * BII_{ij} \qquad (2)$$

Where,
i = stand, i = 1,…, n; j = Mill, j = 1…3
ED_{ij} = estimate of the real distance from stand i to the mill j,
GWC_{j} = general winding coefficient for the mill j,
BII_{ij} = straight-line distance from stand i to the mill j.

In Table 2.1, general winding coefficients for the different three mills for the years 1999-2002 have been illustrated. The biggest coefficients were calculated for Mill C (from 1.45 to 1.56), whereas the largest variation between years was typical for Mill A (from 1.38 to 1.55). This may indicate variations in the geographical composition of the stands. In reality, the location of waterways and the structure of the local road network caused the differences in winding coefficients between the mills.

With the above mentioned basic stand information, it was possible to further calculate the amount of forest residues, amount of carbon in those residues and the costs of the carbon converted into carbon dioxide (CO_2) and delivered to the mill. The carbon recovery, as a function of the distance from a stand marked for a final felling to Mill A, B or C, was also calculated.

Table 2.1. General winding coefficients for the mills A, B and C for the years 1999-2002.

	1999	2000	2001	2002
Mill A	1.548	1.495	1.409	1.380
Mill B	1.482	1.437	1.437	1.400
Mill C	1.555	1.506	1.441	1.448

2.2.1 Wood procurement information on Mill A

Mill A is a chemical pulp mill using birch and pine as raw material, and a sawmill using pine. Records for stands marked for felling covered the years 1999-2002. In Table 2.2, information was collected on stands marked for felling by two alternative methods, namely the roadside chipping (RC) and the residue log (RL) method. Stands were normal stands marked for final felling, from where only saw logs and pulpwood were harvested. However, in this study the stands were used to demonstrate two integrated harvesting methods, namely the RC and the RL methods. A mean and a median volume of spruce, pine and hardwoods per stand was calculated separately for the years 1999, 2000, 2001 and 2002. From the group of these four means and medians, the overall mean and median of 1999-2002 was calculated. The sum volume of different tree species was calculated in the same way as the mean and the median volume per stand. The volume of certain tree species in each stand was summed up in order to get the total sum of that particular year. This was done separately with the data of the years 1999, 2000, 2001 and 2002. From these four values, mean sum volumes for each tree species were calculated. Also, means and medians of a long-distance transport, area and haulage distances in the forest were calculated in the same way as described above. All those means and medians are illustrated in Table 2.2. Basically, the same stands were used for both of the two above mentioned harvesting methods. However, in some stands the recovery of forest residues was so low that these stands were ignored. Generally, residues are not harvested from some stands due to high costs compared to low actual recovery. The RC and the RL methods in this study are used as options, not complementing each other. In reality, the suitable method is chosen considering local circumstances, such as chipping or crushing methods in use, the landing area in the forest and vehicles used for the long-distance transportation.

According to the roundwood record of Mill A, the total use of roundwood transported by timber trucks was on average 1 047 380 m^3 per year in 1999-2002. On average 735 820 m^3 of wood per year was harvested from final fellings, of which 93 % was available for the roadside chipping method and 95 % for the residue log method. 7 % of stands using the RC and 5 % using the RL method were eliminated from the original stand records due to a low yield of tops and branches per 100 m hauled in forest. Moreover, the structure and the volume of a stand were so limited that it was not possible to harvest enough residual forest biomass.

Table 2.2. Mean and average median values from the procurement area of Mill A calculated from the individual means and medians of the years 1999-2002.

	Roadside chipping method (RC)		Residue log method (RL)	
	mean	average median	mean	average median
number of stands/year	945		979	
area, ha	3.3	2.4	3.7	2.5
haulage distance in forest, m	278	216	280	216
volume of pine, m^3/stand	235	117	241	124
Sum volume of pine, m^3/year	217 960		232 140	
volume of spruce, m^3/stand	409	279	397	270
sum volume of spruce, m^3/year	388 130		389 810	
volume of hardwoods, m^3/stand	81	39	80	38
sum volume of hardwoods, m^3/year	76 420		78 580	
volume of all species, m^3/stand	725	527	718	522
sum vol. of all species, m^3/year	682 510		700 530	
Long-distance transport, km	62	66	62	66

2.2.2 Wood procurement information on Mill B

Mill B is an integrated mill consisting of a chemical pulp mill and a paper mill. Pine and birch are the main tree species used for pulp and paper making there. As in the case of Mill A, records for stands marked for felling covered the years 1999-2002. In Table 2.3, the mean and average median values on stands marked for final fellings can be seen. The values have been computed in the same way as with Mill A.

According to the stand record, the total use of roundwood transported by timber trucks was on average 278 150 m^3 per year in 1999-2002, of which 172 890 m^3 originated from final fellings. Stands available for the RC method covered 78 % and those available for the RL method covered 89 % of all stands marked for final felling. The remaining stands were rejected due to low recovery of residual forest biomass. However, according to wood reception information from Mill B, the total amount of roundwood transported by timber trucks was on average 786 600 m^3 per year from 1999 to 2002. The reason for the large difference between informed volumes resulted from the fact that stands were selected within the radius of approximately 100 km from the mill for all three mills. This distance was still economically viable for the collection of forest residues. The roundwood procurement area of Mill B extended far beyond the 100 km distance, which eliminated a major part of the stands away from this study.

Table 2.3. Mean and average median values from the procurement area of Mill B calculated from the individual means and medians of the years 1999-2002.

	Roadside chipping method (RC)		Residue log method (RL)	
	mean	average median	mean	average median
number of stands/year	204		234	
area, ha	4.9	4.0	6.2	4.6
haulage distance in forest, m	318	250	323	253
volume of pine, m^3/stand	351	252	353	258
sum volume of pine, m^3/year	71 660		82 930	
volume of spruce, m^3/stand	189	100	171	84
sum volume of spruce, m^3/year	39 150		40 400	
volume of hardwoods, m^3/stand	120	53	129	66
sum volume of hardwoods, m^3/year	24 480		30 120	
volume of all species, m^3/stand	661	515	653	498
sum volume of all species, m^3/year	135 290		153 450	
long-distance transport, km	61	59	62	58

2.2.3 Wood procurement information on Mill C

Mill C is also an integrated mill consisting of a chemical pulp mill, a mechanical pulp mill, a sawmill and other mills for manufacturing paper and cardboard. All main tree species, namely pine, birch and spruce are used for pulp and paper manufacturing. As in the case of mills A and B, records for stands marked for a final felling covered the years 1999-2002. In Table 2.4, mean and median values on stands marked for felling can be seen. The values have been computed in the same way as with mills A and B.

According to the roundwood records of Mill C, roundwood volume transported by timber trucks was on average 1 211 270 m^3 per year from 1999 to 2002, of which 881 880 m^3 originated from final fellings. The mean sum volume of all tree species covered 92 % with the roadside chipping method and 93 % with the residue log method on all this wood volume originating from final fellings. The reason for the rejection of remaining stands was identical with two former mills, i.e. too low yield of tops and branches per 100 m hauled in the forest.

Table 2.4. Mean and average median values from the procurement area of Mill C calculated from the individual means and medians of the years 1999-2002.

	Roadside chipping method (RC)		Residue log method (RL)	
	mean	average median	mean	average median
number of stands/year	1297		1316	
area, ha	2.4	1.8	2.6	1.8
haulage distance in forest, m	294	250	296	250
volume of pine, m^3/stand	147	71	148	72
sum volume of pine, m^3/year	189 910		194 180	
volume of spruce, m^3/stand	423	290	418	284
sum volume of spruce, m^3/year	550 870		552 310	
volume of hardwoods, m^3/stand	55	26	55	26
sum volume of hardwoods, m^3/year	71 480		72 760	
volume of all species, m^3/stand	624	450	621	446
sum volume of all species, m^3/year	812 260		819 260	
long-distance transport, km	54	55	54	55

2.3 Calculation methods

2.3.1 From roundwood to forest residues

The amount of roundwood in different stands marked for final felling was converted into wood residues by using conversion factors determined by Hakkila (1991). The conversion factors were based on measurements of crown dry masses in proportion to the volume of stemwood, including bark for both Southern and Northern Finland. The crown mass is the sum of all masses of living branches with needles, bark and wood and dead branches. In order to get the amount of the whole biomass available for energy purposes, the share of non-merchantable stemwood must be added to crown mass. Non-merchantable stemwood is the part of a stem in the upper part of a trunk, which does not fulfil diameter requirements of pulp wood or industrial wood as well as the wood with inadequate quality due to decay, crooked-growth and crook. The share of non-merchantable stemwood varied from 10 to 12 % on the sum of crown and non-merchantable stemwood masses. The highest proportion (12 %) was with spruce, then with pine (11 %) and the lowest proportion (10 %) with hardwoods (Asikainen et al. 2001). The share of crown mass was higher in northern Finland than in southern Finland due to the trunk form. In the north, trees are short and firm and their living crown is proportionally longer than in the south (Hakkila 1991). Thus, the share of residual forest biomass was also higher in the north than in the south. However, the overall yield became lower due to a minor areal recovery in the north (Hakkila et al. 1998). The dry mass of residual forest biomass (both crown and non-merchantable stemwood) was converted to solid cubic metres by dividing it by the basic density of the residual forest biomass (see Table 2.5). The recovery rate in both logging operations of residues was estimated to be 70 % (Asikainen et al. 2001). In the roadside chipping method, dry-matter losses between felling and the collection of residues were estimated to be 10 % (Asikainen et al. 2001). The main reason for dry-matter losses was due to the falling off needles. Hardwoods in Table 2.5 and also in other tables concerning conversions to volume, mass or energy units were mainly birch, and the values of birch were then used in the calculations.

Table 2.5. Information on residual forest biomass for Southern Finland (south) and Northern Finland (north) (Hakkila 1991, Asikainen et al. 2001) and basic densities (Asikainen et al. 2001).

	Spruce	Pine	Hardwoods
crown and waste stem wood mass, kg/m^3 (stemwood), south	187	92	92
crown and waste stem wood mass, kg/m^3 (stemwood), north	247	121	133
basic density, kg/m^3	425	395	500

In the residue log method, the amount of forest residues in each stand for each tree species (pine, spruce, hardwoods) was calculated separately with the formula:

$$\sum_{n=1}^{k} FR_{rl} = (RW*(CWM/BD))*RT \qquad (3)$$

Where,
FR_{rl} = amount of forest residues in residue log method, solid-m^3
RW = amount of roundwood, logs and pulpwood, solid-m^3
CWM = crown and non-merchantable stemwood mass for pine, spruce and hardwoods, kg/m^3 (stemwood)
BD = basic density for pine, spruce and hardwoods, kg/m^3
RT = recovery rate (70 %) = 0.7 (coefficient)
1…k = number of stands marked for final felling.

The formula for the roadside chipping method is identical with the formula above, except the coefficient LO was added. The formula is thus written:

$$\sum_{n=1}^{k} FR_{rc} = (RW*(CWM/BD))*RT*LO \qquad (4)$$

Where,

FR_{rc} = amount of forest residues in roadside chipping method, solid-m^3
LO = dry matter loss of residues after drying (10 %) = dry matter content after drying 0.9 (coefficient) (Asikainen et al. 2001).
1…k = number of stands marked for final felling.

2.3.2 From forest residues to carbon

The forest residues of different tree species were converted to carbon in order to calculate the price of carbon in residues at the mill. The conversion was done separately for each tree species, namely pine, spruce and hardwoods. The basic densities and the carbon contents (Karjalainen & Kellomäki 1996) varied according to tree species (Table 2.6).

Table 2.6. Basic densities (Asikainen et al. 2001) and carbon contents (Karjalainen & Kellomäki 1996) of different tree species.

	Basic density, kg/m^3	Carbon content
Pine	395	0.519
Spruce	425	0.519
Hardwoods	500	0.505

The volume of forest residues with different tree species was separately converted to carbon with the formula

$$\sum_{n=1}^{k} AC = (FR*BD*CC)/1000 \qquad (5)$$

Where,
AC = amount of carbon, tonnes of carbon, tC
FR = amount of forest residues with pine, spruce and hardwoods, solid-m^3
BD = basic density of pine, spruce and hardwoods, kg/m^3
CC = carbon content of the dry matter
1…k = number of stands marked for final felling.

2.3.3 From forest residues to energy

In order to discover the potential of forest residues from an energy point of view, the volume of forest residues from different tree species was converted to an energy unit, MWh. With respect to fuels used for energy conversion at the mills, energy content of forest residues offered an interesting possibility to estimate the potential of residues relating to energy conversion at the mills. The conversion was performed with the formula for different tree species:

$$\sum_{n=1}^{k} AE = FR*EC \qquad (6)$$

Where,
AE = amount of energy, MWh
FR = amount of forest residues of pine, spruce and hardwoods, solid-m^3
EC = energy content, MWh/m^3
1…k = number of stands marked for final felling.

The energy content was almost equal according to the logging method used (see Table 2.7). According to practical moisture content measurements of the United Paper Mills (UPM) in real circumstances in 2004-2005, the moisture content for the RC method was set to 45 % and for the RL method to 46 %. An effective heating value of oven dry biomass was determined according to the literature (Hakkila 1978). Thus the formula for energy content of different tree species was

$$\sum_{n=1}^{k} EC = ((EFO* (1-MC)-2.441*MC) * (1/(1-MC)) *0.2778*0.001) *BD*FR \qquad (7)$$

Where,
EC = energy content, MWh/m^3
EFO = effective heating value of oven dry biomass according to tree species, MJ/kg
MC = moisture content, either 0.46 (46 % moisture) in the residue log method or 0.45 (45 % moisture) in the roadside chipping method
2.441 MJ/kg = the latent heat of vaporization of water at 20 ºC
0.2778*0.001 = conversion factor from MJ to MWh
BD = basic density of different tree species, kg/m^3
FR = amount of forest residues of pine, spruce and hardwoods, solid-m^3
1…k = number of stands marked for final felling.

Table 2.7. Effective heating values of oven dry biomass (Hakkila 1978) and energy contents according to logging method and tree species (m.c. = moisture content).

Effective heating value of oven dry biomass, MJ/kg	Pine	Spruce	Hardwoods
- roadside chipping	20.4	19.7	19.7
- residue log	20.5	19.8	19.7
Energy content, MWh/m^3			
- roadside chipping (45 % m.c.)	2.02	2.09	2.46
- residue log (46 % m.c.)	2.02	2.09	2.45

2.4 Calculation methods of harvesting costs

In order to calculate procurement costs at the mill, the calculation programme developed by Asikainen et al. (2001) was used in this study. The calculation procedure slightly differed between the roadside chipping (RC) and the residue log (RL) methods. The main formulas of both the methods to calculate harvesting costs at the mill are presented in the chapters 2.4.1 and 2.4.2. These formulas are identical to the formulas presented by Asikainen et al. (2001). In both harvesting methods, the total procurement costs were calculated as a sum of different subcosts which corresponded separate work stages (see Figures 2.3 and 2.4).

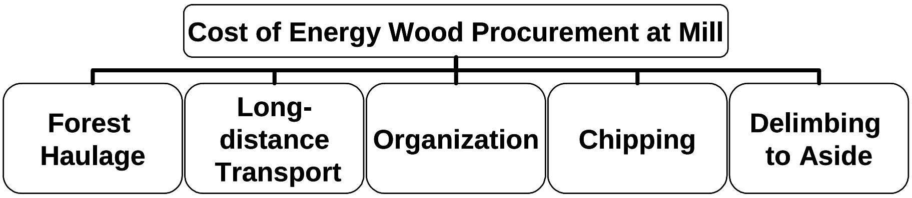

Figure 2.3. The cost structure of the roadside chipping (RC) method.

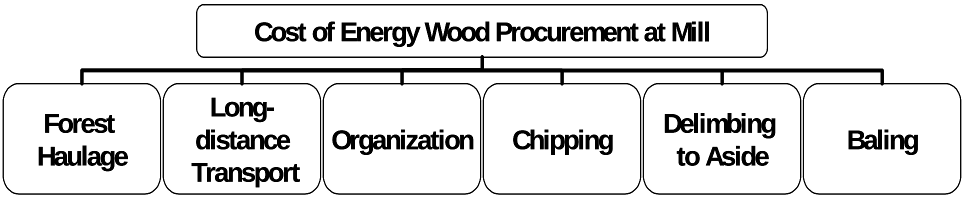

Figure 2.4. The cost structure of the residue log (RL) method.

2.4.1 The roadside chipping

The first work stage in the harvesting operations of the roadside chipping (RC) method is forest haulage. The operations of forest haulage can be divided into five different stages. They are:

1. Drive without load to a cutting site,
2. Loading,
3. Drive while loading,
4. Drive with load to an intermediate storage,
5. Unloading at the intermediate storage.

The first stage, time consumption for a drive without a load was calculated with the formula

$$Y1 = b0 + b1 * (T_{distance}) \quad (8)$$

Where,
Y1 = time consumption, drive without load (min/m^3)
b0 = 0.5 (assistance time, min/load)
b1 = 0.018
$T_{distance}$ = drive distance without load, unit m = 2* mean distance in forest * 0.53

The second stage, time consumption of loading was calculated with the formula

$$Y2 = KUassistance + (b0 + b1 * \ln(t)) \quad (9)$$

Where,
Y2 = time consumption in loading, min/m^3
KUassistance = assistance time of loading, min/m^3 = 0.6 (forwarder)
b0 = 0.059 (forwarder)
b1 = -0.78 (forwarder)

The load size (t) was further calculated with the formula

$$t = b2 + b3 * \ln(a1 * x) \quad (10)$$

Where,
t = load size, m^3
b2 = 0.29
b3 = 0.12
a1 = 0.06, a1* x = the size of working post, unit m^3
x = logging road density, m^3/100m

The third step, time consumption for a drive while loading was calculated with the formula

$$Y3 = (t_{assistance} / (a1 * x) + 0.25 + 2.44 / x) \quad (11)$$

Where,
Y3 = time consumption, drive while loading (min/m^3)
$t_{assistance}$ = 0.04
a1 = 0.06, a1* x = the size of working post, unit m^3
x = logging road density, m^3/100m

Further, the function for a drive speed with a load as a function of a load size was calculated with the formula

$$v(k) = b0 + (b1 / k) \quad (12)$$

Where,
$v(k)$ = drive speed with load, unit m/min
b0 = 24.55
b1 = 96.33
k = load size = 7.8 m^3

The fourth stage, the function for a time consumption of a drive with a load was calculated with the formula

$$Y4 = (b0 + b1 * K_{distance})/(Z * k) \qquad (13)$$

Where,
Y4 = time consumption, drive with load, (min/m^3)
b0 = 0.87, assistance time, min/m^3
b1 = 0.019
$K_{distance}$ = distance in forest with load, unit m = 2* mean distance in forest *0.47
k = load size = 7.8 m^3
Z = correction constant due to drive speed decrease as a result of increase in load size
=> $Z = v(k)/50$ (14)

where,
$v(k)$ = drive speed as a function of load size, unit m/min
50 = according to data, average drive speed without load, m/min

The fifth stage, the function for time consumption of an unloading was calculated with the formula

$$Y5 = PU_{apu} + (b0+b1*\ln(t)) \qquad (15)$$

Where,
Y5 = time consumption, unloading (min/m^3)
PU_{apu} = assistance time of unloading, min/m^3 = 0.2
b0 = 0.28 (forwarder)
b1 = -0.40 (forwarder)
t = unload size, unit m^3 = 0.38

The time consumption of forest haulage was calculated as a sum of the five substages described above. Then the total time consumption was described with the formula

$$Y6 = Y1+Y2+Y3+Y4+Y5 \qquad (16)$$

Where,
Y6 = time consumption of forest haulage, min/m^3

The time consumption per one load was calculated with the formula

$$Y7 = (60/Y6) * k \qquad (17)$$

Where,
Y7 = time consumption per one load, unit m^3/h
k = load size = 7.8 m^3

Finally, the total costs of forest haulage were calculated with the formula

$$CH = (k/Y7)+(t/r) \tag{18}$$

Where,
CH = cost of forest haulage, €/m^3
k = hourly cost of forest logging, €/h
Y7 = time consumption per one load, m^3/h
t = transportation of logging machines –cost, €/stand
r = amount of forest residues per stand, m^3

Cost values used for parameters k (=hourly cost of forest logging) and t (=transportation of logging machines) can be found in Appendix 1.

The cost of long-distance transportation consisted of two work stages, namely a drive speed without a load and a drive speed with a load. The drive speed without a load was calculated with the formula

$$vt = 5.7917+30.630*\log(l) \tag{19}$$

Where,
vt = drive speed without load, km/h
l = distance to mill, km

The drive speed with a load was calculated with the formula

$$vk = -0.44591 + 31.695*\log(l) \tag{20}$$

Where,
vk = drive speed with load, km/h
l = distance to mill, km

Finally, the cost of long-distance transportation was calculated with the formula

$$CLD = [(l/vt)+(l/vk) *dc + (lt + ut) * luc]/ k \tag{21}$$

Where,
CLD = cost of long-distance transportation, €/m^3
l = distance to mill, km
vt = drive speed without load, km/h
vk = drive speed with load, km/h
dc = hourly driving cost, €/h
lt = loading time, h
ut = unloading time, h
luc = loading&unloading cost, €/h
k = load size of a timber truck, m^3

The chipping is executed at a landing near the cutting area. From the chipper, chipped material is transferred into a chip truck. The cost of that operation was calculated with the formula

$$CC = cc + (tc/tr) \tag{22}$$

Where,
CC = cost of chipping, €/m^3
cc = chipping cost, €/m^3
tc = cost of chipper transportation, €/stand
tr = total amount of residues, m^3

Organization costs cover all those costs which are needed to ensure a flexible and an undisturbed chain of operations from forest to the mill. These costs include e.g. supervision of work and planning. The cost of delimbing to aside covers those extra costs of cutting and delimbing operations with a harvester which are needed to make branches into loadable piles for a forwarder. Then the total costs of residual forest biomass at the mill using the RC method were the sum of the following costs:

- Forest haulage,
- Long-distance transportation
- Chipping,
- Organization,
- Delimbing to aside.

2.4.2 The residue log

Concerning the forest haulage, the functions for the residue log method were very identical to those of the roadside chipping. For the first stage, drive without load to a cutting site, the function was equal with formula (8). For the second stage, loading, the fixed value 6.67 min/m^3 was used. The third stage, drive while loading, was written in the form

$$Y3 = (t_{assistance} / (T\text{-point}) + 0.25 + 2.44/ x) \tag{23}$$

Where,
Y3 = time consumption, drive while loading (min/m^3)
$t_{assistance}$ = 0.04
T-point = S/20, where 20 is the amount of residue logs in a load space of a forwarder
x = logging road density, m^3/100m

For the fourth stage, drive with load to an intermediate storage, the function was similar to formula (13), but the parameter Z (=correction constant) got the value 1. The fifth stage, time consumption for unloading, got the fixed value 6.67 min/m^3.

Again, the total time consumption of forest haulage with the RL method was calculated as a sum of above five different stages. Time consumption per one load was calculated with the formula

$$Y7 = (60/Y6) * S \qquad (24)$$

Where,
Y7 = time consumption per one load, unit m^3/h
Y6 = time consumption of forest haulage, min/m^3
S = load size, unit m^3
=> $S = 20* (sv*SP + pv*P)$ (25)

Where,
20 = amount of residue logs in a load space of a forwarder
sv = volume of one spruce residue log = 0.59 solid-m^3
SP = share of spruce in the volume of a residue log
pv = volume of one pine residue log = 0.44 solid-m^3
P = share of pine in the volume of a residue log

The cost of forest haulage with the RL method was calculated using the same formula as with the RC method (Formula 18). Cost values for the forest haulage and for the transportation of logging machines can be found in Appendix 1.

The cost calculation of a long-distance transportation followed the same procedure as with the RC method (Formula 21). The load size of a timber truck with residue logs was calculated with the formula

$$ST = 68* (S/20) \qquad (26)$$

Where,
ST = load size of timber truck with residue logs, m^3
68 = amount of residue logs per one timber truck
S = load size of a forwarder, m^3
20 = amount of residue logs in a load space of a forwarder

The cost values for driving and for both loading and unloading can be found in Appendix 1.

The baling cost of residue logs was calculated with the formula

$$BC = bc/ \text{T-point} \qquad (27)$$

Where,
BC = baling cost of a baling machine, €/m^3
bc = baling of residues, €/residue log
T-point = S/20
S = load size of a forwarder, m^3

The transportation cost of a baling machine should also be included with the cost of baling. This cost was calculated with the formula

$$TB = t/r \qquad (28)$$

Where,
TB = transportation cost of a baling machine, €/m^3
t = transportation of machines –cost, €/stand
r = amount of residues per stand marked for cutting, m^3

The costs of baling and transporting the baling machine can be found in Appendix 1. Also the organization, chipping and delimbing to aside costs can be found there. The total cost of residual forest biomass at the mill using the RL method consisted of the same cost items as with the RC method. Only baling was the extra cost included into the RL method. Then the total costs of residual forest biomass with the RL method were the sum of the following costs:

- Forest haulage,
- Baling,
- Long-distance transportation
- Chipping,
- Organization,
- Delimbing to aside.

2.5 Prediction of a carbon yield on the basis of a procurement area

In early discoveries of each procurement area at different mills, it was noticed that a carbon recovery does not accumulate according the square of a radius of a procurement area. The observation was considered as a hypothesis for the prediction of a recovery model. This hypothesis was not realised, and it was rejected. However, the prediction of a carbon recovery in residues according to the distance from the mill could offer tools for a more general approach. This leads to develop a new, more generalized model for the three mills.

In this study, the maximum distance from the mill was set to 100 km with the integrated harvesting of energy wood. When the cumulative carbon recovery is known at the distance of 100 km from the mill, it would be interesting to predict the recovery and the price of wood fuel according to the distance from the mill. This would offer information to energy wood suppliers, how much energy wood material and at what price they can assume to be collected from a certain radius of the study mill. In order to predict the carbon recovery, a regression model which could predict the recovery in the case of all three mills has to be defined. The parameters of the equation should be the same for each study mill in order to ensure a generalized approach for all mills.

2.6 Energy saving at the three mills

2.6.1 Energy information on the three mills

The research material used in this part of the study covers energy conversion, energy use, and energy saving. The data originates from three mills of the consolidated forest corporation. All mills are situated in Finland. Later in the text, the mills are demonstrated as Mill A, Mill B and Mill C in the same order as with the energy wood procurement section. First, a brief background on energy information for the different mills is given below.

Mill A is a chemical pulp mill with two pulping lines. Normally one line is used for the production of softwood pulp, and the other for the production of hardwood pulp. However, if needed, both lines can be converted into the production of either hardwood or softwood pulp. Normally two thirds of the production is birch pulp and one third is pine pulp. The mill uses 2.3 million cubic metres of wood annually, and the production is about 620 000 tonnes air dried (90 % dryness) pulp. The cooking method used is Super Batch. Another part of Mill A is the sawmill producing 237 000 cubic metres of timber annually. The residue wood of timber making is used for pulp production at the pulp mill.

The heat conversion at Mill A was 3 148 GWh and the electricity conversion was 687 GWh in 1998. The self-sufficiency in fuels was over 99 % and in electricity 170 %. In 1998, 282 GWh of electricity could be sold to the national electric network. The main part of the heat was used for the drying of sulphate pulp, because they do not have their own paper or cardboard production.

Mill B is an integrate of a chemical pulp mill and a paper mill. The pulp mill produces fully bleached soft and hardwood pulp at one pulping line. The pulp mill also includes a power plant. According to the energy saving report from the year 1999, the production capacity of the pulp mill was 370 000 tonnes air dried (10 % moisture) pulp. At the paper mill, there are two paper machines producing fine papers and a sheeting plant. In 1999, the annual production capacity of the paper mill was 800 000 tonnes.

The heat consumption at Mill B was 3 650 GWh and the electricity consumption was 850 GWh in 1999. The self-sufficiency in fuels was 73 % and in electricity 65 %. Part of the produced steam can be sold outside the mills, but one third of the used electricity must be purchased from elsewhere. The main part of the produced pulp is pumped without drying to the paper machines. The excess heat from the pulping process can be utilised in paper making.

Mill C consists of a chemical pulp mill, a mechanical pulp mill and mills for manufacturing paper and cardboard. According to the energy saving report from the year 2000, the chemical pulp mill used pine, birch and other broadleaves as a raw material. Part of the integrate is a sawmill specialising in spruce sawing. A residual wood material from timber making is chipped and used for the production of mechanical pulp.

The heat consumption at Mill C was 2 021 GWh and the electricity consumption was 1 059 GWh in 1999. The self-sufficiency in fuels was 81 % and in electricity 25 %. Due to a high share of mechanical pulps (51 % of pulp production in 1999), electricity of 836 GWh was purchased from outside the mill in 1999. On average in 1998-2002 at Mill C, 73 % of all electricity consumption (1 038 GWh) was purchased outside the mill and 27 % was produced at the mill. The highest electricity consumption took place at the TMP (thermo mechanical pulp) –plant, which covered about 36 % of the whole electricity consumption. The highest consumers of heat were paper machines and the production of sulphate pulp.

Data on fuels used for energy conversion, amounts of energy produced with different fuels, and amounts of heat and electricity used for pulp and paper production covered the years from 1998 to 2002. From this data, the average amounts of energy produced with different fuels were calculated. CO_2 emissions were calculated using energy amounts and CO_2 coefficients for different fuels. The following coefficients were used for different fuels:

- black liquor 110 g CO_2/MJ (IPCC 1996, Volume 2)
- bark 109.6 g CO_2/MJ (IPCC 1996, Volume 2)
- methanol 60.6 CO_2/MJ (Atkins 1994)

- soap 109.6 g CO_2/MJ (IPCC 1996, Volume 2)
- heavy fuel oil 77.4 g CO_2/MJ (IPCC 1996, Volume 2)
- light fuel oil 74.1 g CO_2/MJ (IPCC 1996, Volume 2)
- peat 106 g CO_2/MJ (IPCC 1996, Volume 2)
- liquefied petroleum gas 63.1 g CO_2/MJ (IPCC 1996, Volume 2)
- coal 94.6 g CO_2/MJ (IPCC 1996, Volume 2)
- reject 62.4 g CO_2/MJ (Atkins 1994)

It is important to notice that wood based fuels (black liquor, bark, methanol, soap) were calculated according to gross CO_2 coefficients, not using net coefficients. The carbon emissions of methanol were calculated according to mole masses of CO_2 and methanol (CH_3OH) and combustion of organic compounds in methanol at 298 K (=Kelvin), which yields 726 kJ/mol of energy (Atkins 1994). When carbon emissions from the combustion of wood-based fuels are assumed to be absorbed into new biomass, the net coefficient factor for wood is zero. However, in this study gross values were used with all fuels in order to enable addition and comparison of all fuels. Then only the direct carbon emissions from an actual combustion process were only included.

In Table 2.8, it can be seen that a main part of energy and emissions was originated from biofuels. 88 % of all energy produced at the mills was produced from biofuels. The most important biofuel was black liquor, a by-product of chemical pulping. Also bark was an important bio-based source of energy at the mills. At Mill A, the share of fossil fuels (heavy and light fuel oil) was only 1.3 % of all energy use. The main source for heavy fuel oil use was a lime kiln where calcium oxide (CaO) was produced for chemical pulping. At Mill B, the use of peat formed main a part of the energy use and emissions of fossil fuels. The share of fossil fuels on all energy conversion was 24 %. At Mill C, main fossil fuels were coal and heavy fuel oil, when all fossil fuels covered 13 % of all energy conversion. At Mill C, as a by-product of raw material processing for cardboard manufacturing, a process reject was recovered for energy purposes. That reject consisted mainly of plastic (polythene) and aluminium waste. The CO_2 coefficient factor for reject was calculated according to polythene with mole masses of CO_2 and ethene (C_2H_4) which is used in the manufacture of polythene and combustion of organic compounds in ethene at 298 K (=Kelvin), which yields 1 411 kJ/mol of energy (Atkins 1994).

Table 2.8. Fuels used for energy conversion and amounts of energy converted from different fuels (unit MWh) on average in 1998-2002 at three mills.

Fuels	Energy (MWh)
Mill A	
Biofuels:	
Black liquor	2 984 565
Bark	1 123 118
Methanol	13 596
Soap	127 538
Fossil fuels:	
Heavy fuel oil	55 408
Light fuel oil	2 063
TOTAL (bio+fossil)	4 306 288
Mill B	
Black liquor	2 208 527
Bark	620 185
Methanol	19 085
Fossil fuels:	
Peat	628 194
Heavy fuel oil	129 576
Light fuel oil	2 712
Liquefied petroleum gas	130 414
TOTAL (bio+fossil)	3 738 694
Mill C	
Black liquor	1 229 834
Bark	826 045
Fossil fuels:	
Coal	82 295
Heavy fuel oil	106 956
Peat	49 785
Reject	75 813
TOTAL (bio+fossil)	2 370 728

2.6.2 Energy saving reports of the three mills

One of the main research topics was the energy saving of the three mills. Information on energy saving was collected from the energy saving reports of the mills submitted to MOTIVA (Information Centre for Energy Efficiency and Renewable Energy owned by the Ministry of Trade and Industry in Finland). The reports contained an analysis of the different production units in terms of how these units are capable of saving heat and electricity through technical improvements in their processes. In one particular year, the report on technical objects for energy saving was found to be the state of the art. This report gave the saving potential of different production units equipped with machinery now in use, when a technical inspection was made. At Mill A, the energy saving data was from 1998, and at mills B and C from 1999 which were the latest databases when this study was done.

The basic structure of the report is the technical description of a certain part of the pulp- or paper-making process, where it is possible to save either heat or electricity or both. Moreover, there is information for a period of repayments without payment of interest for this certain object, energy saving of heat in energy units (MWh/year) and in monetary units. The same information also covers the saving of electricity in both units. In each case, the total sum of heat and electricity savings is also given. An important part of the further calculations is information on the investment cost of a certain energy saving measure. In the cases where this information failed, it was not possible to make economic calculations. Thus for a further analysis, only those saving projects are included where information on investment costs is available. All monetary values have been converted to euro using the conversion coefficient 1 euro (€) = 5.94573 FIM, because the Finnish mark is the monetary unit used in the reports.

In Table 2.9, data has been gathered on the energy saving investments that were used later in calculations of the cost curves of the different mills. The values presented in the table are not exactly the same as in the original reports due to insufficient information concerning investment costs. For this study, only those technical saving objects were chosen where the cost of investment was available. At the three mills under a previous provision, it was possible to save heat and electricity amounting 353 GWh/a and 66 GWh/a, respectively (Table 2.9). Some new heat and electricity saving objects were included into this study, which were not mentioned in detail in the energy saving reports. After personal contact with each mill, for Mill A, one saving object of electricity at the sawmill (saving capacity 720 MWh/a) and one heat object at the evaporating plant (saving capacity 15 000 MWh/a) were included. At the sawmill of Mill C, one saving object of electricity (saving capacity 3 150 MWh/a) and one heat object (saving capacity 44 811 MWh/a) were also included into this study. At mills A and C, some heat and electricity saving objects had to be omitted due to unavailable information on investment cost.

Table 2.9. Information from the energy saving reports of the different mills.

MILL	Investment (1000 euro)	Number of energy saving projects	Computational annual saving				
			Heat		Electricity		ENERGY COST SAVING TOTAL
			Energy	Costs energy	Energy	Costs energy	
			MWh/a	1000 euro/a	MWh/a	1000 euro/a	1000 euro/a
A	1 695	6	93 585	505	12 278	289	794
B	6 398	6	121 000	636	-15 600	-394	242
C	14 864	8	138 397	1 599	69 310	1 917	3 516
TOTAL	22 957	20	352 982	2 740	65 988	1 812	4 552

The sum of investment costs at the three mills was 22.9 million € of which 65% was covered by Mill C. The main reason for that was the planned replacement investment of debarking facilities at the sawmill of Mill C. At Mill B, the main part of the investment costs originated from the capacity increase of one paper machine which created a greater demand of electricity and thus higher costs for purchased electricity outside the mill. This indicated negative values for electricity in Table 2.9. Although this investment was not basically an energy saving investment, 5.9 million € out of total investment cost was included into energy saving purposes. This issue has been discussed in more detail in Chapter 3.6. The prices of heat and electricity calculated straight from annual savings in energy costs and saved energy amounts were as follows for the different mills: Mill A 5.4 €/MWh (heat) and 23.5 €/MWh (electricity), Mill B 5.3 and 25.2 €/MWh and Mill C 11.6 and 27.7 €/MWh, respectively.

The main target of energy saving is to reduce heat or steam in energy processes. The reason for this aim is that the chemical energy, contained in fuel, is first converted to steam in a boiler, and after this steam is then further converted to electricity in a steam turbine. Primarily, heat is needed in pulp and paper making processes, but excess steam is converted to electricity. The system where both heat and electricity are produced is called co-generation process, and a plant with both heat and electricity conversion is called combined heat and power (CHP) plant.

In order to achieve a net saving potential in economic calculations, the amounts of saved energy of heat and electricity must be linked to investment costs. Because the GHG emission abatement, in this study carbon dioxide (CO_2) abatement, is generally linked to different fuels used for energy conversion, as energy saving costs were expressed as reductions of CO_2 emissions. The main fuel, producing the largest amount of useful energy at different mills, varied according to the mill. This fuel and the CO_2-coefficient factor was typical for the fuel determined CO_2 emissions of a certain saving object. At Mill A, this main fuel was wood, while peat was at Mill B and coal at Mill C. The CO_2-coefficient factors used for different fuels were as follows:

- wood 109.6 g CO_2/MJ (IPCC 1996, Volume 2);
- peat 106 g CO_2/MJ (IPCC 1996, Volume 2);
- coal 94.6 g CO_2/MJ (IPCC 1996, Volume 2).

Here the CO_2-coefficient factor for wood used was 109.6 g CO_2/MJ instead of 0 g CO_2/MJ, which is typically used when CO_2 emissions from wood combustion are supposed to be absorbed into a new growth of forests. In this study, the most important aspect was to calculate reductions in CO_2 emissions as a result of energy saving investments in different kinds of mills and to compare these reductions between the study mills. Thus, coefficients of CO_2 emissions as a result of the combustion process were used for different fuels, i.e. gross emission coefficients were used instead of net values. Thus a carbon absorption into a new biomass was not included, and for that reason the net value of 0 g CO_2/MJ for wood was not used. Concerning energy saving, saving natural resources is justified although fuel is renewable, such as wood. The energy saving will lead to a more efficient use of natural resources which is always beneficial from the environmental point of view.

In some cases only electricity was saved, especially in the production of mechanical pulp. In the big Finnish forest companies, electricity is purchased either from power companies, which are partly owned by the forest companies, such as PVO (Pohjolan Voima Ltd.) or independent power companies, such as Fortum or Vattenfall. This purchasing of electricity differs depending on pulp and paper processes used and their need of electricity. In order to calculate CO_2 emissions of the external purchasing, the average emissions of the Finnish electricity conversion were used. This was done because the consolidated corporation purchased its external electricity mainly from the domestic sources. The years chosen for the accurate observation were from 1998 to 2002. The calculation of the average Finnish values is based on the following factors: the mode of electricity conversion (condensing power, CHP, nuclear, hydro etc.), fuels used for the conversion, the conversion of electricity expressed as an energy unit, CO_2 coefficients typical for each fuel and the efficiencies typical for each mode of electricity conversion. When the average CO_2 emissions were calculated, annual emissions were weighed with the amounts of external electricity purchased by the Finnish mills (Table 2.10). After these calculations, the result was 189 g CO_2/kWh.

Table 2.10. Average CO_2 emissions of the Finnish electricity conversion (Electricity and district…2002) and the external purchases of electricity for three Finnish mills of the consolidated corporation during 1998-2002.

	CO_2 emissions (g/kWh)	Electricity purchases (TWh)
1998	170	1.8
1999	170	1.7
2000	160	1.9
2001	210	2.0
2002	230	1.9

At Mill A, electricity conversion from its own chemical pulping process (recovery and bark boilers) was sufficient to cover all the electricity consumption of the mill. However, some saving objects were only aimed at saving electricity so electricity was supposed to be purchased from outside the mill, as it was also presumed with the two other mills. In those cases where both heat and electricity were saved, CO_2 emissions were calculated according to the main fuel used at the mill.

The cost of a certain technical saving operation (CS) was calculated with the following formula:

$$\mathrm{CS} = (\mathrm{IC} - \mathrm{SE})/\mathrm{RC} \qquad (29)$$

Where,
CS = an annual net value of one energy saving investment per saved CO_2 tonne (1000 kg), unit €/tCO_2/a,
IC = investment cost of a certain energy saving project, unit €,
SE = monetary sum value of heat and electricity savings per year, unit €/a,
RC = an annual CO_2 emission reduction of one particular energy saving investment, unit tonne (1000 kg) of CO_2, tCO_2/a

For the formula (29), an annual carbon (C) emission reduction as a result of energy saving investment was first calculated, and then this reduction was converted to CO_2 by multiplying emissions by the factor of 44/12. This figure is the ratio of the mole masses of C and CO_2. However, in order to compare the costs of energy saving with the procurement costs of forest residues at the mill, the unit €/tCO_2 was mainly used. The main idea in the previous formula is to connect the investment costs needed for a certain energy saving object and savings in the energy bill as a result of this investment together. The reduction in

CO_2 emissions is a result of reduced energy use at the mill. It is worth noticing that heat and electricity savings have been included in this study only for one year, not in general, as for example for the whole period of the saving investment or longer time period. This aspect will be discussed in more detail in Chapter 4.3.

2.6.2.1 The calculation procedure of Mill A

According to the energy saving report of Mill A, the carbon emissions of the heat and electricity savings were calculated. In the case of this mill, the efficiency of wood burning in the main energy boiler was 88 %. It was assumed that in the co-generation process of the mill, the energy conversion ratio from fuel (here wood) to produced heat was 63 % and further to produced electricity 37 %. Then power to heat ratio was 0.59 (=0.37/0.63). The proportion of electricity was larger than that of usual at this kind of mill, because one of the main targets was to maximise the amount of electricity that could be sold to the external electric network. In order to divide CO_2 emissions between heat and electricity conversion, the amount of input fuel had to be determined. This calculation process is illustrated in Figure 2.5.

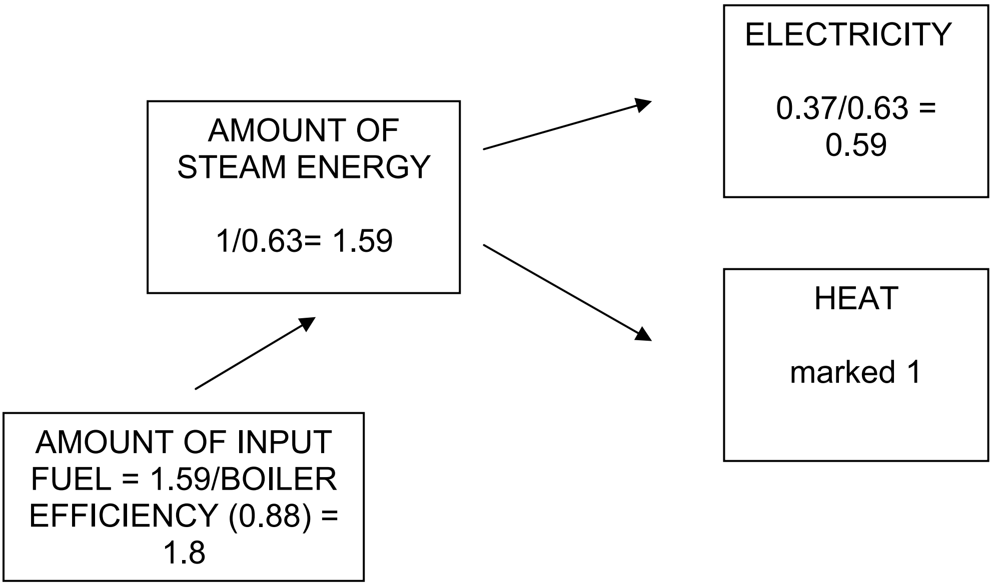

Figure 2.5. The calculation of input fuel amount in a co-generation conversion.

The CO_2 emissions of the heat conversion were then calculated with the formula

$$EH = ((IF)*HR*CFW/CF)\ *AHS \tag{30}$$

Where,
EH = CO_2 emissions of heat conversion per one year, unit 1000 kg of CO_2 per year = tCO_2/a,
IF = proportion of input fuel = 1.8 [=(1/0.63)/0.88],
HR = ratio of heat conversion = 0.63
CFW = CO_2-emission coefficient factor for wood = 109.6 g CO_2/MJ,
CF = (0.2778/1000))/1000000 = conversion factor from MJ to MWh and to t CO_2,
AHS = heat saving of certain technical improvement per one year, unit MWh/a

CO_2 emissions of the heat conversion were calculated by using the formula 30. In the co-generation process, the aim is to produce both heat and electricity. Thus the energy content of fuel is used efficiently. Harmful emissions are also decreased, contrary to the condensing mode, where only electricity is produced and heat is lost as a waste either to air or water. In the end, in order to get total CO_2 emissions, the CO_2 emissions of heat and electricity conversion were added up. The formula for the calculation of CO_2 emissions in the electricity conversion was then

$$EE = ((IF)*ER*CFW/CF)\ *AHS \tag{31}$$

Where,
EE = CO_2 emissions of electricity conversion per one year, unit 1000 kg of CO_2 per year = tCO_2/a,
IF = proportion of input fuel = 1.8 [=(1/0.63)/0.88],
ER = ratio of electricity conversion = 0.37,
CFW = CO_2-emission coefficient factor for wood = 109.6 g CO_2/MJ,
CF = (0.2778/1000)/1000000 = conversion factor from MJ to MWh and to t CO_2,
AHS = heat saving of certain technical improvement per one year, MWh/a

At Mill A, two energy saving objects were found in the sawmill. In those cases only electricity was saved. Thus it was assumed that the used electricity was purchased outside the mill from the national electric network, and CO_2 emissions of this electricity were the average emissions of the Finnish electricity described earlier (see Chapter 2.5.2). The CO_2 emissions of external electricity conversion was calculated with the formula

$$EXE = CFC*AES \tag{32}$$

Where,
EXE = CO_2 emissions of external electricity conversion per one year, unit t CO_2/a
CFC = CO_2-emission coefficient factor for the average Finnish electricity = 0.189 Mg CO_2/MWh
AES = electricity saving of certain technical improvement per one year, MWh/a

2.6.2.2 The calculation procedure of mills B and C

The general structure for the calculation of CO_2 emissions in heat and electricity conversion of Mills B and C followed same principles as with Mill A (see Figure 2.5). In the case of Mill B, the main fuel was peat, and the efficiency of peat burning in the main energy boiler was 88 %. In the co-generation process of the mill, it was assumed that the energy conversion coefficient from fuel (here peat) to produced heat was 79 % and 21% to produced electricity. At Mill C, the main fuel was coal, and the efficiency of combustion in the main solid fuel boiler where coal and peat were combusted was 91 %. It was calculated that in the co-generation process of the mill, the energy conversion coefficient from fuel to produced heat was 81 % and 19% to produced electricity. Different parameters for the Formulas 30-31 have been presented in Table 2.11. The parameters of heat conversion for each mill were substituted to the Formula 30 and the parameters of electricity conversion were substituted to the Formula 31. At Mill B, one saving investment (adjustment of electrostatic precipitator of one energy boiler) was classified as an object where CO_2 emissions of purchased electricity were calculated with the Formula 32. At Mill C, Formula 32 was applied with two objects (the grinding mill and the production of TMP pulp).

Table 2.11. Used parameters for allocation of CO_2 emissions between heat and electricity conversion at the mill at Mills B and C.

	Heat conversion			Electricity conversion at the mill		
	Proportion of input fuel (IF)	Ratio of heat conversion (HR)	CO_2 – emission coefficient factor (g CO_2/MJ)	Proportion of input fuel (IF)	Ratio of electricity conversion (ER)	CO_2 – emission coefficient factor (g CO_2/MJ)
Mill B	1.4 [=(1/0.79)/ 0.88]	0.79	106 (peat)	1.4 [=(1/0.79)/ 0.88]	0.21	106 (peat)
Mill C	1.4 [=(1/0.81)/ 0.91]	0.81	94.6 (coal)	1.4 [=(1/0.81)/ 0.91]	0.19	94.6 (coal)

2.7 Carbon trading based on energy saving and principles of this trading

Carbon trading is an activity which combines biofuel conversion and various saving measures of energy as an elementary part of business. In the studied mills carbon trading was based on energy saving and trading of emission allowances. It was possible to trade emission allowances, when energy use was decreased and thus less carbon emissions were emitted. Thus it was possible to trade the surplus allowances to other mills under the trading scheme. The idea of energy saving and the reduction of carbon emissions were illustrated in more detail in Chapter 2.6. The coupling of energy saving and carbon trading was a task which was tested with procedures of experimental economics among different students. The energy saving material of the three mills was used as background information but the actual data was modified and it was only used to the appropriate extent for experiments (see Appendix 2). Thus only the idea to combine energy saving and carbon trading was applied, but the straight use of exact values from saving information of the three mills described earlier was abandoned.

The carbon trading experiments illustrated in this study were first implemented in 2002 in Laxenburg, Austria during the young scientists' summer program of the IIASA (International Institute for Applied Systems Analysis). The experiments were used as tests or pilot ones in order to gain experience and further develop experiment procedures. In autumn 2002 (November), in spring 2004 (May) and in spring 2005 (late February), modified experiments were performed with different participants. In 2002, the participants were undergraduate students from the course "Economic control in nature conservation" from the Faculty of Social Sciences, the programme of Law and Economics, at the University of Joensuu. In 2004, participants were also undergraduate students from the field course of the growth and yield study at the Faculty of Forestry, University of Joensuu. In 2005, the participants were from another educational institution, the North Karelia University of Applied Sciences. They were students from the degree programme in environmental technology and participated in the course of "Air protection". Experiments were not carried out among specialists concentrated on issues of emissions trading due to difficulties of recruiting suitable candidates. For the actual analysis, a total of 30 experiments were investigated by calculating results for each subject representing one mill. The best performance of different experiment variations was found when the total costs were the lowest. This means that the participant had achieved profit by trading emission allowances and thus diminished his/her costs compared to the situation where a subject made an energy saving investment at his/her mill without trading.

Different experiment variations, such as a double auction with limited exchange of information, a bilateral trading with open exchange of information and a bilateral trading with limited exchange of information, were tested. These variations are presented in more detail in Chapters 2.7.1 and 2.7.2. All experiments were repeated and performed simultaneously by two separate groups. The only exception was in 2005, when there was only one group in each variation (see Table 2.12). Each experiment variation required three participants, which formed one group, and they did the same experiment twice. Thus each experiment was repeated. This procedure gave subjects an opportunity to learn from those practices they met at the first round. Students were chosen randomly for each group. Subjects were also randomly divided into three categories: Mill D, Mill E and Mill F. Each participant represented one mill. It can be mentioned that Mill D loosely fits with Mill A, Mill E with Mill B and Mill F with Mill C.

Due to unsatisfying experiment results of some participants in earlier games of 2002, more detailed information on carbon trading experiments was prepared for the years 2004 and 2005. This information was sent by e-mail to all participants about one week before the gaming day (see Appendix 3). Before the actual experiment this material was studied thoroughly in order to avoid misunderstandings. Motivation was found to be an important aspect in order to improve the performance of participants. According to the literature (Davis and Holt 1993), a monetary fee is a way to motivate people to participate in the experiment more efficiently. In the experiments of spring 2004, monetary fee was used in this sense. All participants were paid 3 € as a compensation for their participation in the experiment, but it was possible to earn an extra 7 €, if the personal result of a student was better than the calculated optimum. The minimum payment was loosely determined according to a student's hourly salary, when a normal Finnish student grant was a basic living. The optimum, which is presented in more detail in Chapter 3.7, was calculated for each of the three mills.

Table 2.12. Information on different trading experiments in 2002-2005. Experiment variations: Bilateral open= bilateral trading with open exchange of information, Bilateral limited= bilateral trading with limited exchange of information, Double auction= double auction with limited exchange of information.

Time	Number of Participants	Number of Experiments	Experiment Variations
Autumn 2002	18	12	Bilateral open, Bilateral limited, Double auction
Spring 2004	18	12	Bilateral open, Bilateral limited, Double auction
Autumn 2005	9	6	Bilateral open, Bilateral limited, Double auction
TOTAL	45	30	3

2.7.1 Laws of bilateral trading

Bilateral trading is an experiment where participants negotiate with each other to find the optimum solution for them. When an experiment is arranged, the amount of information is an important background parameter. Generally, each participant representing one mill has his cost curve with emission reductions. The cost curves of other mills are not so well known. To solve this problem, participants must find the optimum solution through the process of negotiations. Information on the cost curves of other participants matters, because more detailed information on these cost curves may help an individual participant to find his/her optimum solution easily. The extent of available information and its effect on the performance of a participant is an interesting research topic. It is worth noticing that emission trading in this study is not based on historical emissions and constraints ordered according to those emissions, but emission reductions achieved through energy saving measures and trading with those reductions. A basic problem in each three experiment variation is a decision between two alternatives: either to make an energy saving investment at their own mill and as a bonus gain excess allowances for trading or to purchase missing allowances from other mills in order to fulfil the constraint set by trading authorities.

The first option in the bilateral trading experiment was an open exchange of information. In this option each participant received the cost curves of all participants before the experiment started and had 20 minutes to examine them. The delivered information contained a graph with numerical data on the subject's own mill and an overview of the cost curves of all mills without numerical data. After that the actual test began, in which participants (here subjects) could freely find a subject with whom to transact. However, in order to avoid information leaks, subjects should not talk with each other, but with numbers (price and quantity) and "yes" and "no" symbols they can exchange information. Basically, experiment was carried out by exchanging information written on pieces of paper. Once the agreement had been reached, the pair reported the price, the quantity, the seller and the buyer to the experimenter, who then announced the result to other participants by listing information on a trading record. Three subjects participated in one experiment, which meant one subject normally negotiated with another subject, while the third subject waited for his turn. One subject could naturally give his offer to both subjects at the same time. Subjects were capable of acting in both roles during one experiment, namely as buyers and sellers. In an individual target each subject had his own constraint for carbon emission reductions. In order to make the experiment technically rational, constraints for each mill were set as follows: 17 500 tC (= tonnes of carbon) for Mill D, 17 000 tC for Mill E and 13 000 tC for Mill F. Each subject had to fulfil his/her personal constraint in the end of each game. In the actual test situation, subjects knew only their personal limitation exactly, but had only the range of the other participants' constraints (see Appendix 2). The ranges were set in order to increase motivation among participants. Each subject was supposed to achieving his emission reduction target in the most cost-effective way.

The second option was bilateral trading with a limited exchange of information. In this option, subjects did not have information on the cost curves of other subjects. Instead, each of them had only the graph with numerical information on their own mill (see Appendix 2). By negotiating with each other, a subject should find the optimum solution for his trading. The actual test procedure was identical to the bilateral trading with an open exchange of information. Moreover, constraints for carbon emission reductions and ranges for subjects' carbon reductions were set identical with the alternative of an open exchange of information.

2.7.2 Laws of double auction

Double auction is a variation of an experiment where each participant trades independently, not knowing the actions of other subjects before they are revealed. Generally, an auction can be conducted in two different ways: either disclosure or closure of cost curves. Because in this variation of an experiment, like in other alternatives in which only three subjects participated, the closure of abatement cost curves was used. Then subjects did not have information on the cost curves of the other mills. After a 20-minute observation of the cost, the actual auction happened so that an auctioneer called on the subject who raised his hand first. This subject then stated to the auctioneer whether he was willing to sell or buy, quantity (tonnes carbon, tC) and at what price (euro/tC). The subject also indicated which mill was in charge of an operation. Mills were marked as follows: Mill D (single chemical pulp mill), Mill E (chemical pulp mill with two paper machines), Mill F (an integrate, with wood-containing and wood-free paper grades). The previous marking system was also used in other experiment variations. Subjects could make both selling and buying bids during the experiment. However, one condition was followed in the auctions: the price of each buying bid had to be higher than the price of previous buying bid and on the other hand, the price of each selling bid had to be lower than the price of the previous selling bid. In this way the auction was supposed to proceed in a rational way. For example, the selling bid could be as follows: Mill F sells 1 000 tC at the price of 50 euro/tC and the buying bid: Mill E buys 500 tC at the price of 150 euro/tC. Both bids were now public and were written on a chalkboard. After that, by raising his hand, a subject expressed his willingness to trade. This could be either a new bid or an acceptance of an earlier bid. For example: Mill E accepts the bid of Mill F and buys 500 tC. The accepted bid became now public and it was written on the paper for the education of all subjects. At the same time any earlier selling bids lost their validity. The goal for each subject was to fulfill his personal constraint in the most cost-effective way. These constraints and ranges for constraints were identical to the previously described experiments. The double auction was closed when new trades were no longer concluded. An example from the actual trading material of the double auction can be found in Appendix 2.

3. RESULTS

3.1 From roundwood to forest residues, carbon and energy use at the three mills

Two optional harvesting methods, namely roadside chipping (RC) and residue log (RL), are studied in Chapters 3.1-3.3. In the years 1999-2002, the amount of forest residues from the RC and the RL methods can be seen in Figure 3.1. The highest potential of forest residues can be found at Mill C with the RL method, where the annual yield was on average 211 140 m^3 in 1999-2002. With the RC method at Mill C, the annual yield was on average 188 850 m^3. At Mill B on average in 1999-2002, the recovery was the lowest among the three mills, when the recovery with the RL method was 39 830 m^3 and 32 270 m^3 with the RC method. The recovery at Mill A was between the recovery at mills B and C. The annual recovery was on average 168 030 m^3 with the RL method and 148 390 m^3 with the RC method in 1999-2002.

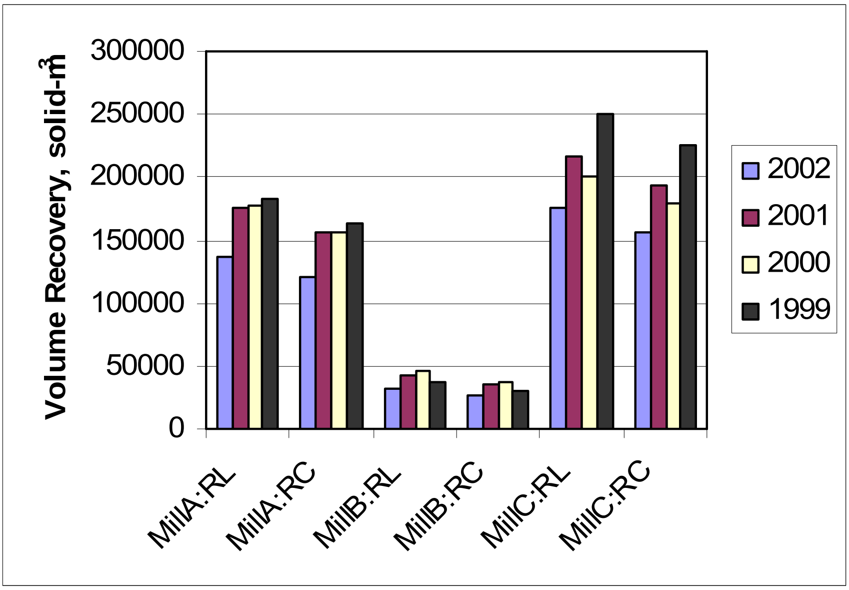

Figure 3.1. The amount of forest residues (solid-m^3) with two optional harvesting methods: roadside chipping (RC) and residue log (RL) in 1999-2002 at three mills A, B and C.

In order to outline the costs of carbon at three different mills, it is vital to know the amount of carbon in forest residues. In 1999-2002, the mean annual amount of carbon was the highest at Mill C with the RL method, when it was 46 380 tC (Figure 3.2). On the other hand, the mean annual amount of carbon was the lowest at Mill B using the RC method, when the carbon amount was 7 030 tC. At Mill A, the annual carbon amount was on average 36 800 tC using the RL method and 32 520 tC using the RC method. Regardless of the harvesting method, the ratio of the mean carbon amount and the mean volume of forest residues was 0.22 tC/m^3 calculated as an average of a carbon amount and an amount of residues in individual stands.

The forest residues harvested alongside roundwood logging would have offered a reasonable amount of potential energy for energy conversion at the three mills. In 1999-2002 at the three mills, the annual energy content in residues was on average 258 GWh using the RC and 293 GWh using the RL method (Figure 3.3). At Mill C in 1999-2002, these annual energy contents were on average 396 and 443 GWh, respectively. At Mill B, the values were on average 68 and 84 GWh and at Mill A, 311 and 352 GWh, respectively. The best result was found in 1999, and it was a total of 990 GWh of energy in residues for the three mills. The amount of energy in forest residues is directly linked to the demand of industrial pulp and timber wood, because the harvesting of industrial and energy wood have been integrated. However, the need of industrial wood is a determinant factor in this integration. Industrial wood assortments are again purchased according to an overall demand of wood products at world markets.

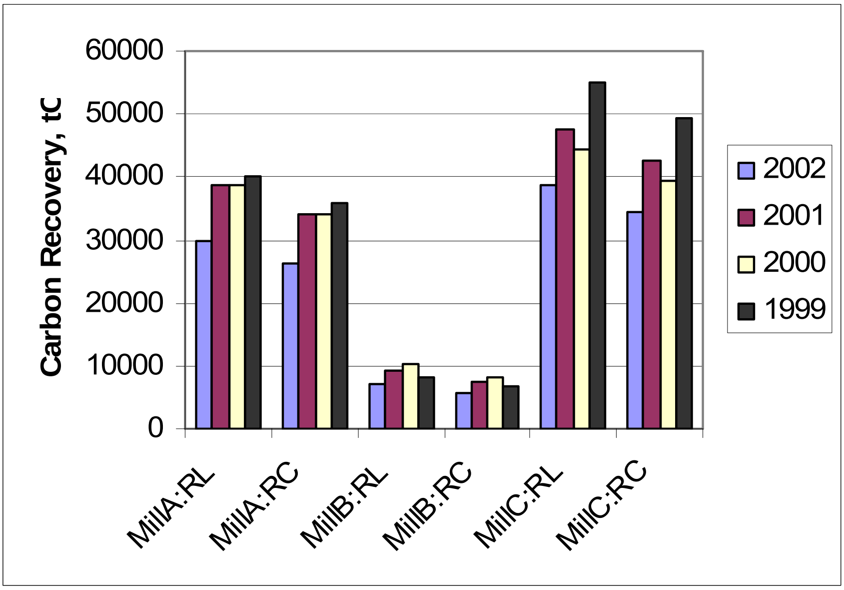

Figure 3.2. The amount of carbon (tC, tonnes of carbon) with two alternative harvesting methods: roadside chipping (RC) and residue log (RL) in 1999-2002 at three mills A, B and C.

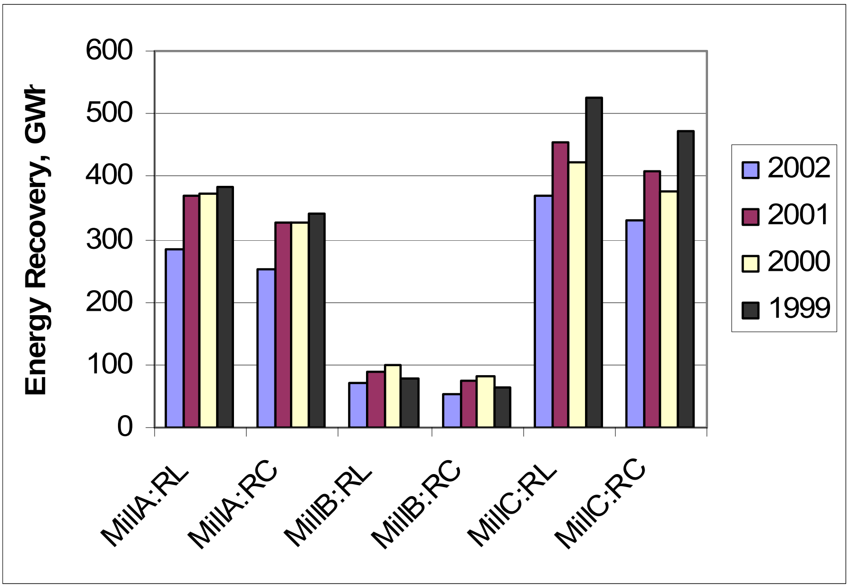

Figure 3.3. The amount of energy (GWh) with two alternative harvesting methods: roadside chipping (RC) and residue log (RL) in 1999-2002 at three mills A, B and C.

3.2 The cost of CO_2 in residues at the three mills

Forest residues contain carbon as discussed in the paragraph above. This material is suitable for energy conversion at a mill producing different forest products, where it can be combusted e.g. in a bark boiler. However, forest residues have purchasing costs. The costs consist of forest haulage, chipping, long-distance transportation and compensation payment for organisations in charge of purchasing forest residues, also called organisation costs (Asikainen et al. 2001). The above cost items formed the total costs of forest residues at the mill. Costs compared here with other mills did not contain value added tax (VAT). By dividing the harvesting costs with the carbon amount of the residues, the costs of carbon at the mill were calculated. In Figures 3.4-3.7, the costs of carbon at the mills are presented as a cumulative figure. All costs at a mill were set in order, from the lowest to the highest, and figures were drawn according to the real values. Each fuel cost (unit €/tCO_2) was linked to a corresponding carbon amount in residues (unit tC/a). When all stands with residues were supposed to be collected, the cumulative function reached its maximum. The maximum value was equal to the value presented in Figure 3.2 for each mill and for two alternative harvesting methods.

In Figures 3.4-3.7, as in other figures and tables in Chapter 3, the carbon in residues was transformed into carbon dioxide (CO_2) by multiplying the carbon amount with the ratio of mole masses (44/12). In Figures 3.4-3.7, it can be seen that the procurement costs of CO_2 at the three mills were cheaper with the RL method than with the RC method. However, the difference was not very high and it varied from only 2 to 7 %. Average values of procurement costs indicated that the RL method was 7 % at Mill C, 5% at Mill A and 2% at

Mill B cheaper than the RC method. The only exception was Mill B in 2001, when the RC method was slightly cheaper (0.4 %) than the RL method. The average procurement costs per unit CO_2 varied from 21.8 €/tCO_2 to 24.9 €/tCO_2. The lowest price was with Mill C and the highest with Mill B. When the unit was €/m^3, the variation in average costs was from 17.5 €/m^3 to 19.9 €/m^3. When the cheapest 75 % of all stands were supposed to be harvested and the most expensive ones, i.e. 25 %, were omitted, the variation in mean costs was from 20.5 €/tCO_2 to 23.9 €/tCO_2 (16.5…19.3 €/m^3).

Regardless of the harvesting method used, the overall procurement costs increased when new, more expensive stands were included. The procurement costs of CO_2 in residues was the lowest in those stands where the amount of residues and thus the amount of carbon was high, and distances from the forest to the mill was short. Then both the haulage costs in the forest and the long-distance transportation costs were low per harvested biomass volume. With regard to the annual recovery of carbon in residues, it can be stated that with all three mills the recovery was at the lowest in 2002. The highest recovery was collected in 1999 for mills C and A, and in 2000 for Mill B.

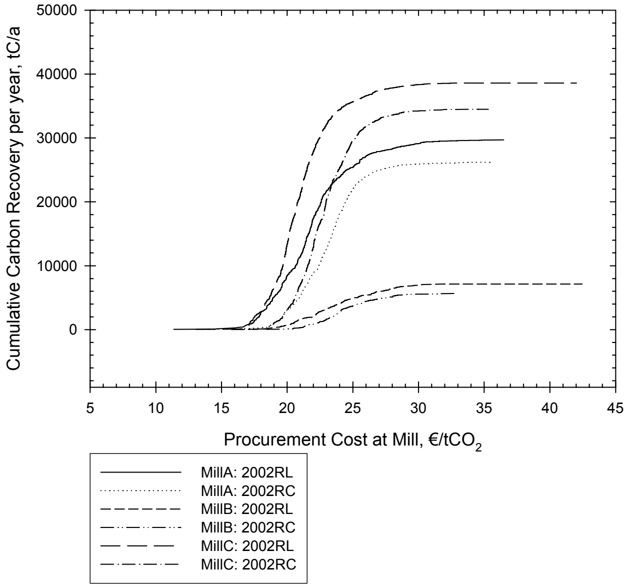

Figure 3.4. The cumulative carbon recovery of residues in 2002 (unit, tC/a) and procurement costs of CO_2 in residues (unit, €/tCO_2) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL).

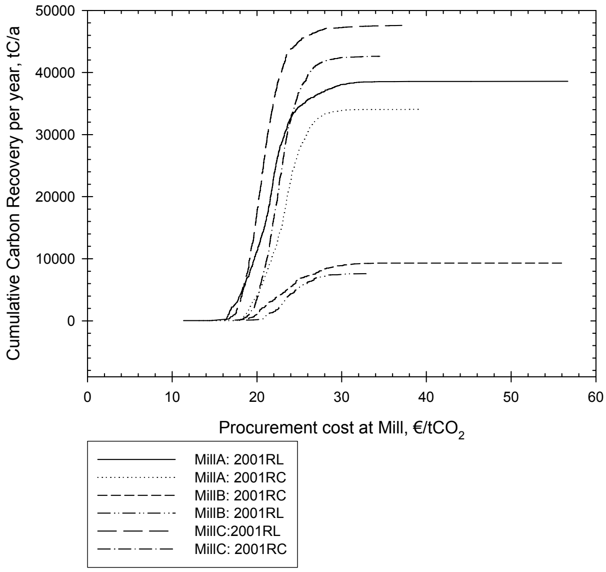

Figure 3.5. The cumulative carbon recovery of residues in 2001 (unit, tC/a) and procurement costs of CO_2 in residues (unit, €/tCO_2) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL).

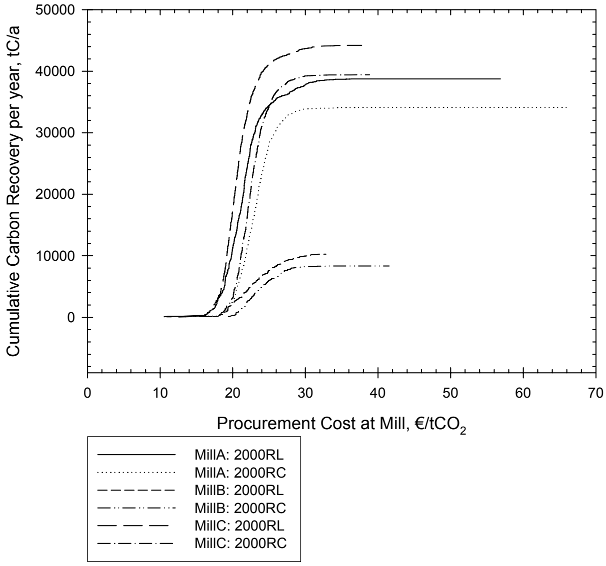

Figure 3.6. The cumulative carbon recovery of residues in 2000 (unit, tC/a) and procurement costs of CO_2 in residues (unit, €/tCO_2) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL).

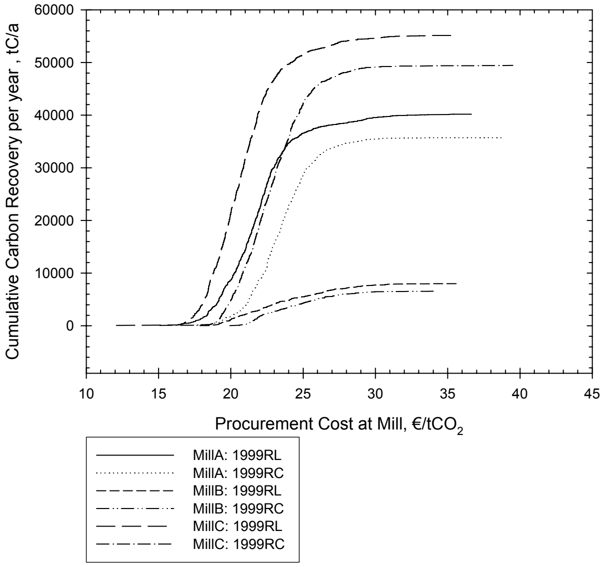

Figure 3.7. The cumulative carbon recovery of residues in 1999 (unit, tC/a) and procurement costs of CO_2 in residues (unit, €/tCO_2) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL).

3.3 The cost of energy in residues at the three mills

The average cost of energy in residues varied from 8.3 €/MWh to 9.4 €/MWh (Figure 3.8). The cheapest costs originated from Mill C and the most expensive ones from Mill B. The average costs of the RL method in 1999-2002 was approximately 5 % lower than that of the RC method. The difference in costs between the two methods was the lowest with Mill B and the highest with Mill C.

The possibilities of residual forest biomass to cover energy need at the mill varied according to the overall recovery of the residual forest biomass (Figure 3.2). At Mill C in 1999, the energy amount in residues could have covered even 22 % of all energy in fossil and renewable fuels used at the mill (Figure 3.9). At Mill B in 2001, the above share could have been less than 3 %. For Mill A also in 2001, at the maximum, 13 % of all used energy at the mill could have been produced with the residual forest biomass harvested together with industrial wood.

In Figures 3.10 – 3.11, the variation of procurement costs has been illustrated in the order from the lowest values to the highest ones. In 2000, the average procurement costs in residues were the lowest with most of the mills and alternative harvesting methods (Figure 3.8). In that year, out of six cases three ones were the cheapest. Whereas in 1999, the average costs at the mill were the highest in three cases out of six.

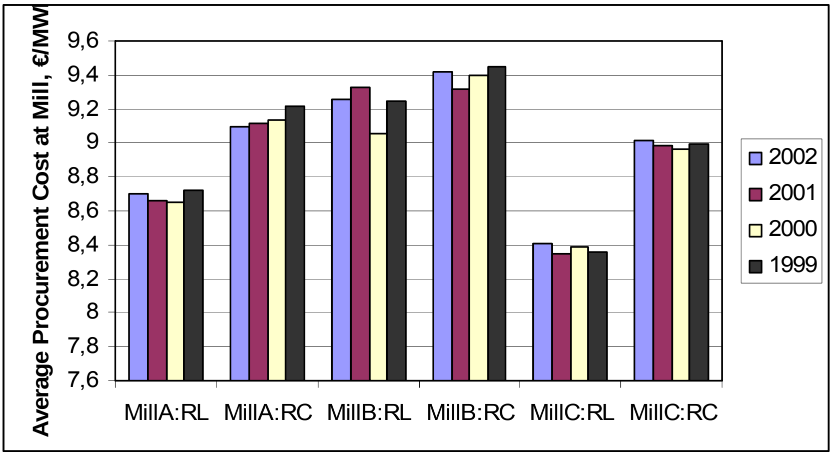

Figure 3.8. The average procurement cost (unit, €/MWh) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL) in 1999-2002. Moisture content is 46 % with RL and 45% with RC.

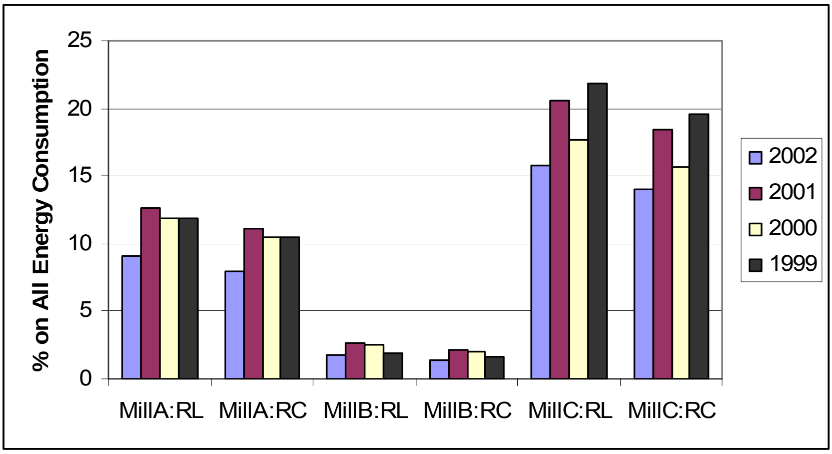

Figure 3.9. The share of energy in residues on all energy consumption of each mill produced with fuels used at the mills in 1999-2002. Wood residues were produced with two alternative harvesting methods - roadside chipping (RC) and residue log (RL). Moisture content is 46 % with RL and 45% with RC.

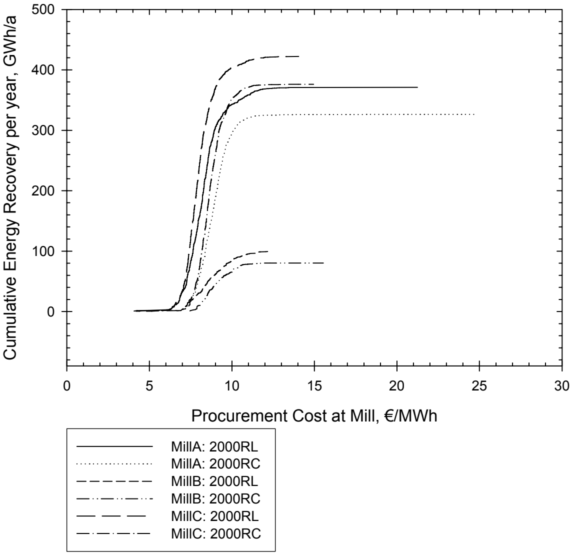

Figure 3.10. The cumulative energy recovery of residues in 2000 (unit, GWh/a) and procurement costs of energy in residues (unit, €/MWh) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL). Moisture content is 46 % with RL and 45% with RC.

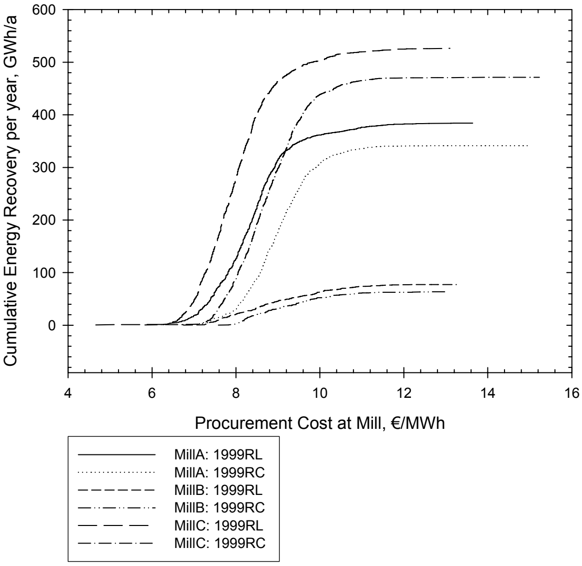

Figure 3.11. The cumulative energy recovery of residues in 1999 (unit, GWh/a) and procurement costs of energy in residues (unit, €/MWh) at three mills using two alternative harvesting methods: roadside chipping (RC) and residue log (RL). Moisture content is 46 % with RL and 45% with RC.

3.4 The effect of moisture content on procurement costs

In this study, a calculation of procurement costs is generally performed at a volume basis where moisture content does not effect on procurement costs. However, when energy content is used as a calculation basis, such as in Chapter 3.3, moisture content is affected by costs. When the moisture content of forest residues increases from 45 % or 46 % to 55 %, procurement costs at the mill (unit €/MWh) go up on average 8 % with the RC method and 10 % with the RL method (Figure 3.12 and 3.13). With regard to cost calculations, all costs are compared with the lowest costs of Mill C at the moisture content of 45 or 46 %.

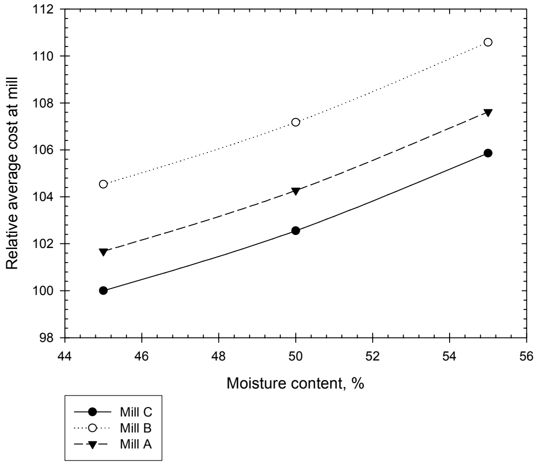

Figure 3.12. Effect of moisture content on relative average procurement costs at mill (unit €/MWh) using the roadside chipping (RC) method at three mills: A, B and C.

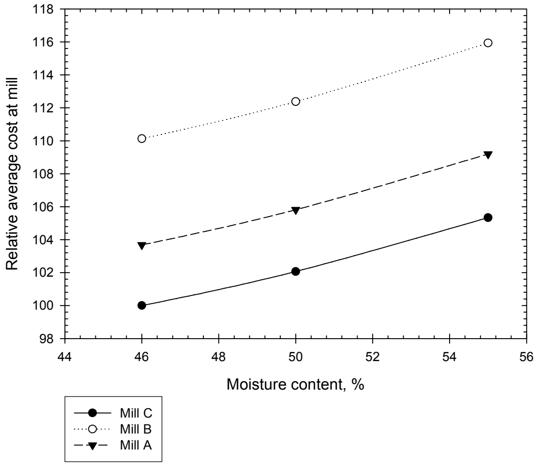

Figure 3.13. Effect of moisture content on relative average procurement costs at mill (unit €/MWh) using the residue log (RL) method at three mills: A, B and C.

3.5 Prediction of carbon yield on the basis of the procurement area

In order to predict a carbon yield with a mathematical function on the basis of a procurement area, the sigmoidal form of function was considered to present the phenomenon in the best way (Figure 3.14). The best model for the prediction was the Hill equation with three parameters.

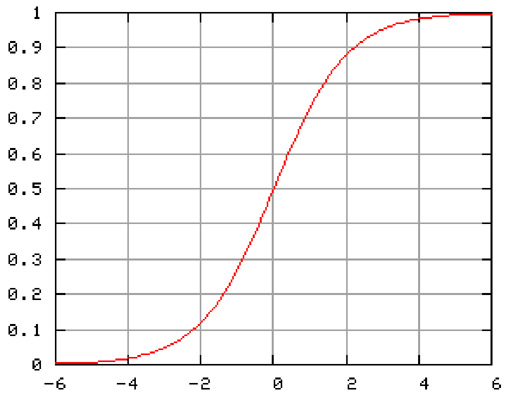

Figure 3.14. The logistic function, specially the sigmoid function (Wikipedia 2006).

The three parameters of the equation should have a connection to phenomena in the real world in order to ensure its validity. The validity was best fulfilled with the Hill equation where three parameters describe regarding 1) carbon recovery within the radius of 100 km, 2) the radius of the population centre outside the mill and 3) the relative forested area within the radius of 100 km from the mill. The first parameter, carbon recovery, can also be called a predefined carbon recovery in residues within the radius of 100 km from the mill which were the stands decided to be harvested for the mill. The second parameter, the radius of the population centre of the mill, has an effect on carbon recovery just outside the mill. The bigger the area of population outside the mill is, the further harvesting operations have to be extended in order to gain any residues (Table 3.1). It is worth noticing that in this context the population around the mill is understood as an urban form of housing so sparsely populated areas were not included into the above category.

The third parameter, the relative forested area within the radius of 100 km from the mill, was calculated so that a circle within a 100-kilometre radius for each mill was divided into eight sectors and the extension of a forested area in kilometres in each eight sectors was defined (see Table 3.1, Figure 3.15). When the average values were calculated for all mills, the most forested purchase area was proven to be for Mill C. The relative forested area for Mill C was set to 1 which describes one of the most forested areas in the Finnish circumstances. The other two forested areas around mills A and B were defined in a relation to the area around Mill C. The relative forested area describes the structure of a wood procurement area outside the mill. The relative forested area is decreased by waterways, agricultural land and a road network. When the parameters of the relative forested area were defined, it was noticed that especially the sea, big lakes and the border of Finland had an influence on the relative forested area.

Table 3.1. The radius of an urban population centre outside the mill, unit km and the relative forested area at the radius of 100 km from the mill in the case of mills A, B and C.

	Radius of urban population centre, km	Relative forested area
Mill A	1	0.82
Mill B	20	0.5
Mill C	6	1

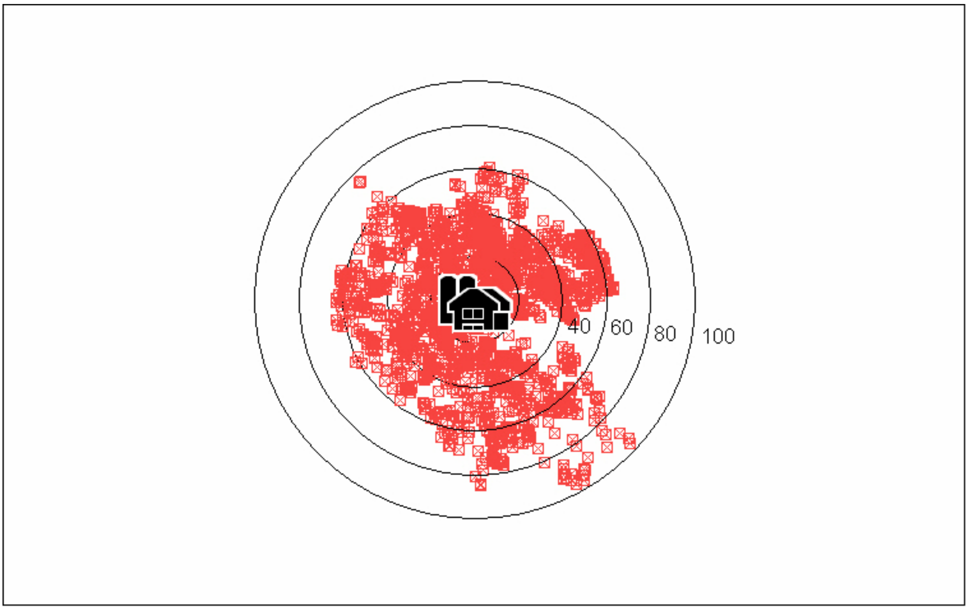

Figure 3.15. Actual location of study stands within a 100-kilometre radius from Mill C in 1999.

The general form of the Hill equation can be written in a simplified way for all three mills as follows:

$$F(x) = (a*b)/(a+b) \tag{33}$$

Where,
F(x) = carbon recovery at a certain radius from the mill, tC
a = slope function
b = saturation function

The Hill equation has both an ascending part described by the slope function (a) and a normalizing part which is described by another function, the saturation function (b). The saturation function approaches asymptotically the predefined carbon recovery within the radius of 100 km from the mill.

The slope function (a) is further written in the form as:

$$a = (Q/1000) * (x - r)(\exp(n)) \quad (34)$$

Where,
Q = carbon recovery at the radius of 100 km from the mill, tC
x = distance from a stand to the mill, km
r = radius of an urban population centre of the mill, km
n = 0.0654*sqrt(r)+1.467, where r = radius of an urban population centre of the mill, km
The saturation function (b) is written in the form as:

$$b = -(x - l)\,[(\exp(f(\exp(2)+2)]+g \quad (35)$$

Where,
x = distance from a stand to the mill, km
l = 11.77* [(sqrt(r)-3.96)(exp(2)]+102, where r = radius of an urban population centre of the mill, km,
f = relative forested area at the radius of 100 km from the mill
g = 2*Q = 2* carbon recovery within the radius of 100 km from the mill, tC

The two functions above were determined mathematically by testing their statistical fitness with the partial data of three mills. The functions and the whole combination of the Hill equation were tested by predicting the statistical fitness with the data from another year which differed from the original data.

In Figure 3.16, actual and predicted cumulative carbon recoveries according to the distance from the mill can be seen. For the predicted curves, total carbon recoveries within the distance of 100 km from the mill varied from 5 387 to 47 441 tC (Table 3.2). The total recovery was one of the three parameters in the variation of the Hill equation (Formula 34). The applicability of the predicted curves, i.e. the coefficient of determination, was the highest with Mill C ($r^2 = 0.999$), then with Mill A ($r^2 = 0.993$) and Mill B ($r^2 = 0.977$).

Table 3.2. The total carbon recovery within the radius of 100 km from the mill with mills A, B and C using the Roadside chipping (RC) method in 1999-2002.

	1999	2000	2001	2002
Mill A			33 739	26 068
Mill B		7 609		5 387
Mill C	47 440			34 320

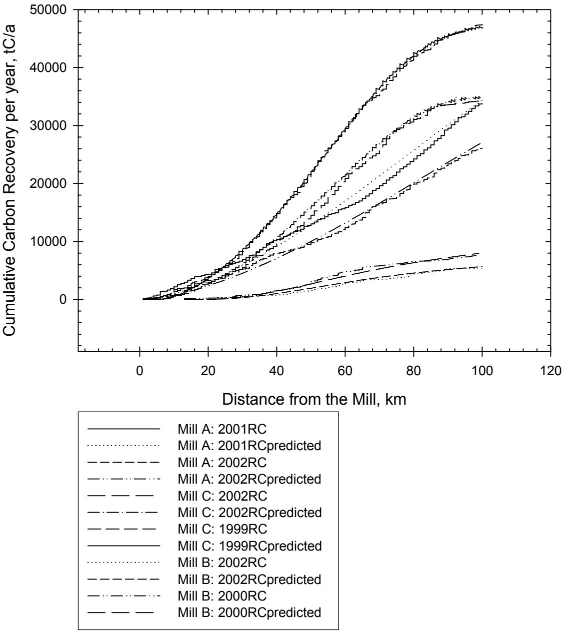

Figure 3.16. The actual and predicted cumulative carbon recovery per year using the roadside chipping (RC) method at Mills A, B and C in 1999-2002.

3.6 Energy saving investments linked to carbon emission reductions at the three mills

In Figure 3.17, the carbon emission reductions linked to the different energy saving investments have been connected to the costs in order to achieve the reductions. It can be seen from the figure that the costs for achieving energy saving and thus carbon emission reductions varied from almost – 400 €/tCO_2 to 600 €/tCO_2. With regard to negative values, energy savings per year were higher than the actual cost of that particular energy saving investment. At each mill, the saving objects with negative values could be found in three cases and in nine cases in total for all three mills. The above investments were very profitable in the sense of energy saving, because the repayment period without an interest was less than one year. The matter is even more important, when it is considered that savings in energy costs were calculated only for one year, not for the whole lifetime of an energy saving investment.

In Table 3.3, energy saving investments and the costs of the investments are illustrated in more detail. In general, it can be concluded that it was possible to achieve in total 51 610 tC of carbon emission reductions at the three mills, when all separate investment objects were summed up. The biggest potential was at Mill C and the lowest at Mill B. At mills A and B, investments were mainly supposed to be targeted to a chemical pulping process and sawmilling. At Mill C, energy saving objects were also found in the mechanical pulping process, such as TMP and groundwood pulps, and in paper machines. At all three mills, the biggest potential was in heat saving, which covered 77 % (= 39 776 tC) of all energy saving

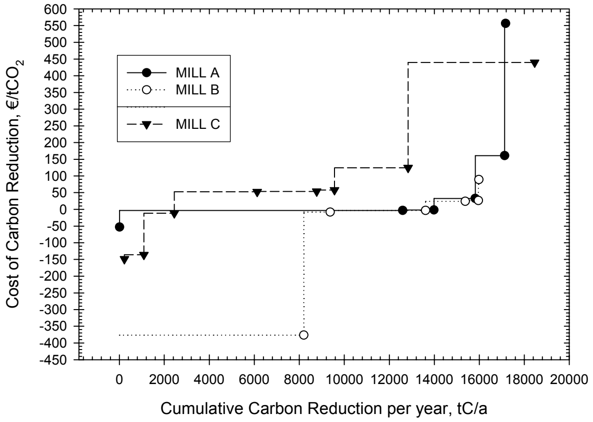

Figure 3.17. The cumulative carbon recovery per year (unit, tC/a) as the result of energy saving and the cost of carbon reduction (unit, €/tCO_2) in order to achieve the carbon reduction.

potential. However, electricity saving potential at Mill C is not insignificant, because electricity must be purchased outside the mill due to insufficient electricity generation at the mill. At Mill A, it is not necessary to purchase energy due to a favourable energy balance of chemical cooking process with a recovery boiler and missing paper and cardboard production. Thus, electricity needs not to be purchased outside the mill. However, by selling surplus electricity to the national grid, the mill can earn extra revenues. In order to increase these revenues, investments into electricity saving are also justified.

Concerning Mill B, one energy saving investment, the increase in the capacity of one paper machine, needs a more detailed attention. The cost of the investment per saved CO_2 emissions was -377 €/tCO_2 (Table 3.3). It was not possible to report the cost of the energy saving investment, so cost was calculated as the difference of the whole investment cost (58.9 million €) and the value of the increased production of this fine paper machine during one year (95 000 tonnes * 740 euro/ton). However, this was a critical point, since the result varies considerably depending on the initial values used. If 10 % (5.9 million €) of the total investment cost was used as a value of an energy saving investment which was estimated from similar investments materialized earlier, the cost of the investment was remarkably positive (200 €/tCO_2 = 733 €/tC). The former example describes difficulties with regard to valuing energy savings as part of larger investments, such as an increase in the production of pulp and paper in the forest industry. Sometimes it is even questionable to speak about energy saving, because as a result of the investment, the use of energy increases. Concerning the results of this study, the previous was valid for the electricity consumption at Mill B, where the annual consumption rose by 16 000 MWh. However at the same time, the annual consumption of heat decreased by 55 000 MWh, so the net saving was 39 000 MWh per year.

The average cost of energy saving investments was calculated by adding up individual costs of saving investments and dividing the sum by the sum of all carbon reductions. The former result varied from mill to mill. The cost was 14 €/tCO_2 at Mill A, -191 €/tCO_2 at

Mill B and 167 €/tCO_2 at Mill C. At Mill B, one saving object, the increase in capacity of one paper machine, had the biggest effect on the negative value. Without this investment, the average cost would have been 5 €/tCO_2. At Mill C, the extremely high costs of energy saving operations at the sawmill caused the high average cost of saving investments.

Table 3.3. Capacity of heat and energy savings in carbon emission reductions in connection with technical improvements at the three different mills, A, B and C, unit tC (=tonnes of carbon) and the cost of the energy saving investment per reduction in carbon, unit €/tC and €/tCO_2.

Mill A	Heat saving, tC	Electricity saving, tC	Total, tC	€/tCO_2 (€/tC)
renewal of compressor, sawmill	0	13	13	-53 (-194)
warming of white alkali lye, fibre lines	7 927	4 655	12 582	-3 (-12)
filtration of washing result, fibre lines	876	514	1 390	-2 (-6)
dry matter increase of white alkali lye, evaporating plant	1 837	0	1 837	33 (119)
oxidation of pressurised white alkali lye, fibre lines	822	483	1 305	161 (590)
handling of snow and stone pile, sawmill	0	37	37	557 (2041)
Total (Mill A)	11 462	5 702	17 164	
Mill B				
increase in capacity of one paper machine	6 474	1 721	8 195	-377 (-1 381)
Use of secondary heat in the pulp bleaching	1 177	0	1 177	-8 (-30)
Use of secondary heat in the pulp-drying process	4 238	0	4 238	-3 (-12)
Use of secondary heat in handling of frozen wood	1 766	0	1 766	24 (88)
Use of secondary heat in heating of mill buildings	588	0	588	26 (97)
adjustment of electrostatic precipitator of one energy boiler	0	21	21	89 (327)
Total (Mill B)	14 243	1 742	15 985	
Mill C				
Grinding mill	0	226	226	-149 (-545)
TMP	0	863	863	-136 (-498)
Paper machine 2	1 097	257	1 545	-12 (-43)
Paper machine 4	2 984	700	4 202	53 (193)
Paper machine 3	2 143	503	3 017	54 (197)
Paper machine 1	641	150	903	58 (212)
Pulp mill	2 650	622	3 732	125 (457)
Sawmill	4 556	1 069	5 625	439 (1 611)
Total (Mill C)	14 071	4 390	18 461	

Without this saving object, the cost per saved carbon emissions would have been 48 €/tCO_2. In reality, a very expensive energy saving investment is omitted, if it is not a part of a capacity increase or a quality improvement investment connected to the actual production process.

The possibilities of energy saving to decrease carbon emissions should be considered in the context of total carbon emissions of different mills as a result of the mills' energy consumption. In Table 3.4, the average CO_2 emissions of different fuels and mills during 1998-2002 have been described. With regard to Mill A, the decrease in CO_2 emissions as a result of energy saving (= 62 935 tCO_2) could have covered 4 % of all fuels' CO_2 emissions. It is worth noticing that almost all emission reductions (over 99 %) originated from a decreased use of wood as a result of energy saving measures. Also over 99 % of all CO_2 emissions at Mill A originated from wood based fuels. Thus at Mill A, the CO_2 emission reduction as a result of energy saving could have covered over 4 times those

Table 3.4. Fuels used for energy conversion and the average amount of CO_2 emissions originating from combustion of different fuels (unit tCO_2) at the three mills in 1998-2002

Fuels	Emissions (tCO_2)
Mill A	
Biofuels	
Black liquor	1 181 793
Bark	443 102
Methanol	2 966
Soap	50 317
Fossil fuels	
Heavy fuel oil	15 438
Light fuel oil	153
TOTAL (bio+fossil)	1 693 769
Mill B	
Black liquor	874 507
Bark	244 681
Methanol	4 163
Fossil fuels	
Peat	239 700
Heavy fuel oil	36 102
Light fuel oil	723
Liquefied petroleum gas	29 623
TOTAL (bio+fossil)	1 429 499
Mill C	
Black liquor	486 975
Bark	325 898
Fossil fuels	
Coal	28 024
Heavy fuel oil	29 800
Peat	18 997
Reject	17 029
TOTAL (bio+fossil)	906 723

emissions originated from the use of fossil oil. At Mill B, CO_2 emission reductions as a result of energy saving (= 58 612 tCO_2) could have covered 4 % of all fuels' CO_2 emissions. The share of the CO_2 emission reductions would have been 19 % of the average emissions of semi-fossil - peat - and fossil fuels. At Mill C, the reduction in CO_2 emissions as a result of energy saving were 67 690 tCO_2. This value covered 7 % of all CO_2 emissions at the mill. Concerning the emissions from fossil fuels and peat, the share was 72 %. It can be concluded that energy saving offers good possibilities for a CO_2 emission reduction at Mill C and reasonable possibilities at Mill B. Due to technical reasons, the replacement of fossil fuels is not always possible, such as at Mill A the use of oil in the lime kiln.

3.7 Analysis of different carbon trading experiments

Two viable alternatives for carbon trading could be analyzed according to the cost curves and constraints given to mills. These alternatives were as follows: either Mill D made an investment and sold extra carbon allowances to mills E and F, or Mill E made an energy saving investment and sold extra licenses to Mill F. In the latter case, Mill D made its energy saving investments independently up to its constraint of 17 500 tC. The cost for Mill D to make an energy saving investment was 218 700 euro [=(19 773 tC – 16 857 tC) * 75 euro/tC] (Appendix 2). After Mill D had fulfilled its constraint, it could sell 2 273 tC to mills E and F (Figure 3.18, Appendix 2). The assumption for the trading price was that in the long run a seller and a buyer would halve the price (Baird et al. 1995). This indicated that in the first case Mill F would buy 1 370 tC from Mill D at a price range of] 0, 400 euro/tC], and Mill E would buy 406 tC at the price range of] 0, 69 euro/tC] (Figure 3.18, Appendix 2). In Figure 3.16 carbon reductions are marked cumulatively. Thus the value 406 tC is the difference between 1 776 tC and 1 370 tC. It is worth noticing that in Figure 3.18 different alternatives for each mill are described in a situation where the last energy saving investment in order to fulfill emission constraint is considered (Appendix 2).

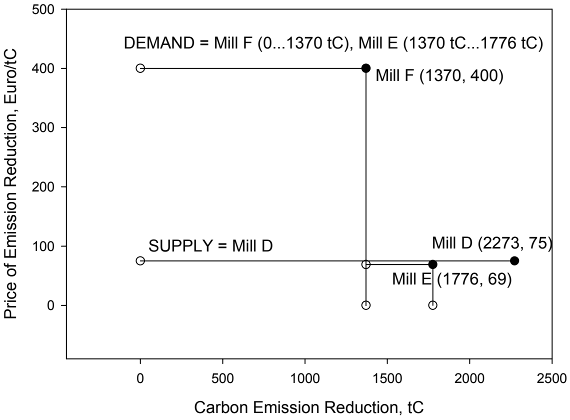

Figure 3.18. Trading alternatives in a case where Mill D makes an energy saving investment and sells the surplus carbon allowances (carbon emission reduction, tC) to mills E and F at a certain price (price of emission reduction, euro/tC). Supply and demand illustrate the position of the mill in an experiment.

In the second case, Mill F would buy 1 370 tC from Mill E where the price range was]0, 400] (Figure 3.19). Then Mill E made an energy saving investment which gave 1829 tC for sale. The total cost for Mill E was 154 215 euro [=(18 829 tC – 16 594 tC) * 69 euro/tC] (Appendix 2). Mill D fulfilled its constraint by making an energy saving investment independently, because it could not buy enough allowances from Mill E (Appendix 2).

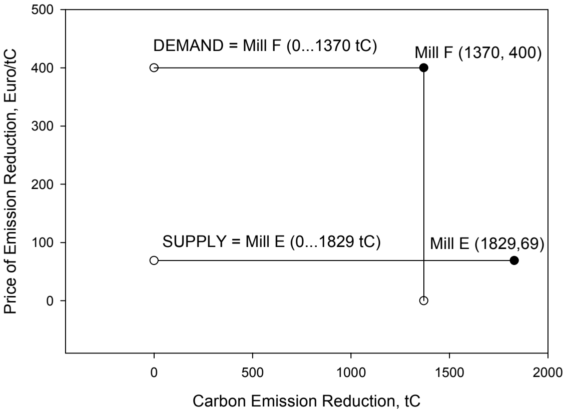

Figure 3.19. A trading alternative in the case where Mill E makes an energy saving investment and sells the surplus carbon allowances (carbon emission reduction, tC) to Mill F at a certain price (price of emission reduction, euro/tC). Supply and demand illustrate the position of the mill in an experiment.

The optimum for different mills was calculated as a mean value of two possible solutions: either Mill D makes an energy saving investment and sells part of its surplus to mills E and F or Mill E makes an investment and sells part of its surplus to Mill F. In the first case, an expected price for trades between D and F was 200 €/tC and between D and E, the price was 34.5 €/tC. In the second case, the expected price for the trade between E and F was 200 €/tC. According to prices and sold carbon amounts, an optimum was calculated for different mills (Table 3.5).

Table 3.5. Expected costs (unit euro, €) with two possible solutions and optimums (unit euro, €) for mills D, E and F.

	Mill D makes investment	Mill E makes investment	Optimum
Mill D	-69 307 (=218 700 – 274 000 – 14 007)	218 700 (=2 916 tC * 75 €/tC)	74 696.5 [=(-69 307 + 218 700)/2]
Mill E	14 007 (=34.5 €/tC * 406 tC)	-119 785 (= 154 215 – 274 000)	-52 889 [=(14 007 – 119 785)/2]
Mill F	274 000 (=200 €/tC * 1 370 tC)	274 000 (=200 €/tC * 1 370 tC)	274 000 [=(274 000 + 274 000/2)]

An experiment cost for each subject was compared with the optimum calculated in Table 3.5. The proportional value between the optimum and an experiment cost for a subject was called individual effectiveness (IE). The individual effectiveness of each subject was calculated separately at both rounds using the formula

$$IE = [(CC - OP)/OP] * 100 \qquad (36)$$

Where,
IE = individual effectiveness of each subject, per cent (%),
CC = calculated costs of each subject representing certain mill, euro (€),
OP = optimum value, euro (€).

Calculated costs of each subject representing certain mill were calculated from trading records of each experiment in both two rounds. It was possible for subjects to act as buyers or sellers. However, in order to ensure a good trading result, choosing between two trading alternatives described above was reasonable. Then, for example, for Mill F, the only justifiable solution was to buy its missing allowances up to the constraint. In the case of a buyer, costs were directly the product of a carbon amount and a price (= amount * price). If a buyer could not fulfill his constraint, or he/she bought too few allowances, he/she actually made an investment without trading and trading costs were added to investment costs. If a subject was a seller, he made the total investment himself and sold the surplus. Then the calculated costs were total investment costs minus a product of a carbon amount and a price. If a subject could not sell his surplus to other mills, trading costs were then just costs of the energy saving investment.

The individual effectiveness of each subject representing certain mill was calculated for the experiments carried out in the autumn of 2002 and in the spring of 2004 and 2005 (Table 3.6). In the experiment played in the spring of 2005, a total of nine different subjects participated, whilst in autumn 2002 and in spring 2004, 36 different subjects participated. Positive values describe that the subject exceeded the optimum calculated for his/her mill, whereas negative values indicate that the subject could beat the optimum. 16 different subjects were able to play below the optimum of their mill as an average value of two played rounds, when the number of those subjects playing over their optimum was 29. In the experiments of spring 2004, a monetary fee was used in order to motivate subjects to play more efficiently. Those participants whose result was less than the optimum calculated for their mills deserved an extra fee of seven euro. The extra fee was paid, when the mean value of two rounds was below the optimum, i.e. the mean value was negative. Six participants were awarded this extra fee in addition to three euros paid to all participants.

It is worth noticing that mills in Table 3.6 represent subjects, and subjects with different numbers describe different participants in different games and gaming variations. Thus, in total, 45 participants played in all games.

The experiment effectiveness according to the experiment type varied. Standard deviation between different experiments in different years can be seen in Table 3.7. The low standard deviation of a certain variation indicated that subjects could understand their position in the experiment and could trade efficiently. Then some participants could not significantly be benefited in their games due to unsatisfactory experiment performance of other participants, which was typical for results with high standard deviation. Concerning the experiments in 2005 and 2002, the lowest standard deviation was with the double auction variation. In the spring 2004, the lowest standard deviation covering both rounds

Table 3.6. Effectiveness of different subjects with different experiment variations in the first and second round and, on average, in both rounds in the experiments of autumn 2002, spring 2004 and spring 2005. (trading with more info = bilateral trading with open information, trading with less info = bilateral trading with restricted information). Mill D1, D4, D7 etc. depict the different participants.

Autumn 2002						
Trading with more info	**Mill D1**	**Mill E2**	**Mill F3**	**Mill D10**	**Mill E11**	**Mill F12**
1st round	+13 %	+291 %	-32 %	+230 %	-697 %	+100 %
2nd round	-28 %	+153 %	-50 %	+254 %	+151 %	+418 %
Average	-7 %	+222 %	-41 %	+242 %	-273 %	+259 %
Trading with less info	**Mill D4**	**Mill E5**	**Mill F6**	**Mill D13**	**Mill E14**	**Mill F15**
1st round	-53 %	+408 %	+429 %	-49 %	+209 %	+466 %
2nd round	-77 %	+650 %	-100 %	-48 %	+151 %	+421 %
Average	-65 %	+529 %	+164 %	-49 %	+180 %	+443 %
Double auction	**Mill D7**	**Mill E8**	**Mill F9**	**Mill D16**	**Mill E17**	**Mill F18**
1st round	-63 %	+184 %	+10 %	+160 %	+146 %	+445 %
2nd round	+235 %	-191 %	+0,9 %	+245 %	+392 %	+431 %
Average	+86 %	-4 %	+5 %	+203 %	+269 %	+438 %
Spring 2004						
Trading with more info	**Mill D19**	**Mill E20**	**Mill F21**	**Mill D28**	**Mill E29**	**Mill F30**
1st round	+46 %	+392 %	-60 %	+138 %	+392 %	-5 %
2nd round	+238 %	-28 %	-31 %	+193 %	+197 %	-62 %
Average	+142 %	+182 %	-46 %	+165 %	+294 %	-34 %
Trading with less info	**Mill D22**	**Mill E23**	**Mill F24**	**Mill D31**	**Mill E32**	**Mill F33**
1st round	+92 %	+187 %	-33 %	-161 %	+643 %	+28 %
2nd round	+273 %	-40 %	-39 %	+176 %	+160 %	-27 %
Average	+183 %	+74 %	-36 %	+7 %	+401 %	+0,4 %
Double auction	**Mill D25**	**Mill E26**	**Mill F27**	**Mill D34**	**Mill E35**	**Mill F36**
1st round	-40 %	+96 %	+485 %	-136 %	+151 %	-20 %
2nd round	+242 %	-251 %	+11 %	+54 %	+392 %	-62 %
Average	+101 %	-77 %	+248 %	-41 %	+271 %	-41 %
Spring 2005						
Trading with more info	**Mill D37**	**Mill E38**	**Mill F39**			
1st round	-26 %	+146 %	-49 %			
2nd round	-40 %	-47 %	+513 %			
Average	-33 %	+49 %	+232 %			
Trading with less info	**Mill D40**	**Mill E41**	**Mill F42**			
1st round	-28 %	+153 %	-50 %			
2nd round	-18 %	+138 %	-50 %			
Average	-23 %	+146 %	-50 %			
Double auction	**Mill D43**	**Mill E44**	**Mill F45**			
1st round	+79 %	-15 %	+9 %			
2nd round	+23 %	+203 %	-17 %			
Average	+51 %	+94 %	-4 %			

and all subjects within each variation was with the experiment institution of bilateral trading with open information. With regard to the effectiveness of separate games, the lowest standard deviation within the experiments of the spring 2005 was again with the double auction variation. Because there were only nine subjects, different experiment variations could not be repeated and thus deviations did not differ from those covering the whole group. In spring 2004, the smallest standard deviation was with the bilateral trading with restricted information variation with the subjects representing mills D22, E23 and F24. In autumn 2002, the smallest standard deviations were with the double auction variation with the subjects representing mills D16, E17 and F18 and with the bilateral trading with open information variation with the subjects representing mills D1, E2 and F3.

When all games played in 2002, 2004 and 2005 and all three experiment variations were included and standard deviations for each three variations were calculated, the double auction variation gave the lowest value, 187. The standard deviations of bilateral trading with open information variation and the bilateral trading with restricted information variation were identical, i.e. 219.

When the results of different experiments are considered, difficulties to understand the link between energy saving and carbon trading can be seen. Especially the economic decision on either to make an investment at the own mill or just buy missing allowances from other mill was not an easy task for many participants. The proper definition of the position concerning their own mill in a relation to other mills was a vital element to achieve a good personal effectiveness in an experiment. Although the choice between a buyer and a seller was free for participants, the right choice according to their own mill's position was important.

Table 3.7. Standard deviations of different experiment variations. Different experiments were carried out in the spring of 2005, in the spring of 2004 and in the autumn of 2002, following all three games. (trading with more info = bilateral trading with open information, trading with less info = bilateral trading with restricted information). Mill D1, D4, D7 etc. describe different subjects.

	Double auction	Trading with more info	Trading with less info
Spring 2005 Mills D37…F45	77	204	87
Spring 2004, all mills	204	159	202
Mills D19…F27	231	166	122
Mill D28…F36	174	148	254
Autumn 2002, all mills	192	269	254
Mill D1…F9	144	124	297
Mill D10…F18	124	360	202
All three games	187	219	219

4. DISCUSSION

4.1 Procurement of forest residues for the three mills

In the section of procurement of forest residues for the mills, two different harvesting methods, the roadside chipping and the residue log, were compared with each other. The residue log method was slightly more inexpensive than the roadside chipping. However, the difference between the two technologies was not remarkable. In Finland, the use of residue log has been limited to applications where fixed crushers have been built to end-user sites. Basically, this has only been possible in the wood reception terminals of the forest industry where the input volumes for crushers have been big enough. The critical cost item in the RL operations was baling which in this study covered about 34 % on overall procurement costs at the mill. According to Asikainen et al. (2001), a share of baling on total costs at a mill was 37 % and it was the single biggest cost item with the RL method. Thus ensuring an adequate workload for a baling machine is a main task to analyze the cost competitiveness of the RL method. The baling technology was commercialized in Finland and it is mainly utilized here. In order to secure the future development of the technology and the price reduction of baling machines as a result of bigger production outputs, the technology must be exported abroad in a larger extent. Concerning the roadside chipping technology, the absence of fixed chipping or crushing units at most communal power plants favours the RC technology. In Finland, entrepreneurs have largely invested to truck-mounted chippers which support the existence of this technology. However, according to this study, the total share of chipping and long-distance transportation covered over 60 % of total procurement costs at the mill. Thus the further development of the above operations is important for the competitiveness of the RC technology. New innovations based on a persistent and effective research ensure a positive trend of the Finnish bioenergy industry.

Concerning the cost calculation of CO_2 and energy in residues, costs per stand were calculated from a stand to the mill in the case of each stand. This tends to overestimate the total procurement costs, because residues from each stand were presumed to be transported to the mill independently. Then transport loads in the long-distance transportation were not full, because the concentration of forest residues from several stands did not take place. By concentrating residues from the same geographical area to one load, the total transportation costs could have been divided between several stands, and then the overall costs per one stand could have been decreased. In order to make full loads for a long-distance transportation, the GIS (Geographic Information Systems) based actual road network system should have been utilized. The mapping system with suitable digital maps was lacking due to inadequate financial resources. Also time losses for obtaining suitable study material from the forest corporation did not justify to increase the scope of this study.

In this study, the average cost of energy in residues at the mill varied from 8.3 €/MWh to 9.4 €/MWh (VAT not included). According to the study in Sweden (Andersson 2000), the cost of chips at the heating plant was 12.4 €/MWh (haulage distance 75 km) and the cost of residue logs from 10.2 to 12.0 €/MWh (haulage distance 30 km). According to Hakkila and Nousiainen (2000) in Finland in 1999, the price of logging residues as chips was 8.1 €/MWh for energy plants over 10 MW. In the mid 2003, the price of wood chips in

Finland was on average 9.95 €/MWh (Energiakatsaus 2/2003). This price covered all costs to energy plant with no information on long-distance transportation distances. The unified price data is not available so far, because the energy market for wood is local and under a development process. According to the study by the Finnish Forest Research Institute (Metsätilastotiedote 2003), the price of wood chips was on average 9.40 €/MWh (Value Added Tax, VAT not included) in 2002. The prices of wood waste from forest industry and bark were 6.45 €/MWh and 6.75 €/MWh, respectively. In 2004, the average price for solid wood fuel was 8.45 €/MWh, 7.95 €/MWh for industrial chips and 9.9 €/MWh for forest chips (Finnish Statistical Yearbook of Forestry 2005). Thus, wood material set aside from roundwood processing was principally cheaper for energy conversion than wood residues procured from the forest. However, the main point is not regarding relatively small differences among different wood fuels but the replacement of fossil oil, natural gas and coal with the renewable biomass. Then all those mechanisms behind the price formation of different fuels should be analysed and changed to favour renewable, environmentally sustainable and domestic fuels.

The prices calculated in this study are at the same level with the above Finnish values. It is worth noticing that the values in this study are average ones. Among values it can be found that there are some stands with very high costs which would not be harvested due to extremely high costs of procurement. The reasons for the high procurement costs are e.g. low yield of wood residues and long forest haulage or road transportation distance to the mill. In this study, the costs of machines used in logging and long-distance transportation operations were almost the same as the ones used in the study of Asikainen et al. (2001). Moreover, machine costs stayed at the same level throughout the whole study period 1999-2002. However, this may not be true in reality where at least the investment costs of machines, the wages of drivers and the fuel and spare part costs of machines tend to change – mainly upwards.

The introduction of an emissions trading scheme has affected the price of fuel at the end user site. In Figure 4.1, it can be seen that the prices of fossil fuels and semi-fossil peat have increased due to emissions trading. The higher the price of an emission allowance is, the more expensive the fuel is for an end user. For example, the price of heavy fuel oil rose by 21 %, coal by 49 % and peat even by 95 %, when the price of emission allowance changed from 0 €/tCO_2 to 20 €/tCO_2. When different price levels of emission allowances are connected to carbon recoveries in residues of this study, it can be noticed that there is an improved competitiveness of wood fuels compared to fossil ones. Already at the emission allowance price of 5 €/tCO_2 (price of peat 10 €/MWh at the plant), at least 81 %, or even 96% of carbon in residues could be competitively harvested for the three mills (Figure 4.2). In the case of the three mills, the overall carbon recovery was then 99 330 tC with the RL method and 85 020 tC with the RC method. At the emission allowance price of 15 €/tCO_2 (price of peat 14 €/MWh at plant), 100 % recovery could be attained at all mills with the RL method. Then an overall recovery was 93 370 tC with the RC method and 105 590 tC with the RL method.

The status of wood fuel on the energy market is connected to its price competitiveness and its secured availability. The price of wood fuel on the energy market is competitive due to a favourable tax treatment and a development work in logging operations. The excise taxes or fiscal charges and fees included in consumer prices are not connected to the price of wood fuel, whereas in the price of coal for heat conversion (16.3 €/MWh in 2005 with VAT, Energiakatsaus 4/2005) the share of those above taxes including VAT was 57 % and in the price of heavy fuel oil it was 31 % in 2005. Only value added tax (VAT) is included in the price of wood fuel, like in the other prices of different fuels. However, this tax is

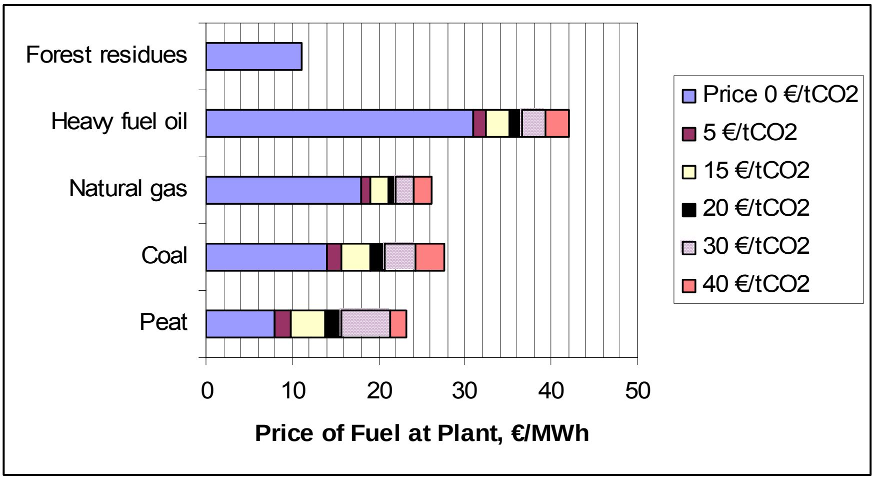

Figure 4.1. The price of different fuels used for heat conversion at plant (€/MWh, VAT not included, Energiakatsaus 4/2005) at different prices of an emission allowance (€/tCO_2).

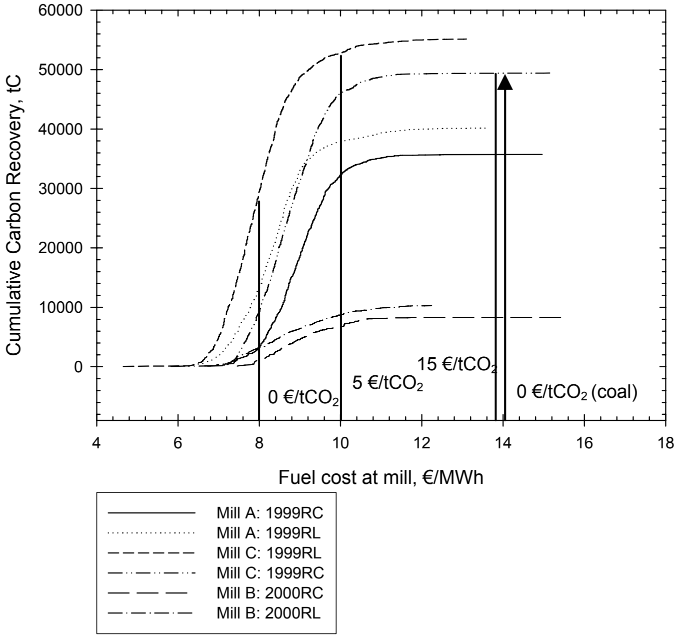

Figure 4.2. Recovery of forest residues at the price level of peat when the price of an emission allowance is 0, 5 or 15 €/tCO_2. An arrow describes the price of coal, when the price of an emission allowance is 0 €/tCO_2.

refunded back to the energy company. Also the secured availability of wood fuel has an important effect on the competitiveness on the energy markets. When the amounts of procured wood fuel increase, a purchase radius must be lengthened. It is not possible to extend the purchase radius beyond all limits, because the procurement area of another mill sets constraints to the expansion. However, the longer the distances to the nearest mill are, the more the long-distance transportation costs tend to be increased. Because the long-distance transportation is mainly carried out by trucks, the cost of diesel oil has an important effect on the total procurement costs. In order to restrain this effect, new cost-effective transportation systems must be developed, and the energy intensity of harvested loads should be carefully monitored.

When it is estimated that 20 % of that energy in fuels is transformed into electricity, the amounts of electricity per year that could have been converted from wood residues were 70 400 MWh at Mill A, 16 800 MWh at Mill B, and 88 600 MWh at Mill C during the period of 1999 – 2002. With regard to fuels used for electricity conversion, electricity converted from wood chips received a subsidy of 0.69 cents per kWh, i.e. 6.9 €/MWh in 2003 (Laki sähkön ja eräiden polttoaineiden…). The financial support for wood-based electricity is not a negligible financial transaction to the mill when the average production costs of forest residues were, on its cheapest, 8.7 €/MWh at Mill A, 9.2 €/MWh at Mill B, and 8.4 €/MWh at Mill C in 1999-2002. In addition, electricity producers, which use renewable energy sources, such as wood, for their electricity conversion, can sell green certificates either straight or through a broker to the electricity suppliers interested in the origin of their electricity. The origin of the electricity is connected to the certificate, so the producer cannot sell the electricity produced with wood as green electricity straight to the consumer and, in addition, sell certificates licensed to this electricity amount on the market of green certificates. Thus an energy company can sell either green certificates or green electricity.

4.2 Carbon accumulation according to the procurement area

According to the recovery model, energy wood can be procured in different parts of Finland due to the large cover of forest resources. However, a uniform forested area around the mill increases the recovery of energy wood. The right distribution of different wood assortments, especially matured spruce stands, improves the overall recovery. Also a small urban population around forest resources and an industry centre enables the increase of energy wood recovery near the mill. However, it is important to keep in mind that the original sampling condition was to cover all the stands marked for a final felling, where the distance from the particular study mill was at the maximum about 100 km. The generalized model was developed using the total carbon recovery from these stand records as a basis.

The carbon accumulation at the procurement area was dependent on both the location of forest stands and overall structure of the forested area. According to the study of Asikainen et al. (2002), the quantity and the costs of logging residues from final fellings varied according to the geographical location in Finland. Power plants using residues and located near the coast obtain their wood fuel within a semicircular area. On the other hand, plants locating in inner Finland can procure their wood fuels from all directions. This affects transport costs considerably. Also the structure of stands has an effect on the recovery. Pine is a dominating species in the coastal area while spruce in central and partly in eastern Finland. The recovery of residual forest biomass from spruce dominated stands is bigger due to the higher yield of crown mass (Hakkila et al. 1998). The best sources of logging residues are located in central Finland.

In this study, Mill A is located in eastern Finland, Mill B in the coastal area and Mill C in central Finland. Mill B had the lowest recovery of carbon due to the pine dominance and the unfavourable form of the procurement area. On the other hand, Mill C had the lowest procurement cost of carbon and the highest carbon yield due to the spruce dominance and an ideal geographical location near wood reserves. Furthermore, Mill A had quite a favourable location, the carbon yield was high due to the forested procurement area and the average procurement cost of carbon at the mill was the second lowest. However, at the moment at this mill, the need for extra wood fuel is minor due to high self-sufficiency of wood fuels as a result of a chemical cooking process in pulp making.

The Hill equation fits best for a procurement area where uniform, forested areas surround quite a small urban population area. Also the geographical composition of a procurement area does not prevent, in a larger scale, the efficient arrangement of long-distance transportation. Taking into account the Finnish circumstances, an ideal procurement area is central Finland where a round, uniform procurement area can easily be achieved. In the future, if administrative and other technical obstacles can be removed from the trade between Russia and Finland, eastern Finland could form a big and efficient centre of expertise for processing renewable energy. The import of industrial round wood is already a well managed business, but the import of energy wood in a large scale still awaits its turn. However, possible market disturbances in the accessibility of industrial wood might also affect the import of energy wood so the source of raw material should not solely be based on one big supplier.

The carbon accumulation in residues was remarkably dependent on the demand of the industrial roundwood, because the residual forest biomass was supposed to be procured in connection with roundwood. The Hill equation with three parameters does not straightly cover market based variables, except the carbon recovery within the radius of 100 km from the mill as a part of the slope and the saturation function. The carbon recovery parameter is substituted to the equation as an external factor. However, the parameter varies remarkably within different years, e.g. even 30 % between 1999 and 2002 in the case of Mill C (see Figure 3.2). Disturbances in the market situation of sawn timber and pulpwood may affect the supply of residual forest biomass. Further research is needed on the actual supply of energy wood in different market situations, if energy wood is procured simultaneously with industrial wood.

To avoid the above situations, procurement sources of renewable energy must be diversified. For example, energy crops at set-aside agricultural land and further processing of agricultural residues, such as biogas from animal manure and other wastes, offer new sources of energy in addition to the forest based material mainly used today. Also new ways to produce energy peat in a more environmentally friendly and efficient way improve the position of peat as a domestic energy fuel. At present especially in central and eastern Finland, peat and wood are combusted together as different mixtures in big energy boilers which have proved to be a workable solution against technical and market based interferences. However, the position of peat has worsened after the introduction of emissions trading, because emission allowances must be purchased for peat combustion.

4.3 Energy saving and CO_2 abatement in forest industry

At the three mills, nine energy saving objects, in total, with negative costs were found. Energy saving with negative costs is an interesting matter and requires more attention. As mentioned earlier in Chapter 3.6, a period of repayment, or a payback period, was used in the economical analysis. However, this method has its limitations which should be taken into consideration. The main weakness is that the method does not take into account either the time value of money or savings in later years. As a result, the method emphasises short-term benefits to an investor at the expense of long-term aspects. Thus, in energy conservation projects, only very short payback periods, less than 2 years, are usually profitable and are realistic (Siitonen & Ahtila 2002, Möllersten & Westermark 2001). However, compared to the lifespan of e.g. bark or recovery boiler in a pulp mill, the requirement for a payback period is very short in energy conversation projects. Normally, energy investments, such as bark and recovery boilers, are made for 25-40 years, and they do not require so strict payback periods as from energy conservation investments. Besides, the need for capital is often much lower in energy conservation projects than in large investments of an energy infrastructure.

Processes that increase the profitability of energy conservation projects need careful development work. Since industry requires the same profitability from investments targeted to energy projects as from the strategic improvements in the capacity for pulp and paper production, other financing alternatives are needed for energy conservation projects. One solution is an Energy Service Company (ESCO) (Kilpeläinen et al. 2000), which develops, installs and finances energy conservation projects aimed at reducing both energy and operating costs. ESCO can finance projects with a payback period of over four years, thus making them more attractive to companies requiring shorter payback periods. An Energy Service Company gains its revenues from the company which has profited from the energy saving investment. The paid revenue is linked to the monetary value of the saved energy. The normal payback period for the ESCO project is 2-6 years (Kilpeläinen et al. 2000).

Outsourcing is another tool for promoting energy saving in the pulp and paper industry (Möllersten & Westermark 2001). In this alternative, another company, usually an energy firm, owns a whole part of the conversion system, e.g. a biofuel-based CHP plant in a pulp mill. Outsourcing enables releasing capital to those businesses that form core competencies to a pulp and paper company. In conjunction with outsourcing, the energy company makes an investment in the outsourcing part of the production line and takes care of the operation of the production line thereafter. As a bonus, there is potential to save energy. According to Swedish estimations (Möllersten & Westermark 2001), the savings are around 10 %.

Basically savings in the heat and electricity bill used in this study are based on prices of heat and electricity when an evaluation of technological infrastructure was done. Thus the gained savings are always dependent on current prices of heat and electricity, i.e. the results of this study are only valid at parameters used in 1998 and 1999. In order to ensure a topicality of the results, parameters should be updated regularly. This is generally possible in an industry where the actual prices of different fuels are known. In order to predict the benefits of energy saving into the future, it might be possible to utilize prediction models for heat and electricity prices in the future. The introduction of emissions trading has increased the prices of energy inputs and thus justified energy saving profoundly. The possibilities of energy saving should be included into the strategic planning of an energy intensive industry in the same way as a procurement and the prices of different energy inputs.

In this study, carbon emission reductions achieved through energy saving are mainly possible at mills B and C where peat and coal are used for energy conversion (Figure 4.3). The carbon emission reductions are based on the prices of above fuels and values of emission allowance prices. In Table 4.1, carbon reductions at the different price of an emission allowance added to the prices of peat and coal at plant have been calculated (see also Figure 4.1). Basically, it was possible to achieve more carbon reductions at Mill B than at Mill C with the price of an emission allowance of 0…30 €/tCO$_2$. The reason for a higher carbon recovery was the lower overall costs of energy saving investments at Mill B compared to Mill C. In total at both mills, the variation in carbon reductions was from 16 053 to 25 549 tC (Table 4.1).

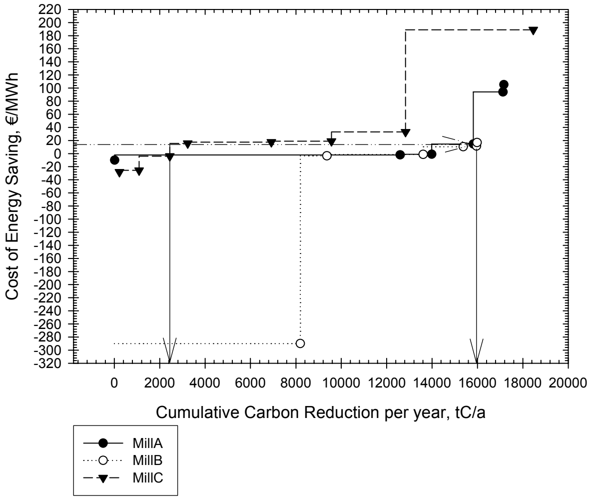

Figure 4.3. Achieved carbon emission reduction per year (tC/a) at different costs of energy saving investments per saved energy amount (€/MWh). A horizontal line with vertical arrows indicates achieved cumulative carbon reductions in the case of mills B and C, when the price of coal and peat is 16 €/MWh (the auxiliary cost of an emission allowance is then 5 €/tCO$_2$ with coal and 20 €/tCO$_2$ with peat).

Table 4.1. Achieved carbon reductions (tC) at the emission allowance price of 0, 5, 15 and 30 €/tCO$_2$ at mills B and C, when main fuel is either peat or coal.

	0 €/tCO$_2$	5 €/tCO$_2$	15 €/tCO$_2$	30 €/tCO$_2$
Mill B		Carbon reduction, tC		
- peat	13 610	13 610	15 964	15 985
- coal	15 964	15 964	15 985	15 985
Mill C		Carbon reduction, tC		
- peat	2 443	2 443	2 443	9 564
- coal	2 443	3 235	9 564	9 564
TOTAL (B+C)		Carbon reduction, tC		
- peat	16 053	16 053	16 053	25 549
- coal	18 407	19 199	25 549	25 549

With regard to the CO_2 emissions abatement achieved with energy saving at three mills, it is important to note that the reduction in CO_2 emissions was targeted to wood at Mill A. Only external electricity was to be purchased from power plants fuelled partly by fossil fuels, such as coal, natural gas etc. Basically, wood fuels are a sink of CO_2 emissions, not a source to the atmosphere, as is the case with fossil fuels, i.e. coal, oil, natural gas or partly fossil peat. This is obvious in circumstances where the growth of CO_2 absorbing biomass is larger than the drain due to natural mortality and fellings. It is true in Finland because the growth of the Finnish forests has exceeded the drain since the 1970s (Finnish Statistical Yearbook of Forestry 2004). In this sense, in Finland, the use of wood for energy purposes in order to replace fossil fuels favours CO_2 abatement in the atmosphere.

In the Finnish pulp and paper industry, the conversion of processed steam and electricity is widely based on a combined heat and power (CHP) conversion. The power to heat -ratio is an important parameter in the CHP conversion. There is a continuous and increasing need for electricity in the pulp and paper industry, due to requirements for paper quality and, more interestingly, for environmental protection. For example, an improved treatment of waste water and the cleaning of flue gas require more electricity due to electric motors of pumps and electrostatic precipitators than was the case earlier when environmental legislation was less regulated. At the same time, improvements in energy efficiency incur lower heat consumption which makes mills more dependent on the procurement of external electricity (Siitonen & Ahtila 2002).

To increase electricity conversion at mills, both efficiently targeted research and development, and subsidies to commercialise new technology are needed. Different ways to improve the power to heat -ratio and thus produce more electricity are the following: raising of steam pressure and temperature in kraft recovery boilers; fuel gasification; drying of moist fuel materials, such as peat, forest residues and bark; using an extraction steam turbine to produce more condensing power at a mill; and integration between industry and the nearby society (Siitonen & Ahtila 2002). The technology of fuel gasification is based on the gasification of fuel in a gasifier and, after cleaning, the use of this gas product in a gas turbine for electricity conversion. In the future, the gasification of wood-based fuels and black liquor will offer a better power to heat -ratio in power conversion when some technical problems, such as the cleaning of the gas product and the corrosion of materials, have been eliminated. A better integration of the heat use for industry and society results higher heat loads in industry and thus yields more electricity while society can utilise more district heat for heating buildings. The pulp and paper industry is a capital-intensive branch of industry. To obtain useful experience, a commercialisation of new technologies requires pilot plants of an industrial size. This is especially true in the applications of new energy technology. At that time, an external financial support, e.g. from public financing organisations, gives a positive signal for the investment decision when other major elements for the investment have been fulfilled. Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market within the European Union offers new business opportunities (e.g. green certificates) and also financial support to possible projects within the pulp and paper industry.

Fuel switching in the sense of environmental conservation means the replacement of fossil fuels with renewable ones. Wood is already largely used in the Finnish pulp and paper industry. However, one clear target for fuel switching is lime kilns where heavy fuel oil is still used as the main fuel. From a technical standpoint, a wood gasifier processing gas products for calcium oxide (CaO) production in a lime kiln can be commissioned (Siitonen & Ahtila 2002). For example, in this study, Mill A would be almost completely run by biofuels, if heavy fuel oil was replaced by saw dust or wood chips in the lime kiln. Of course, other possibilities for fuel switching still exist. The drying of bark, as mentioned earlier and other wood residues improves fuel quality and thus can replace the use of coal and peat at mills. However, fuel switching is either supported or opposed by the following important elements: fuel prices, the environmental legislation, the security of the supply chain of main fuels and the energy technologies available.

4.4 Potential of energy wood and energy saving in the control of CO_2 emissions at the three mills

In Chapters 4.1 and 4.3, it has been found that the procurement of residual forest biomass offers better possibilities to CO_2 abatement than energy saving in the case study of the three mills. At least five times more carbon in residues can be harvested than semi-fossil carbon in peat which can be avoided to be emitted into the atmosphere through energy saving. This is already possible at the emission allowance price of 5 €/tCO_2 when peat is used as fuel. Only when the price of an emission allowance is 15 €/tCO_2 or more, more carbon emission reductions can be achieved through energy saving. However, the overall amount of carbon reductions is then also lower than with the harvesting of residual forest biomass. At the same price of 15 €/tCO_2, almost all cutting sites of forest residues have been harvested. At the European emission allowance markets, the price of CO_2 emission allowance has been more than 25 €/tCO_2 (Pointcarbon 2006a, Nordpool 2006a) recently. Although the most recent market prices have dropped to the level of 16-17 €/tCO_2 (Pointcarbon 2006b, Nordpool 2006b), the price level still favours fuel switching to wood fuels from coal, peat, natural gas and oil.

It is worth to analyze the efficiency of different CO_2 abatement measures. The most efficient ones should be taken into consideration when practical solutions are utilized. In this study, fuel switching into renewable forest residues exceeds the possibilities of energy saving. However, the above finding does not mean that energy saving should be neglected. It must be utilized in all those objects where carbon reductions can be reached in a cost efficient way. The best result is often achieved when the combination of different tools is utilized. The whole process chain must be analyzed in order to find the best possible optimum for the GHG emissions abatement. If the process is not efficient as a whole, i.e. major sinks of GHGs have not been exploited, a good performance in some part of the process is not capable of covering the GHG sources in other parts.

In this study, only aboveground biomass has been included into the biomass category. However, an underground biomass reserve is formed by the roots, and the bigger roots can be utilized for energy, too. According to Hakkila (1976), a potential share of stumpwood was 21 % with pine, 24 % with spruce and 21 % with hardwoods to the stemwood. Thus, theoretically for example, at Mill C on average in 1999-2002, the harvesting of stumpwood would have yielded annually 188 610 solid-m^3 in addition to the annual mean roundwood volume of 819 260 solid-m^3. When at Mill C on average in 1999-2002, the amount of forest residues was at the maximum 211 140 solid-m^3 per year, harvesting of stumpwood could have yielded 53 % more biomass for energy conversion at Mill C. However, the effective recovery of stumpwood is dependent on the amount of reserve trees left in a cutting area after felling, the harvesting technology of stumps used and the site selection. Only large final felling areas with good long-distance transportation routes and spacious wood storage areas are suitable for harvesting stumpwood.

4.5 Learning outcomes of energy saving and CO_2 abatement connected to carbon trading experiments

Carbon trading experiments were included in this study in order to get experience on the combination of energy saving and emissions trading with respect to common understanding and knowledge of non-specialists. The emission trading is one of the abatement elements in the Kyoto Protocol whose aim is to decrease global greenhouse gas emissions, and therefore it should be known by graduates from various fields. In the carbon trading experiments of this study, the number of mills making carbon trades was limited. Basically oligopolistic markets dominated, where only one mill was the evident buyer of emission allowances, and the two other mills that sell their surplus allowances to this oligopoly competed with each other. The true nature of oligopolistic markets was difficult to find for the majority of subjects participated in different game variations. By increasing the amount of mills in the experiment, the effect of an oligopoly situation could have been diminished. This would be possible by collecting more information from other existing mills or by developing unreal data. Due to the complicated nature and long time span of achieving data from existing mills, new mills could not be included in this study. The use of unreal data from imaginary model mills was not available, and also, the use of realistic data on active mills motivated the researcher the most.

It was only possible to achieve reasonable results through the preceding examples on carbon trading and energy saving. This indicated the lowest standard deviations and the best experimental effectiveness in two out of in total three trading institutions traded in 2005. Thus satisfying results could be reached when the experiment was connected to general information on the emission trading and experiments were used as advanced studies, such as in the experiments completed in spring 2005. Then the experiments went deeper into the world of trading with emission allowances. The use of a monetary fee as a way to motivate participants to play more efficiently did not offer remarkably better results in the experiments traded in 2004 than in the ones completed in 2002 and 2005. The double auction variation resulted in the lowest standard deviation and thus the best experimental effectiveness among the three trading institutions. An auction is the most realistic experiment variation among three institutions because the effective trading with emission allowances takes place through brokers or stock exchange of emission allowances. The purchase of emission allowances seldom happens straight from the seller of the allowances on the markets with many parties.

The main conclusion of experiments was that the carbon trade and its consequences were largely unknown to students with background knowledge in forestry or economics. The conclusion shows that, in general, a demanding exercise to train societies on different aspects of global warming is becoming increasingly necessary. Among different instruments, experiments are a practical tool to demonstrate economic instruments on global warming, such as the carbon trading, to different possible interest groups, e.g. students of natural sciences. Their educational possibilities should not be underestimated because experiments highlight important aspects from economical phenomena. After all, just giving information on different aspects of global warming does not offer personal participation or stimulus to revise attitudes. Economic experiments, such as presented in this study, simplify the whole spectrum of emissions trading, but at the same time they set a participant into a role of an economic decision maker. The processes of this decision system need to be analysed more in order to improve its efficiency. However, interactive experiment systems bring the problem close to a participant and require deeper involvement than only participating in lectures on emissions trading.

The trading experiments clearly revealed difficulties to see the consequences of one's own economic decisions from the environmental point of view. This may indicate difficulties to combine energy saving and the trading of emission allowances. A survey made among the Finnish stakeholders (Kankaanpää et al. 2005) showed that spreading information on climate change and adaptation issues was valued as the third most important measure to enhance adaptation after taking measures through research and the integration of climate change issues into planning at all levels. More information on different aspects of climate change is produced but some synthesis on the whole issue and real adaptation strategies over different sectors of the societies are desperately needed.

The logical way for emissions abatement presented in this study consists of three steps. The steps have also larger, more universal interfaces than just the three examples of this study. The first step is to harvest residual forest biomass and replace fossil fuels with wood energy. The second step is to introduce technical innovations into energy conversion and processing units in order to save energy converted from fossil and renewable fuels and decrease emissions originating from the combustion of fossil fuels. The third step is to trade additional emissions allowances, resulted from the fuel switching and the energy saving, to the emission markets in order to decrease costs for investments on the above saving technologies. All possible interest groups should be educated with above or similar examples which present measurable abatement actions with realistic economic key figures. Then those groups should perform economic experiments where they judge between different alternatives and trade emission allowances. In order to trade efficiently they need basic information on abatement alternatives and their costs, and basic information on trading principles of emission allowances. Especially the basic information on differences in mitigation costs between participants should be emphasized as a fundamental reason for the trading of emission allowances. Also the interconnection between the number of emission allowances and the emission constraint set to the activity producing GHGs should be highlighted.

The trading of emission allowances develops into the direction of normal commodities markets when the markets for allowances are big enough and trading rules are widely accepted. Then the trading of allowances takes place in different stocks around the world. If the trading of raw materials, such as oil, coal, natural gas etc. that causes global warming is a normal business, the more vital is the international trading of emission allowances in order to control excess use of those materials. The trading should be developed into the direction of true state capitalism, because every citizen participates in the economic experiment by supplying different commodities. Again citizens need to be educated to understand the causes and effects of their economic choices. They have to be offered real alternatives and be encouraged to invest into renewable and sustainable energy and other activities. The state capitalism which highlights environmentally efficient ways to use energy for housing, transportation, nutrition, manufacturing and delivering of different commodities and recreation etc. should be valued by nations and businesses. Especially those nations and businesses interested in improving their economic, social and ecological welfare should develop means for their citizens and customers to take efficient and measurable actions towards sustainable societies. For example, concerning long-term saving, the quality and a comparison of different saving objects should be improved. Private citizens should be informed by public and independent bodies from implications of their economic choices also from the environmental point of view.

4.6 Some ecological remarks on energy wood procurement

The carbon in forest residues has a major potential for the replacement of fossil carbon in the energy conversion at the mills. However, some important aspects have to be taken into consideration. With regard to the general consequences to forest ecosystems, e.g. nutrient losses of forest soil, when branches, needles and even stumps are taken away from the forest without mineralization of useful nutrients from residues and stumps into forest soil, have to be considered. Needles contain significant amounts of useful nutrients, such as nitrogen, phosphorus, potassium, calcium and magnesium (Mälkönen et al. 2001). When part of these nutrients is not mineralized and all carbon in residues is not recycled back to ecosystems, biodiversity in flora and fauna is lost. Residues are often collected with needles, because leaving them on a cutting site until needles have dropped away leads to losses of dry matter content and thus smaller yield of residues. However, if the removal of residues is mainly targeted to final fellings and to quite fertile soils, losses in forest growth remain reasonable, especially with pine (Mälkönen et al. 2001). The growth of spruce reacts more intensely to the removal of needles on fertile soils, but a good regeneration result of a new wood generation due to the removal of cutting residues may compensate the losses. A large scale removal of forest residues has taken place in Finland mainly since the 1990s and major nutrient losses of forest soils develop after several years of harvesting. Thus, it is important to observe the nutrient concentrations in forest soils for long periods of time. Also changes in biodiversity should be studied in long-term field experiments.

Wood and bark ash is a by-product of the combustion process. It contains the nutrients which can be found in living wood, except for nitrogen which is lost during the combustion stage. Thus ash is a useful, natural fertilizer, which should be taken back to forest soils. The best result is achieved on forested peat lands, where nitrogen is available for wood growth. However, on mineral soils nitrogen is often the limiting factor and ash spreading without the addition of a nitrogen fertilizer does not offer an adequate growth impulse (Mälkönen et al. 2001). One negative aspect of returning ash back to the forest is the difficulty to keep ashes originating from fossil fuels separated from wood and bark ash. Ashes from fossil fuels contain a larger amount of heavy metals, such as cadmium and lead, than wood and bark ash, and an accumulation of these metals in forest soils must be avoided (Hakkila 1986). Also wood and bark ash contain heavy metals whose effects are still not known well enough. If ash spreading becomes a regular practice, and if ash is spread out in a much wider scale than it is done nowadays (Mälkönen et al. 2001), more research on long-term effects is needed.

The procurement of forest residues requires fossil fuel inputs, such as light fuel oil and diesel oil. Forest operations are performed with harvesters, forwarders, truck mounted chippers and bundling machines of residues. Nowadays, these machines use either fossil light fuel oil or fossil diesel oil as their energy source. Again, the long-distance transportation is mainly carried out by timber trucks which use diesel oil as fuel. The fuels are fossil ones which emit harmful fossil carbon to the atmosphere. However, according to the study by Wihersaari & Palosuo (2000), greenhouse gas emissions of logging operations were small, 4-7 kg CO_2-equivalent/MWh produced by wood fuel. Also according to the study by Villa (2000), logging operations were efficient, because the share of emitted fossil carbon from harvesting machinery was 2-3 % on the carbon absorbed into woody biomass and harvested for energy use. On the other hand, the greenhouse gas emissions of the different transportation chains vary, so the GHG emissions of the waterway and railway transportation were smaller per transported wood volume and kilometre than the ones of the road transportation (Karjalainen & Asikainen 1996, Villa 2000). The railway and waterway transportation is seldom performed without the road transportation by a truck to a loading place of the above transportation systems. However, due to environmental reasons, further development of these environmentally friendly transport alternatives connected with the road transportation should be continued. Also an introduction of bio-based transportation fuels, such as ethanol, methanol and bio-diesel from renewable and waste resources, shoud be accelerated in order to introduce more renewable biofuels.

4.7 Some concluding remarks on ecology, energy and innovations

As ecological and general remarks of this study, it can be stated:

- A pressure to utilize more wood energy from the Finnish forests increases due to the continuous high price of fossil fuels, especially oil, and a big demand of energy in forest industry and also in other sectors of the society;
- An increased use of wood energy from forests affects natural ecosystems also with negative effects;
- Due to the enormous energy demand of societies and for environmental reasons, it is vital to diversify energy sources with energy crops from agriculture, organic wastes, agricultural and food processing residues and manure (see Biomass action plan 2005). Also the recycling of different wood industry residues can still be improved;
- No amount of energy is enough to cover all the energy consumption of modern societies if converted energy is wasted due to a free-and-easy attitude and an energy-guzzling technology;
- New innovative technologies – both technological and social – need to be subsidized and promoted at all levels of energy conversion and processing;
- Because of the complex effects of global warming on environmental and socio-economic systems, a persistent and careful education effort based on extensive scientific evidence should be extended to cover all people from specialists to non-specialists.

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APPENDIX 1

The calculation values of logging costs.

	Roadside chipping	**Residue log**
Other costs		
Organization costs	1.35 €/m^3	0.70 €/m^3
Cutting into piles	0.30 €/m^3	0.30 €/m^3
Recovery of residues	70 %	70 %
Baling of residues	---	3.40 €/residue log
Transportation of baling machine	---	63.90 €/stand
Forest haulage		
Load size, m^3	7.8	20 residue logs
Hourly cost	52.60 €/h	51.30 €/h
Transportation of machines	64.00 €/stand	64.00 €/stand
Long-distance transportation		
Load size	44 m^3	68 residue logs
Loading time	96 min.	45 min.
Unloading time	30 min.	21 min.
Hourly driving cost	76.50 €/h	70.00 €/h
Loading&unloading cost	53.80 €/h	57.30 €/h
Chipping		
Cost	5.05 €/m^3	1.70 €/m^3
Transportation of chipper	47.10 €/stand	---

APPENDIX 2 D

Bilateral trading with open exchange of information: regulations and general instructions

Today we will play a bilateral trading game with an open exchange of information. The fundamental fact of the game is that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1) and in addition, a graphic illustration on the curves of all mills (see Figure 2). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg). The investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of the particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents annual cumulative carbon emission tonnes (unit tC/a), where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points, but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

In the game you are the manager of the mill's emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill D** (the chemical pulp mill), whose constraint is **17 500 tonnes of carbon annually**. The constraint of Mill E is between 16 594 and 18 829 tonnes of carbon annually and the constraint of Mill F is between 11 630 and 15 362 tonnes of carbon annually.

You have 20 minutes to study the material you received. The actual game takes place after that. In order to avoid information leakages and other misunderstandings, participants are not allowed to speak to each other, but exchange information with written documents. The main principle is that on each paper you write only one bid. When a mutual understanding between subjects has been reached, the pair informs the result to the supervisor. The supervisor reports the result to the whole group. One trade can take place as in the following example: Mill D sells 500 tonnes of carbon at a price of 60 €/tC to Mill F.

D

If Mill F accepts the bid, he returns the piece of paper with the answer “YES” to Mill D. After that, the pair gives the paper to the supervisor, who writes it down for the whole group to see. If the answer is “NO”, the paper returns back to Mill D, who can make a new bid to Mill F or maybe to Mill E. The participant can give two bids simultaneously to both subjects, if he chooses so. If this does not happen, the subject not receiving any bid can think of his next move and can make his bid, if he chooses so. If a participant has something to ask concerning the game procedure, he can ask permission from the supervisor by lifting his hand. The supervisor will come to the subject.

The game ends when no new bids are made.

FIGURE 2

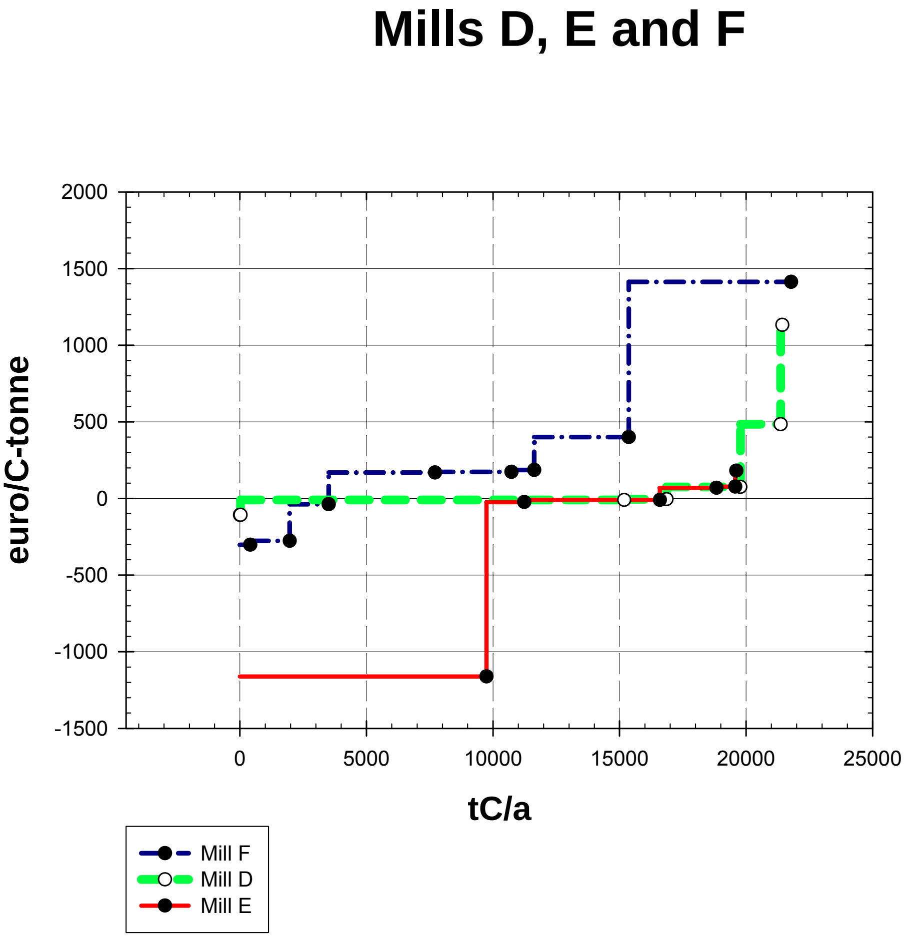
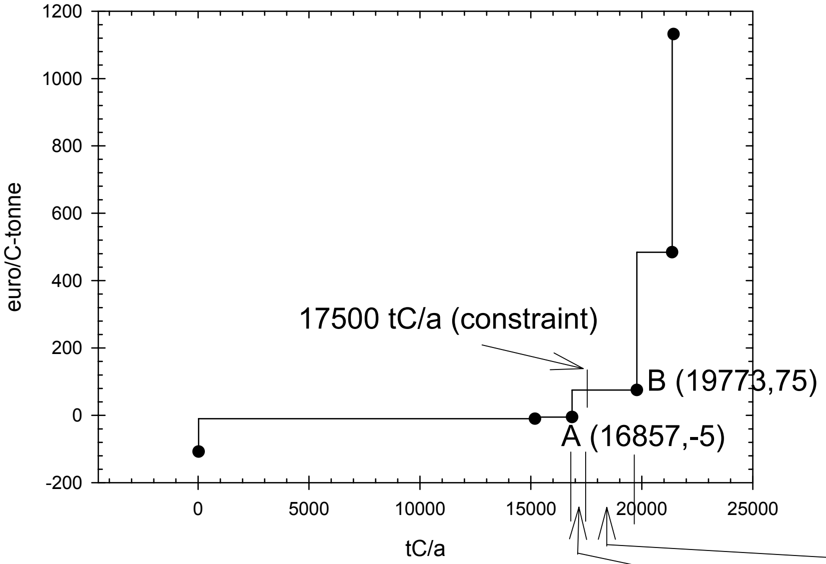

Mills D, E and F
2000
1500
1000
500
0
-500
-1000
-1500
0
5000
10000
15000
20000
25000
euro/C-tonne
tC/a
Mill F
Mill D
Mill E

FIGURE 1

MILL D



You can only choose between two alternative gaming strategies:

You choose **EITHER** point **B**, when you can sell 2 273 tonnes (19773-17500) of carbon emission licences (tC/a) at the best possible price
OR
You choose point **A**, when you buy 643 tonnes (17500-16857) of carbon emission licences at a price not higher than 75 euro per C-tonne.

Double auction: regulations and general instructions

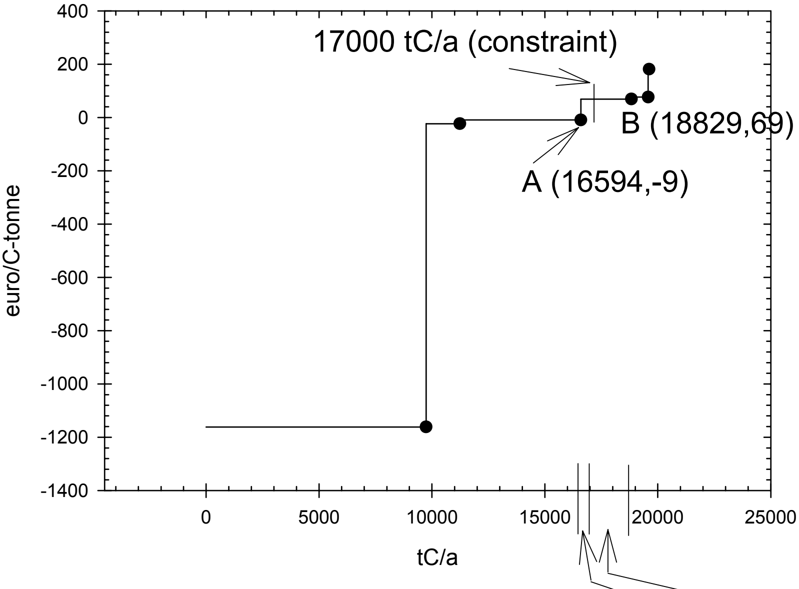
Double auction is a gaming variation where each participant plays independently, without knowing the actions of the other participants before they are revealed. Today we will play a double auction game with limited exchange of information. The fundamental fact of the game is that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into the mill´s technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg). The investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of the particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents the annual cumulative carbon emission tonnes (unit tC/a) where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

In the game you are the manager of the mills's emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill E** (the chemical pulp mill and paper machines) whose constraint is **17 000 tonnes of carbon annually**. The constraint of Mill D is between 16 857 and 19 773 tonnes of carbon annually and the constraint of Mill F is between 11 630 and 15 362 tonnes of carbon annually.

You have 20 minutes to study the material you received. After a 20 minute examination, the actual auction proceeds when the auctioneer opens the auction and calls for the subjects to make their bids. A bid can either be a buying or a selling bid, and it should contain information about the amount of the licences and on the price of that lot. The main principle in the auction is that the price of each buying bid is higher than the price of previous buying bids and on the other hand, the price of each selling bid must be lower than the price of previous selling bids. In this way the auction proceeds in a rational way. When you make your bid, please use the capital letter assigned to your mill. You can find the letter printed on the upper right side on your instruction paper. The subject accepting the bid should raise his/her hand immediately after seeing the bid. After that, the auctioneer gives the subject the permission to address everyone. No other loud speaking is allowed from the subjects during the auction. The selling bid can be as in the following example: Mill D sells 1000 tonnes of carbon licences at a price of 50 €/tonne of carbon and the the buying bid: Mill E buys 500 tonnes of carbon at the price of 150 €/tonne of carbon. Both bids are written on the blackboard for everyone to see. By raising your hand, you get the auctioneer’s attention, and after his permission you may state: Mill E accepts the bid of Mill D. The accepted bid is recorded on the blackboard and at the same time, other bids are no longer accepted. The game will continue until all contracts are completed.

FIGURE 1

MILL E



You can only choose between two alternative gaming strategies:

You choose **EITHER** point **B**, when you can sell 1 829 tonnes (18829-17000) of carbon emission licences (tC/a) at the best possible price
OR
You choose point **A**, when you buy 406 tonnes (17000-16594) of carbon emission licences at a price not higher than 69 euro per C-tonne.

F

Bilateral trading with limited exchange of information: regulations and general instructions

Today we will play a bilateral trading game with a limited exchange of information. The fundamental fact of the game is the information that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into the mill´s technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg). The investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of this particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents the annual cumulative carbon emission tonnes (unit tC/a) where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

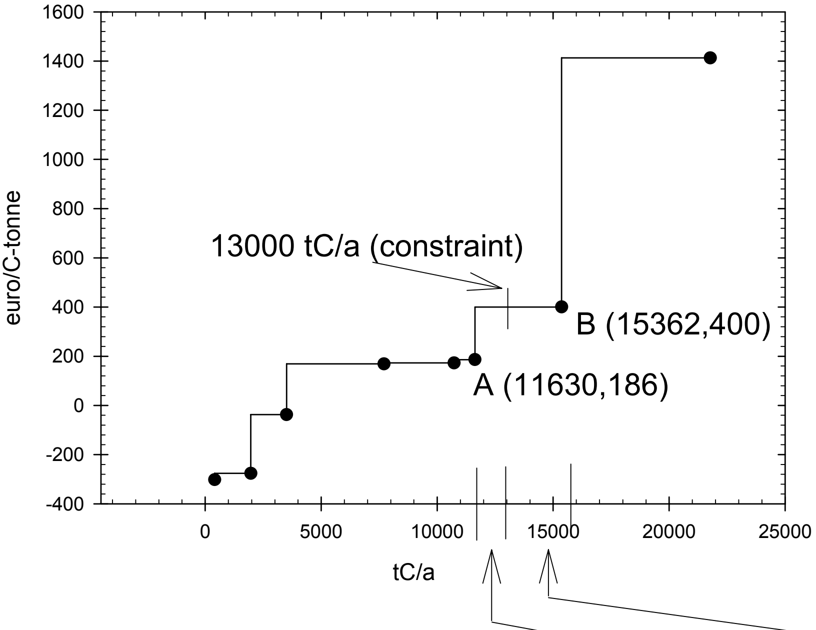
In the game you are the manager of the mill’s emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill F** (the chemical and mechanical pulping, paper and cardboard machines), whose constraint is **13 000 tonnes of carbon annually**. The constraint of Mill D is between 16 857 and 19 773 tonnes of carbon annually and the constraint of Mill E is between 16 594 and 18 829 tonnes of carbon annually.

You have 20 minutes to study the material you received. The actual game takes place after that. In order to avoid information leakages and other misunderstandings, participants are not allowed to speak to each other but exchange information with written documents. The main principle is that on each paper you write only one bid. When mutual understanding between subjects has been reached, the pair informs the result to the supervisor. The supervisor reports the result to the whole group. One trade can take place as in the following example: Mill D sells 500 tonnes of carbon at the price of 60 €/tC to Mill F. If Mill F accepts the bid, he returns the piece of paper with the answer “YES” to Mill D. After that, the pair gives the paper to the supervisor, who writes it down for the whole group to see. If the answer is “NO”, the paper returns back to Mill D, who can make a new bid to Mill F or maybe to Mill E. The participant can give two bids simultaneously to both subjects, if he chooses so. If this does not happen, the subject not receiving any bid can think of his next move and can make his bid, if he chooses so. If a participant has something to ask concerning the game procedure, he can ask permission from the supervisor by lifting his hand. The supervisor will come to the subject.

The game ends when no new bids are made.

FIGURE 1

MILL F



You can only choose between two alternative gaming strategies:

You choose **EITHER** point **B**, when you can sell 2 362 tonnes (15362-13000) of carbon emission licences(tC/a) at the best possible price
OR
You choose point **A**, when you buy 1 370 tonnes (13000-11630) of carbon emission licences (tC/a) at a price not higher than 400 euro per C-tonne.

APPENDIX 3

General instructions of the carbon trading games

Carbon trading is an instrument that can be used to achieve a reduction of harmful greenhouse gases in a cost effective way. Carbon trading is based on the fact that companies under the trading scheme have different costs to decrease their greenhouse gas emissions. This difference in reduction costs enables the trading of emission allowances which give a right for their holder to emit greenhouse gases into the atmosphere.

In order to demonstrate emissions trading, a carbon trading game has been developed. In this game, real costs and real carbon reductions of three Finnish forest mills are utilized in a way where investments to save energy and investment costs of those energy saving projects are used as an information source for the games. Each energy saving investment reduces the use of fuels at the mill and thus reduces harmful carbon emissions (unit tC/annum) to the atmosphere. Each investment has a cost (unit euro/C-tonne) which is needed to achieve the reduction of carbon emissions. In the carbon trading game, by making the energy saving investment, you get surplus emission allowances which you can sell to other mills and thus reduce your investment costs.

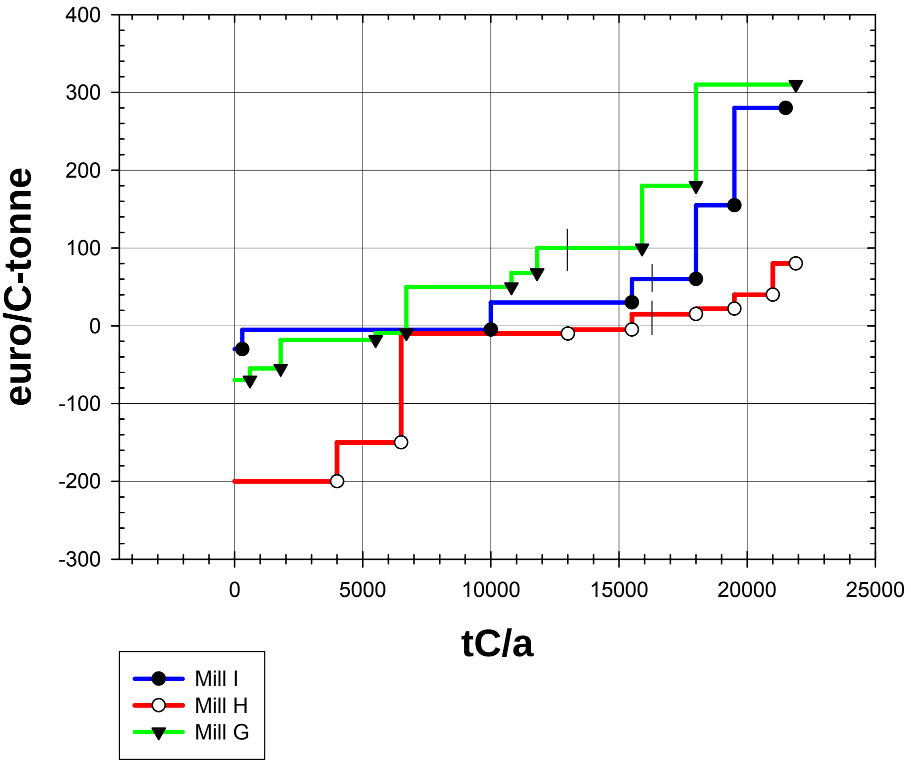
In the trading game, each mill has its own personal cost curve which is based on the individual energy saving investments (step wise –curve). The game has been formulated in such a way that one mill has only the option of buying allowances because of very high costs to achieve its emission constraint, and it has to buy those allowances from one of the other two mills. In most gaming alternatives, a problem emerges from the fact that you do not know whether to buy or sell allowances, because you only know your own cost curve, but not the others'. You have to find out your position by sending buying or selling bids to other participants in order to see whether your reduction costs are higher or lower than theirs. If your investment costs for carbon reduction are higher than of the other two, you should buy allowances from that mill offering the cheapest price. On the contrary, if your reduction costs are lower than of the other mill, you should sell your allowances to that mill at the best possible price, at least at the minimum price exceeding your own investment costs.

Each mill has its own carbon emission constraint ordered by the authorities in charge of emissions trading. This constraint **must** be fulfilled by the mill. The constraint has been set so that you have to buy or sell in order to fulfill your constraint. If you find out that your reduction costs are lower than the other mill, you pay to invest in energy saving. At the same time, you fulfill your constraint, but you can sell the surplus allowances in order to reduce your investment costs. In the actual game, a situation might build up where you cannot sell all your surplus allowances. That should not stop you trading because it is always beneficial to sell at a price higher than you paid yourself, when you made an investment. As a concession, you might sell the small amount of remaining allowances at a lower price than your cost, if you have sold a large share of your allowances at a higher price than you paid earlier when you made an energy saving investment. One option might also arise where you cannot sell the surplus allowances although you made your investment. Then the other mill sold their whole surplus to the third mill at a price which was not possible for you to beat or match. That is not a problem either because it is not wise to sell at a lower price than you paid yourself, when you made your energy saving investment. If after all, you did so, you have lost the game.

Your investment costs to achieve carbon reduction might be higher than of the other mills. If this is the case you should then buy just the amount of emission allowances you need to fulfill your constraint. Do not buy more than you need because you cannot sell them at a satisfying price to the other mills. You do not get any compensation for the extra allowances you bought. Naturally, you buy your missing allowances at a lower price than your own investment costs would have been if you had made your energy saving investment yourself. If you bought them at the price higher than your own investment costs were, you have lost your game.

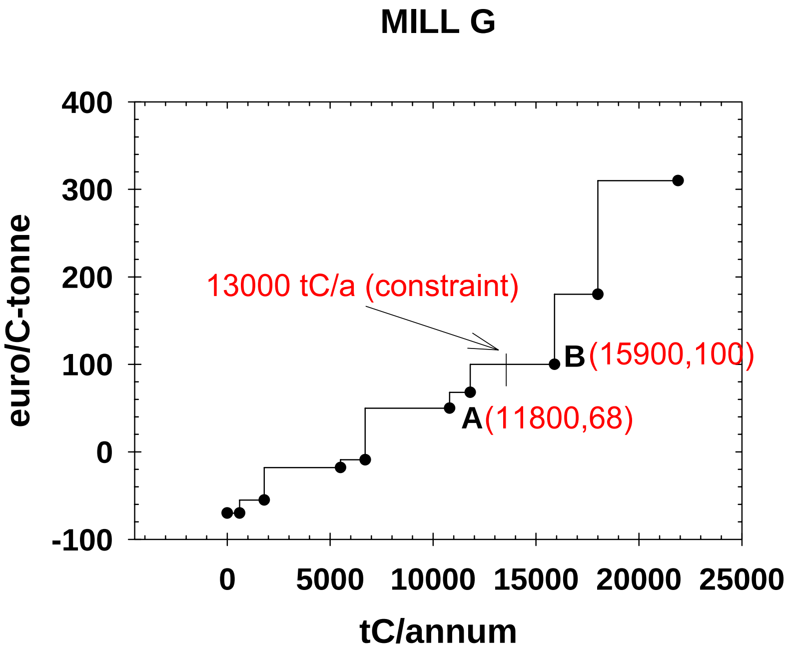
After these instructions, there is an Appendix where you can see the cost curves and carbon reductions of the fictitious mills (Example 2) and the fictitious gaming instructions (Example 1) of each mill. The fictitious examples do not connect to actual games, but they show how actual games work. Before the actual game, you obtain **either** the new gaming instruction (such as Example 1) **or** the new gaming instruction (such as Example 1) **and** the cost curves of the three real mills (such as Example 2). In addition, you get general instructions for all the mills which are used in the actual game. During the actual game, you may become the environmental manager of any one of the mills.

Example 2



Mills G, H and I

Example 1



You can only choose between two gaming strategies:

You choose **EITHER** point **B**, when you can sell 2 900 tonnes (15 900 - 13 000) of carbon emission licences (tC/annum) at the best possible price

OR

You choose point **A**, when you buy 1 200 tonnes (13 000-11 800) of carbon emission licences at the maximum price of 100 euro/C-tonne.

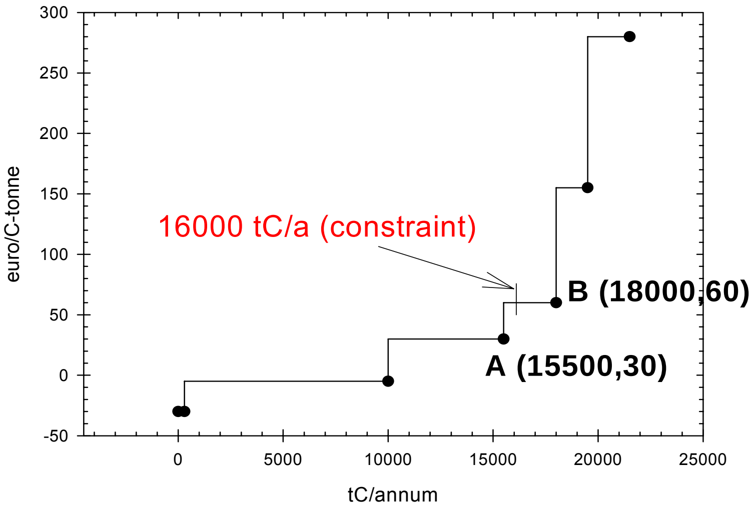
ALTERNATIVES:

B: **investment** ► possibility to sell 2 900 tonnes, the lowest selling price 101 €

A: **no investment** ► have to buy 1 200 tonnes, the maximum buying price 99 €

Example 1

MILL I



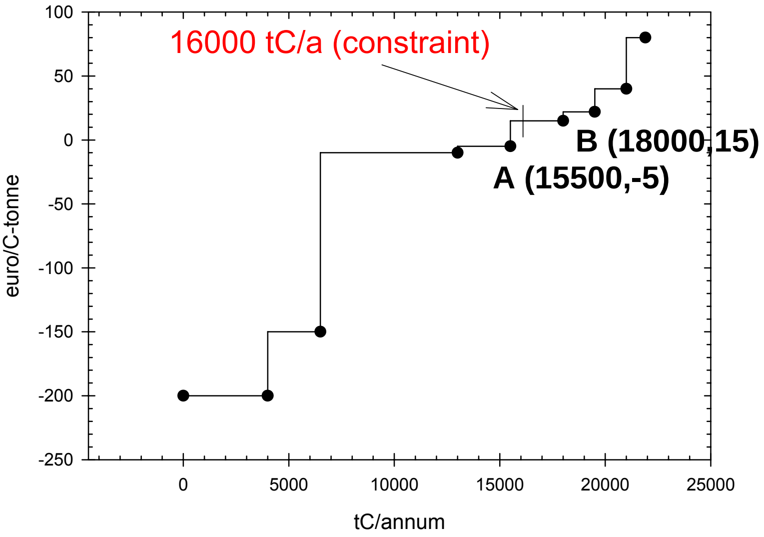
You can only choose between two gaming strategies:

You choose **EITHER** point **B**, when you can sell 2 000 tonnes (18 000 - 16 000) of carbon emission licences (tC/annum) at the best possible price
OR
You choose point **A**, when you buy 500 tonnes (16 000-15 500) of carbon emission licences at the maximum price of 60 euro/C-tonne.

ALTERNATIVES:
B: **investment** ► possibility to sell 2 000 tonnes, the lowest selling price 61 €
A: **no investment** ► have to buy 500 tonnes, the maximum buying price 59 €

Example 1

MILL H



You can only choose between two gaming strategies:

You choose **EITHER** point **B**, when you can sell 2 000 tonnes (18 000 - 16 000) of carbon emission licences (tC/annum) at the best possible price
OR
You choose point **A**, when you buy 500 tonnes (16 000-15 500) of carbon emission licences at the maximum price of 15 euro/C-tonne.

ALTERNATIVES:
B: **investment** ► possibility to sell 2 000 tonnes, the lowest selling price 16 €
A: **no investment** ► have to buy 500 tonnes, the maximum buying price 14 €

Bilateral trading with a limited exchange of information: regulations and general instructions (**Mill G**)

Today we will play a bilateral trading game with a limited exchange of information. The fundamental fact of the game is the information that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into the mill´s technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg) when from the investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of the particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents the annual cumulative carbon emission tonnes (unit tC/a) where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points, but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

In the game you are the manager of the mill’s emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill G** (the chemical pulp mill), whose constraint is **x tonnes of carbon annually**. The constraint of Mill H is between h and i tonnes of carbon annually and the constraint of Mill I is between j and k tonnes of carbon annually.

You have 20 minutes to study the material you received. The actual game takes place after that. In order to avoid information leakages and other misunderstandings, participants are not allowed to speak to each other, but exchange information with written documents. The main principle is that on each paper you write only one bid. When mutual understanding between subjects has been reached, the pair informs the result to the supervisor. The supervisor reports the result to the whole group. One trade can take place as in the following example: Mill G sells 500 tonnes of carbon at the price of 60 €/tC to Mill I. If Mill I accepts the bid, he returns the piece of paper with the answer “YES” to Mill G. After that, the pair gives the paper to the supervisor, who writes it down for the whole group to see. If the answer is “NO”, the paper returns back to Mill G, who can make a new bid to Mill I or maybe to Mill H. The participant can give two bids simultaneously to both subjects, if he chooses so. If this does not happen, the subject not receiving any bid can think of his next his move and can make his bid, if he chooses so. If a participant has something to ask concerning the game procedure, he can ask permission from the supervisor by lifting his hand. The supervisor will come to the subject.

The game ends when no new bids are made.

Bilateral trading with a limited exchange of information: regulations and general instructions (**Mill H**)

Today we will play a bilateral trading game with a limited exchange of information. The fundamental fact of the game is the information that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into the mill´s technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill, whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg) when from the investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of the particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents the annual cumulative carbon emission tonnes (unit tC/a) where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

In the game you are the manager of the mill's emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill H** (the chemical pulp mill and paper machines), whose constraint is **x_0 tonnes of carbon annually**. The constraint of Mill G is between f and g tonnes of carbon annually and the constraint of Mill I is between j and k tonnes of carbon annually.

You have 20 minutes to study the material you received. The actual game takes place after that. In order to avoid information leakages and other misunderstandings, participants are not allowed to speak to each other, but exchange information with written documents. The main principle is that on each paper you write only one bid. When mutual understanding between subjects has been reached, the pair informs the result to the supervisor. The supervisor reports the result to the whole group. One trade can take place as in the following example: Mill G sells 500 tonnes of carbon at the price of 60 €/tC to Mill I. If Mill I accepts the bid, he returns the piece of paper with the answer "YES" to Mill G. After that, the pair gives the paper to the supervisor, who writes it down for the whole group to see. If the answer is "NO", the paper returns back to Mill G, who can make a new bid to Mill I or maybe to Mill H. The participant can give two bids simultaneously to both subjects, if he chooses so. If this does not happen, the subject not receiving any bid can think of his next move and can make his bid, if he chooses so. If a participant has something to ask concerning the game procedure, he can ask permission from the supervisor by lifting his hand. The supervisor will come to the subject.

The game ends when no new bids are made.

Bilateral trading with a limited exchange of information: regulations and general instructions (**Mill I**)

Today we will play a bilateral trading game with a limited exchange of information. The fundamental fact of the game is the information that the mill belonging to the forest consolidated corporation can reduce its carbon (C) emissions by investing into the mill´s technical facilities in order to improve its energy efficiency. The investments to improve the energy efficiency, on the other hand, reduce the use of energy fuels and thus carbon emissions as a result of the reduced use of those fuels. Each participant represents one mill whose cost curve he receives both as a graphic and as a numerical illustration useful for the game (see Figure 1). The value on the vertical axis of the cost curve (y-axis) is a net value of one energy saving investment per saved emission tonne (1000 kg) when from the investment cost of one energy saving project was deducted from the monetary saving value in the energy bill as a result of the particular investment. The net value above was further divided by the emission amount which was not emitted to the atmosphere as a result of that particular investment. Thus the unit of the vertical axis is euro per carbon tonne (unit euro/C-tonne). The horizontal axis (x-axis) of the curve represents the annual cumulative carbon emission tonnes (unit tC/a) where the carbon emission reduction of the one particular energy saving investment is the difference between two successive horizontal points on the curve. On the curve you can see many x-y points but for this game only one energy saving investment has been chosen and the carbon emission reduction (unit tC/a) has been linked to this investment.

In the game you are the manager of the mill’s emissions trading unit. Your task is to fulfill your carbon emission constraint ordered by the authorities in charge of issuing emissions licences to the causes of the emissions. You can fulfill your constraint in a financially efficient way **either** by making the energy saving investment and selling the surplus above your constraint to the other mills **or** by purchasing the amount of licences you need from the other mill in order to reach your constraint. There are two important criteria for gaming: selling or purchasing the emission licences depending on which is financially viable to your mill and which will fulfill the specific emission constraint ordered to your mill. You represent **Mill I** (the chemical and mechanical pulping, paper and cardboard machines), whose constraint is **x_1 tonnes of carbon annually**. The constraint of Mill G is between f and g tonnes of carbon annually and the constraint of Mill H is between h and i tonnes of carbon annually.

You have 20 minutes to study the material you received. The actual game takes place after that. In order to avoid information leakages and other misunderstandings, participants are not allowed to speak to each other, but exchange information with written documents. The main principle is that on each paper you write only one bid. When mutual understanding between subjects has been reached, the pair informs the result to the supervisor. The supervisor reports the result to the whole group. One trade can take place as in the following example: Mill G sells 500 tonnes of carbon at the price of 60 €/tC to Mill I. If Mill I accepts the bid, he returns the piece of paper with the answer “YES” to Mill G. After that, the pair gives the paper to the supervisor, who writes it down for the whole group to see. If the answer is “NO”, the paper returns back to Mill G, who can make a new bid to Mill I or maybe to Mill H. The participant can give two bids simultaneously to both subjects, if he chooses so. If this does not happen, the subject not receiving any bid can think of his next move and can make his bid, if he chooses so. If a participant has something to ask concerning the game procedure, he can ask permission from the supervisor by lifting his hand. The supervisor will come to the subject.

The game ends when no new bids are made.