



# Energy Saving and Carbon Trading - Two Ways to Control CO<sub>2</sub> Emissions in the Finnish Forest Industry

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**Interim Report**

**IR-05-009**

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**Energy Saving and Carbon Trading —  
Two Ways to Control CO<sub>2</sub> Emissions  
in the Finnish Forest Industry**

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2 March 2005

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## Abstract

The major effort of international environmental politics is to control of greenhouse gas (GHG) emissions. Those industrialized countries that have ratified the Kyoto Protocol (KP) are committed to reducing their GHG emissions during the first commitment period of 2008–2012. To reach reduction targets, one of the mechanisms accepted in the KP was emissions trading. Trading offers cost savings to producers of GHGs who are responsible for decreasing their emissions. Each economic unit has its own marginal cost for reductions of GHG emissions, and this variation in abatement costs between different producers' profits the selling and buying of emission licenses on emission markets.

The pulp and paper industry is one of those branches of industry that has to reduce its GHG emissions, mainly carbon dioxide (CO<sub>2</sub>). In this study two ways of controlling CO<sub>2</sub> emissions were investigated: energy saving and carbon trading. The study objects were three Finnish mills of the forest consolidated corporation: (1) a chemical pulp mill with a sawmill, (2) a chemical pulp mill with two paper machines, and (3) an integrate containing mechanical and chemical pulping, paper machines of woodfree and wood-containing paper grades, cardboard production and a sawmill. According to reports delivered to MOTIVA (Information Center for Energy Efficiency) in Finland, reductions in CO<sub>2</sub> emissions resulting from energy saving by means of technical improvements in processes were calculated, and were in total 230,341 tCO<sub>2</sub> (of which 78,246 tCO<sub>2</sub> was from wood) at the previously mentioned mills. Total CO<sub>2</sub> emissions of both bio- and fossil fuels were, on average, 3,913,446 tCO<sub>2</sub>, of which 357,948 tCO<sub>2</sub> originated from fossil fuels.

Carbon trading was simulated with carbon trading games played between the above-mentioned mills. Three different institutions for trading were tested, namely, bilateral trading with open information, bilateral trading with restricted information and double auction with restricted information. The more information on abatement costs of the other mills a participant had, the more profitable was trading for the mill represented by a participant. Carbon trading was mainly a tool to help the mills to reduce their abatement costs, contrary to the situation if they had just invested in abatement technology themselves without trading.

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## **About the Author**

Aki Villa has a licentiate degree in forestry. He is currently working for a doctoral degree as a researcher in the Faculty of Forestry, University of Joensuu, Finland. During the summer of 2002 Aki Villa was a participant in IIASA's Young Scientists Summer Program where he prepared the main part of the report. His supervisor was Michael Obersteiner from IIASA's Forestry Program. Aki Villa's main research interests are the control of CO<sub>2</sub> emissions with energy saving, emissions trading and fuel switching from fossil fuels to renewable ones, especially forest residues from logging operations of commercial roundwood. The focused study object is the Finnish forest industry, especially the pulp and paper industry.

# **Energy Saving and Carbon Trading — Two Ways to Control CO<sub>2</sub> Emissions in the Finnish Forest Industry**

Aki Villa

## **1 Introduction**

The increase in greenhouse gas (GHG) emissions to the atmosphere is a threat to living ecosystems. Changes in air, soil and water fluxes also affect the well-being of human beings. Combustion of fossil fuels, especially oil and coal, in order to produce energy is a key factor in the rising temperature of the atmosphere. The most important GHG, carbon dioxide (CO<sub>2</sub>), is a residue of this combustion process and a main factor in GHG emissions causing a rise in the global temperature of the atmosphere. The control of GHG emissions is vital for mitigating the negative effects of global warming. To reach measurable results, this control must include technical, economic, political and social actions.

This study concentrates on energy production and use in the Finnish forest industry. Here, the forest industry covers mainly the pulp and paper industry, as well as the sawmill industry if related to pulp production as a producer of raw material, wood chips. A sawmill is then located in the same complex as a pulp and/or paper mill. The pulp and paper industry purchases energy from its own production, namely by burning residues, such as bark and black liquor, in recovery and bark boilers. In addition, owing to inadequate production capacity at mills, energy is purchased from external companies, especially in the form of electricity. In Finland, in 2001, industry made up 53% (43,009 GWh) of all electricity consumption (Energy Statistics, 2002), and of the electricity consumed by Finnish industry the pulp and paper industry covered 55% (23,789 GWh). For 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). Thus, energy saving is a justified way of controlling energy costs and also decreasing GHG emissions. The key issue in this study is energy saving linked to the reduction in CO<sub>2</sub> emissions.

Control of GHG emissions is an international task due to the even distribution of sources emitting GHGs throughout the globe and due to free circulation of these gases in the atmosphere. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) was agreed upon in 1997 as a goal to reduce GHG emissions to the atmosphere. This protocol includes different mechanisms, such as joint implementation (JI), clean development mechanism (CDM), and emissions trading, all



of which aim at softening the economic adjustment of industrialized countries (in the protocol, Annex 1 countries) for reducing their GHG emissions (see Grubb *et al.*, 1999). In this study carbon trading was investigated as a tool to decrease the costs of GHG abatement. The study objects were three Finnish pulp and/or paper mills of the forest consolidated corporation. These plants should be part of the EU's preliminary GHG trading scheme starting in 2005 (see CEC, 2001), since the pulp and paper industry belongs to the activities mentioned in this directive.

The basis for tradable reductions of CO<sub>2</sub> emissions was linked to energy saving, because the amount of tradable reductions in carbon emissions is dependent on the amount of fuels used for energy production. Saved energy means less CO<sub>2</sub> emissions compared to previous development and thus possibilities to trade additional emissions over the mill specific constraint. This study continues a research tradition similar to that illustrated in the book "Factor Four Doubling Wealth — Halving Resource Use" (von Weizsäcker *et al.*, 1998). The purpose of this book was to ensure social and economic welfare by producing goods and services with more efficient and sustainable means. Besides energy saving, fuel switching to renewable energy sources prevents the negative impacts of global warming. According to previous studies (Hall *et al.*, 1991, Houghton 1996, Obersteiner *et al.*, 2001), the use of biomass, rather than fossil fuels, in energy production stabilizes atmospheric concentrations of GHGs more effectively than merely sequestering carbon into terrestrial sinks, namely into living biomass.

## **2 Materials and Methods**

### **2.1 Cost Curves of Three Mills**

The research material used in this study covers both energy production and use, and energy saving. The data originate from three mills of the consolidated forest corporation; all situated in Finland. Later in the text, the mills are designated as A, B and C. However, brief background information on different mills is presented.

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 meters of wood annually, and the production is 620,000 tonnes of air dried (90%) pulp. The cooking method is Super Batch.

One part of Mill A is a sawmill producing 237,000 cubic meters of timber annually. The residue wood from timber making is used for pulp production at the pulp mill.

Mill B is an integrate consisting 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 an energy saving report from 2000, the production capacity of the pulp mill was 370,000 tonnes of air dried (10% moisture) pulp. At the paper mill, there are two paper machines producing fine papers and a sheeting plant. In 2000, the annual production capacity of the paper mill was 800,000 tonnes.

The heat consumption at Mill B was 3650 GWh and the electricity consumption 850 GWh in 2000. 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 externally. The main part of the produced pulp is pumped without drying to paper machines. Excess heat from the pulping process can be utilized in paper making.

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

Data on the fuels used for energy production, the amounts of energy produced with different fuels, and the amounts of heat and electricity used for pulp and paper production covers the years from 1995 to 2001. According to these data, the average amounts of energy produced with different fuels were calculated.

The main research topic was energy saving of the above-mentioned mills. The main source was the energy saving reports of the mills to MOTIVA (Information Center 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. The report on objects for energy saving was basically the state-of-the-art in one particular year. This report gave the saving potential of different production units equipped with the machinery now in use, when a technical inspection was made. At Mill A the energy saving data were from 1998, and at mills B and C from 1999.

According to the energy saving report of Mill A, in 1998 the annual heat consumption was 1,985 GWh. Of the previously mentioned energy amount, it was possible to save of 278 GWh heat per year, i.e., 14.0%. In 1998, the consumption of electricity was 405 GWh/y, of which the saving capacity was 11 GWh/y, i.e., 2.7%. In 1999 at Mill B, the heat consumption was 2,472 GWh/y, and the saving capacity was 121 GWh/y, i.e., 4.9%. For electricity, in 1999 the consumption was 852 GWh/y, and the saving capacity was -16 GWh. This indicated a rise in the use of electricity of 1.9%. At Mill C, in 1999, the heat consumption was 1,408 GWh/y, and the saving potential 99 GWh/y, i.e., 7.0%. With regard to annual electricity consumption in 1999, it was 1,059 GWh, and the saving potential was 69 GWh, i.e., 6.5%.

The basic structure of the energy saving report was a technical description of a certain part of the pulp- or paper-making process, where it was possible to save either heat or electricity or both. After that there was information for a period of repayment without paying interest for this certain object, energy saving of heat in energy units (MWh/year) and in monetary units (1000 Finnish Markka (FIM)/year). The same information also covered the saving of electricity in both units (MWh/year and 1000 FIM/year). In each case, the total sum of heat and electricity savings (as 1000 FIM/year) was also stated. An important part of the further calculations was information on the investment cost of a certain energy saving measure. In those cases this information failed; it was not

possible to make economic calculations. So in next stages these objects were omitted. All monetary values were converted to euros using the conversion coefficient 1 euro = 5.94573 FIM. In each case the actual saving of one particular saving object was calculated by subtracting the investment cost from the sum of the saved heat and electricity.

In Table 1 data have been gathered on those energy saving investments that were used later in calculations of the cost curves of different mills. The biggest investment cost was at Mill C. The main reason for this was the planned replacement investment of debarking facilities at the sawmill. At Mill B the capacity increase of one paper machine resulted in a larger need for electricity and thus also higher costs for purchased electricity. This indicated negative values for electricity.

*Table 1:* Information from the energy saving reports of the different mills.

Mill	Investment 1000 euros	Computational Annual Saving				Energy Cost Saving Total 1000 euros/y
		Heat		Electricity		
		Energy MWh/y	Costs energy 1000 euros/y	Energy MWh/y	Costs energy 1000 euros/y	
A	1,695	93,585	506	12,278	289	795
B	6,384	121,000	636	-15,600	-394	242
C	14,864	143,685	1,665	71,746	1,991	3,656

The main target of energy saving is to reduce heat in energy processes. The reason for this aim is that the chemical energy, contained in fuel, is first converted to heat in a boiler, and after that heat is then further converted to electricity in a steam turbine. The system where both heat and electricity are produced is called a cogeneration process, and a plant with both heat and electricity production is called a combined heat and power (CHP) plant.

In economic calculations, in order to achieve the net saving potential, the saved energy amounts of heat and electricity were linked to investment costs. Since the GHG emission abatement is generally related to different fuels used for energy production, energy saving costs were expressed as reductions of carbon emissions. The main fuel, producing the largest amount of useful energy at different mills, varied according to the mill. This fuel and the CO<sub>2</sub>-coefficient factor typical for the fuel determined the CO<sub>2</sub> emissions of a certain saving object. At Mill A this main fuel was wood, at Mill B peat, and at Mill C coal. The CO<sub>2</sub>-coefficient factors used for different fuels were as follows:

- wood 109.6 g CO<sub>2</sub>/MJ (IPCC 1996);
- peat 106 g CO<sub>2</sub>/MJ (IPCC 1996);
- coal 94.6 g CO<sub>2</sub>/MJ (IPCC 1996).

In some cases only electricity was saved, especially in the production of mechanical pulp. It was then assumed that electricity was purchased from external power plants fuelled by coal. Among the Finnish power plants, the largest emitters of fossil CO<sub>2</sub> to

the atmosphere are these coal-condensing power plants. In reality, this electricity might have been purchased, e.g., from hydro or nuclear power plants, but the assumption here was that the coal-condensing plants mentioned above were used in the external procurement of electricity for all three mills. At Mill A the electricity production from its own chemical pulping process (recovery and bark boilers) was sufficient to cover all of the electricity consumption of the mill. In order to follow the same procedure with external electricity procurement, the external electricity was assumed to be purchased from a coal condensing power plant. This was valid in those energy saving objects, where only electricity was saved. In those cases where both heat and electricity were saved CO<sub>2</sub> emissions were calculated according to the main fuel used at the mill.

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

$$(\text{investment cost} - \text{savings of heat and/or electricity}) / (\text{CO}_2 \text{ emission reduction}) .$$

The unit used in the formula is euro/tC. The unit, tC means tonnes (1000 kg) of carbon, where CO<sub>2</sub> emissions were converted to carbon (C) by multiplying emissions by a factor of 12/44. This figure is the ratio of the mole masses of C and CO<sub>2</sub>. The main idea in the previous formula is to connect together the investment costs needed for a certain energy saving object and the savings of the energy bill as a result of this investment. The reduction in CO<sub>2</sub> emissions is a result of reduced use of energy at the mill.

## **2.2 Carbon Trading Game**

### **2.2.1 Arguments for carbon trading**

Carbon trading is a tool for achieving abatement of CO<sub>2</sub> emissions in a cost effective way. Cost effectiveness is based on the fact that marginal costs of the CO<sub>2</sub> abatement are different for each economic unit that emits CO<sub>2</sub>. Then those CO<sub>2</sub> producers with low marginal costs can sell their surplus emissions over their constraint to emission markets, and on their behalf, those units with high marginal costs prefer to buy emission licenses at a price lower than their own abatement costs. As a result, the total abatement costs needed to reach reductions in CO<sub>2</sub> emissions will be lower than the independent abatement measures for each economic unit. In addition, trading offers a way to collect the necessary capital for further emission reductions, since the agreed reductions in GHG emissions cover less than 5% of the emissions in the base year 1990 (see Grubb *et al.*, 1999). However, in order to stabilize the GHG concentrations, especially CO<sub>2</sub> concentrations, current emissions should be more than halved.

In order to simulate the effects of trading on GHG emissions and abatement costs, the carbon trading game offers a way to achieve this goal (see Hizen and Saijo, 2001). The trading game also provides valuable experience to participants seeking real world trading opportunities. In the trading game, the active players are those who need to decrease their carbon emissions, such as individual countries responsible for the implementation of the Kyoto Protocol or companies emitting major quantities of CO<sub>2</sub>. As a result of the game, it is possible to gather information on traded CO<sub>2</sub> emissions and contracted prices. Furthermore, individual trades between different players are the

results of trading. Several candidates for emissions trading institutions have been discussed; among those are bilateral trading, auctions and a mixture of these. Here, bilateral trading and auction are the institutions that are studied more carefully. At the same time, practical instructions for the participants of the trading game are discussed.

The pulp and paper industry, due to its high consumption of fossil fuel-based energy, is one of the industry branches that has to meet the requirements of GHG abatement. Simulations of carbon trading within this branch give valuable experience for future market operations, especially within the European Union (EU) and later for the commitment of the Kyoto Protocol. Within the EU, the preliminary GHG trading scheme is to start in 2005 (CEC, 2001). This period from 2005 until the end of 2007 precedes the Kyoto Protocol's first commitment period in 2008–2012. In these simulations, described later in this section, data on energy saving investments linked to carbon emission reductions, achieved with the assistance of those investments, was used. The same data for the previously described three mills formed the basis for simulations.

### ***2.2.2 Rules of bilateral trading***

Bilateral trading is a game where participants negotiate with each other to find the optimum solution for them. When the game is arranged, the amount of information is an important background parameter. Every participant (here, the mill) naturally has its cost curve with emission reductions. 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. This alternative reflects the situation in reality, where each mill is a profit center for the same consolidated corporation and thus has information on marginal cost curves of other mills, at least at a general level. On the other hand, mills can be treated as independent players, because a consolidated corporation can trade with other companies within or outside the EU, e.g., in Russia. The cost curves of other companies are not so well known. To solve this problem, participants must find the optimum solution through a process of negotiation.

The first option in bilateral trading was the open exchange of information. In this option each participant received the cost curves of all players before the game 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. This information was identical with the information described earlier in this section and in more detail in section 3.1. After the actual game began, in which participants (here, the 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 exchange information. Basically, this happens by exchanging information written on pieces of paper. Once agreement has been reached, the pair reports the price, the quantity, the seller and the buyer to an experimenter, who informs all players. Three subjects participated in one game, which meant that one subject normally negotiated with another subject, while the third subject waited for his/her turn. One subject could naturally give his/her offer to both subjects at the same time. Subjects were capable of acting in both roles during one game, namely as buyers and sellers. In an individual

target, each subject had its own constraint for carbon emission reductions, which was 17,500 tC for Mill A, 17,000 tC for Mill B, and 13 000 tC for Mill C. Each subject had to fulfill his/her personal constraint by the end of each game. In an actual game situation, the subjects knew only their personal limitation exactly, but had only the range of the other players' limitations. This range was 16,857 to 19,773 tC for Mill A, 16,594 to 18,829 tC for Mill B, and 11,630 to 15,362 tC for Mill C. Each subject aimed at achieving his/her emission reduction target in the most cost-effective way. It is important to note that for each subject, technically the maximum amount of carbon reductions was at the upper right end of the cost curve. At this point, the cumulative sum of the carbon emission reductions reached its maximum.

The second option was bilateral trading with limited exchange of information. In this option, subjects ignored the information on the cost curves of other subjects. Instead, each of them had only the graph with numerical information about their own mill. By negotiating with each other, a subject should find the optimum solution for his/her game. The actual gaming procedure was identical to bilateral trading with open exchange of information. Moreover, constraints for carbon emission reductions and ranges for subjects' carbon reductions were identical to the open exchange of information alternative.

### **2.2.3 Rules of double auction**

Double auction is a variation in the game where each participant plays independently, not knowing the actions of the other subjects before they are revealed. Basically, an auction can be concluded in two different ways: either disclosure or closure of cost curves. Because in this variation of the trading game, like other alternatives in which only three subjects participated, we used the closure of abatement cost curves, the subjects ignored the information on the cost curves. After a 20 minute examination, the actual auction happened so that an auctioneer called on the subject who raised his/her hand first. This subject then stated whether he/she was willing to sell or buy, how much (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 A (single chemical pulp mill), Mill B (chemical pulp mill with two paper machines), Mill C (an integrate, with wood-containing and wood-free paper grades). The previous marking system was also used in other gaming variations. The subjects could make both selling and buying bids during one game. For example, the selling bid could be as follows: Mill C sells 1,000 tC at a price of 50 euro/tC and the buying bid: Mill B buys 500 tC at the price of 150 euro/tC. Both bids were now public and were written on a blackboard. After that, by raising his hand, a subject expressed his willingness to trade. This could be either a new bid or acceptance of an earlier bid. For example: B accepts the bid of A and buys 500 tC. It is important to note that the accepted amount of carbon reductions could be lower than the original bid, but the price could not be changed. Then the acceptor of a bid informed a possible change in the amount to the auctioneer. The accepted bid was now public and was written on the blackboard. At the same time, any earlier selling bids lost their validity. The goal for each subject was to fulfill his/her personal constraint in the most cost-effective way. These constraints and ranges for constraints were identical to previously described games. The double auction was closed when new trades were no longer concluded.

## 3 Results

### 3.1 Energy Saving Investments Linked to Carbon Emission Reductions at the Three Mills

#### 3.1.1 *The cost curve of Mill A*

The energy saving units at Mill A are a power plant, fiber lines, machines for drying produced pulp, an evaporating plant, and a sawmill. These energy saving objects were included in the calculation process, when both investment costs and annual savings in an energy unit (MWh/a) and in a monetary unit (FIM/a) were delivered. The previously mentioned preconditions (both energy and monetary units) fulfilled 6 of the total 22 objects. Three objects were situated at the fiber lines, two at a sawmill, and one was at an evaporating plant. The annual saving capacity of those objects was 93,590 MWh of heat and 12,280 MWh of electricity. At the fiber lines, energy saving objects were white alkali lye warming, a filtration of washing result, and oxidation of a pressurized white alkali lye. At the sawmill, these objects were renewal of a compressor and handling of a snow and stone pile. At the evaporating plant, the energy saving object was an increase in the dry matter of white alkali lye.

At Mill A, bark and black liquor from a chemical cooking process were used as the main fuels in a cogeneration power plant, where both heat and electricity were produced for the process. Heavy fuel oil was used in a lime sludge reburning kiln and in start-ups and shutdowns of the main energy boiler. About 98% of the produced energy came from wood-based fuels. Thus, energy saving mainly meant saving wood in energy production because, for technical reasons, the replacement of oil was difficult. For example, white alkali lye is produced in a lime kiln where, due to technological limitations, heavy fuel oil is the only possible fuel. Wood is a carbon neutral fuel, which means new net carbon emissions do not develop when the emitted CO<sub>2</sub> emissions are absorbed into a new growth of woody biomass. However, energy saving measures are always beneficial because they will lead to the development of more efficient use of resources, even renewable ones, such as wood.

According to the energy saving report of Mill A, carbon emissions of 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 cogeneration process of the mill, the energy transformation ratio from fuel (here, wood) to produced heat was 63% and further to produced electricity 37%. The proportion of electricity was larger than it is normally at this kind of mill, because one of the main targets was to maximize the amount of electricity that could be sold to the external electric network. In order to determine the amount of saved heat, the ratio of input fuel was calculated first. When the proportion of heat was marked as 1, the ratio of heat was 0.63, and the boiler efficiency in wood burning was 0.88, the proportion of input fuel was thus 1.8 [= (1/0.63)/0.88]. This ratio was multiplied by the amount of energy in the saved heat (unit MWh). To obtain the gross CO<sub>2</sub> emissions from wood burning, the amount of energy was transformed to CO<sub>2</sub> by multiplying it by the coefficient of 394,528 [= 109.6/(0.2778/1000), unit g/MWh]. The CO<sub>2</sub> emission coefficient factor for wood is 109.6 g CO<sub>2</sub>/MJ, and the transformation factor between GJ and MWh (1 GJ = 0,2778

MWh) is 0.2778. Finally, in order to obtain Mg CO<sub>2</sub> as a unit, the whole calculation formula was divided by 10<sup>6</sup>.

In the above paragraph, the CO<sub>2</sub> emissions of heat production were calculated. In the cogeneration 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 waste either to air or water. The CO<sub>2</sub> emissions of saved electricity were calculated by multiplying the coefficient mentioned in the former paragraph by 0.37, which is the coefficient factor for electricity production. In the end, in order to get total CO<sub>2</sub> emissions, the CO<sub>2</sub> emissions of heat and electricity production were added together. Because in all later calculations the unit of CO<sub>2</sub> emissions was tC (tonnes of carbon), CO<sub>2</sub> emissions were transformed to carbon by multiplying emissions by a factor of 12/44.

Two energy saving objects were found at a sawmill of Mill A. In these cases only electricity was saved. Then it was assumed that the used electricity was purchased outside the mill from the national electrical network, and this electricity was produced in a coal-condensing power plant. CO<sub>2</sub> emissions were calculated by multiplying saved electricity by 340,533 g/MWh [= 94.6/(0.2778/1000)], where 94.6 g CO<sub>2</sub>/MJ is a CO<sub>2</sub> emission coefficient factor for coal. The total CO<sub>2</sub> emissions of saved electricity were 331 tCO<sub>2</sub>.

Figure 1 illustrates the costs related to investments in energy saving and reductions in carbon emissions achieved through the decreased use of energy as a result of energy saving. The unit of the y-axis is euro/tC (see section 2). The particular value at the x-axis (unit tC, tonnes of carbon) is the cumulative value for reductions in carbon emissions. Thus, the reduction in carbon emissions of one energy saving object is the difference between two successive x-values. It is interesting to note in the figure that the first three objects are negative. This means that annual savings due to improvements in energy efficiency were larger than the actual cost for investing in that improvement. This kind of investment was thus very profitable, because the period of repayment without interest was less than one year. At Mill A these kinds of investment objects at the chemical pulp mill were warming of white alkali lye and filtration of the washing result, and at the sawmill the renewal of a compressor. So far, the filtration of the washing result has been invested. The largest reduction in emissions could be achieved with the previously mentioned investment, where an actual carbon emission reduction was 15,160 tC. The other two most profitable energy saving investments caused the carbon emission reductions of 23 tC (white alkali lye warming) and 1,675 tC (renewal of a compressor).

The next three objects in Figure 1 were positive ones. From the lowest cost level (75 euro/tC) to the highest level (1132 euro/tC) for these three objects, the period of repayment without interest was 3.7, 11.8, and 5.5 years. The largest reduction in carbon emissions for the previously mentioned group was 2,916 tC, which was the result of the investment in a dry matter increase of white alkali lye. For the other two objects, the reductions in carbon emissions were 1,590 tC (oxidation of a pressurized white alkali lye) and 67 tC (handling of a snow and stone pile). The total CO<sub>2</sub> reduction of 78,577 tCO<sub>2</sub> (=21,430 tC) was 4.2 times larger than the average CO<sub>2</sub> emissions of fossil fuels (heavy and light fuel oil) in 1995–2001 (= 18,658 tCO<sub>2</sub>) at Mill A. However, 78,246



tCO<sub>2</sub> (=21,340 tC) of the saved emissions originated from the decreased use of wood as a result of energy saving measures. For both biofuels (bark, black liquor, methanol, black soap) and fossil fuels together, the average CO<sub>2</sub> emissions in 1995–2001 were 1,678,818 tCO<sub>2</sub>. Thus, at Mill A the reduction in the CO<sub>2</sub> emissions of energy saving investments covered 4.7% of all CO<sub>2</sub> emissions originating from fuels used for energy production.

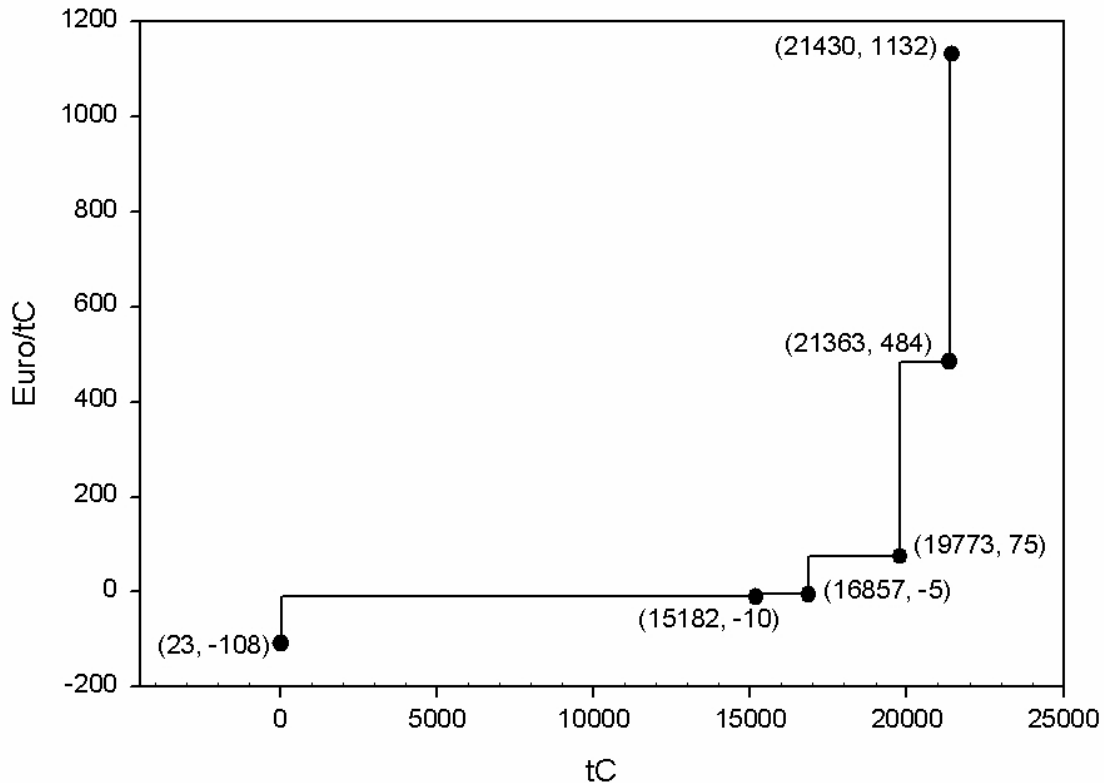


Figure 1: The cost curve (euro/tC) of Mill A as a function of cumulative reduction in carbon emissions (tC).

### 3.1.2 The cost curve of Mill B

At Mill B, six energy saving objects were found. These were wood handling, pulp drying, bleaching of pulp, power production, and one paper machine. The annual saving capacity of these objects was 121,000 MWh of heat and 400 MWh of electricity. As a result of the increase in the capacity of the one paper machine, electricity consumption increased considerably, i.e., 16,000 MWh/year. The total consumption of electricity increased by 15,600 MWh/y. However, at the same time, the heat saving was 55,000 MWh/y. Thus, this investment was also included in the category of energy saving.

According to the energy saving report from 2000, both fossil and renewable fuels were used at the mill. In 1995–2001, the most important fossil fuel was milled peat, which made up 63% of the average use of fossil fuels. After peat came heavy fuel oil (22%), liquefied petroleum gas (14%), and light fuel oil (0.5%). The total use of fossil fuels was, on average, 683,040 MWh. The importance of renewable fuels for the energy use of the mill was more striking than that of fossil fuels in 1995–2001, because their use,

on average, was 2,800,690 MWh. The most important fuel was the cooking residue from chemical pulping, black liquor, which covered 77% of all renewable fuels. After that came bark (22%) and methanol, also a by-product of pulping (0.7%).

Carbon emissions of heat and electricity savings were calculated based on the report on energy saving produced by the mill. In the case of Mill B, the efficiency of peat burning in the main energy boiler was 88%. In the cogeneration process of the mill, it was assumed that the energy conversion coefficient from fuel (here, peat) to produced heat was 79% and further to produced electricity 21%. In order to determine the amount of heat saved, the ratio of input fuel was calculated first. When the proportion of heat was marked with 1, the ratio of heat was 0.79 and the boiler efficiency in peat burning was 0.88, the proportion of input fuel was thus 1.44 [= (1/0.79)/0.88]. This ratio was multiplied by the amount of energy in saved heat (unit MWh). For four out of all six energy saving objects, only heat was saved. Thus, in these cases only CO<sub>2</sub> emissions of heat savings were calculated. To obtain the gross CO<sub>2</sub> emissions from peat burning, the amount of energy was transformed to CO<sub>2</sub> by multiplying it by the coefficient of 381,569 [=106/(0.2778/1000), unit g/MWh]. The CO<sub>2</sub> emission coefficient factor for peat is 106 g CO<sub>2</sub>/MJ, and the transformation factor between GJ and MWh (1 GJ = 0.2778 MWh) is 0.2778. Finally, in order to obtain Mg CO<sub>2</sub> as a unit, the whole formula was divided by 10<sup>6</sup>.

In the paragraph above the CO<sub>2</sub> emissions of heat production were calculated. The aim of the cogeneration process is to produce both heat and electricity. The CO<sub>2</sub> emissions of the saved electricity were calculated by multiplying the coefficient in the former paragraph by 0.21, which is a coefficient factor for electricity production. Concerning Mill B, only one energy saving object (capacity increase of one paper machine) was such that it was possible to make calculations for both heat and electricity. In the end, the CO<sub>2</sub> emissions of heat and electricity production were added together in order to get total CO<sub>2</sub> emissions. Because in all later calculations the unit of CO<sub>2</sub> emissions was used tC (tonnes of carbon), CO<sub>2</sub> emissions were transformed to carbon by multiplying emissions by a factor of 12/44.

At Mill B one energy saving object (adjustment of electrostatic precipitator of one energy boiler) was found where electricity was saved. CO<sub>2</sub> emissions were calculated by multiplying the saved electricity by the coefficient 340,533 [= 94.6/(0.2778/1000)], where 94.6 g CO<sub>2</sub>/MJ is a CO<sub>2</sub> emission coefficient factor for coal. The total CO<sub>2</sub> emissions of saved electricity were 136 tCO<sub>2</sub>.

Figure 2 illustrates the costs of energy saving investments and carbon emission reductions achieved through these energy saving investments. The general structure of the figure is identical to that of Figure 1. From the figure, it can be seen that the greatest carbon emission reduction (9,740 tC) was a result of the increase in the capacity of one paper machine. Furthermore, the use of secondary heat in pulp drying offered the large carbon reduction of 5,360 tC. The total CO<sub>2</sub> emission reduction of the energy saving investments was 19,612 tC (= 71,911 t CO<sub>2</sub>). The average CO<sub>2</sub> emissions of fossil fuels (peat, heavy and light fuel oil, liquid gas) were at Mill B: 229,774 tonnes in 1995–2001, which was 3.2 times larger than the reduction in CO<sub>2</sub> emissions due to energy saving investments. In 1995–2001 at Mill B, the average CO<sub>2</sub> emissions of both bio (black liquor, bark, methanol) and fossil fuels used for energy production were 1,334,126

tonnes. Thus, the CO<sub>2</sub> emissions reduction with the assistance of energy saving investments was 5.4% of those emissions emitted from all fuels used for the energy production at the mill.

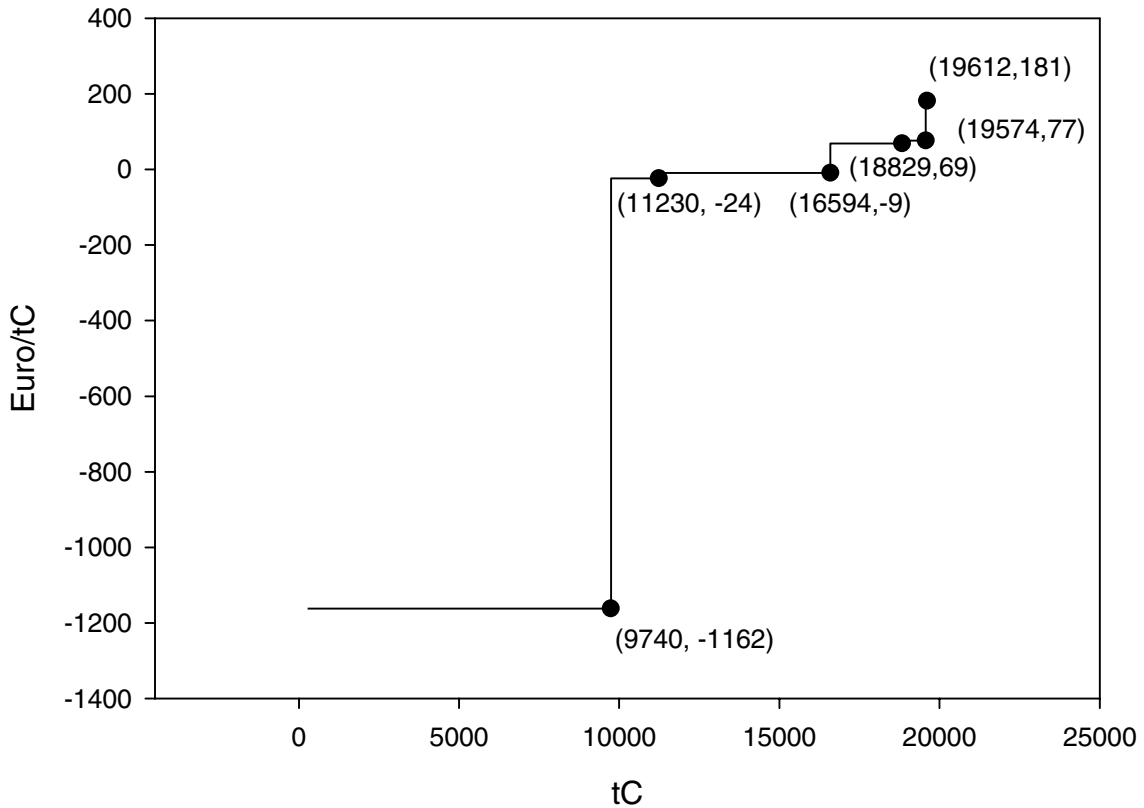


Figure 2: The cost curve (euro/tC) for Mill B as a function of the cumulative reductions of carbon emissions (tC).

The interesting aspect is to note the negative marginal costs of the three objects. The explanation is the same as in the case of Mill A. To obtain savings, the annual savings in heat and electricity bills were larger than the actual energy saving investment. However, it is not always easy to report the proportion of energy saving in a larger investment project. An example of such a project at Mill B was the increase in capacity of one paper machine, which led to the reduction in marginal cost of -1,162 euros per ton carbon (Figure 2). In this case it was not possible to report the price of energy saving, so the investment cost was calculated as the difference in the whole investment cost (58.9 million euros) and the value of produced extra capacity of fine paper during one year (95,000 tonnes \* 740 euro/ton). However, this was a critical point and the result can vary considerably depending on the initial values used. If 10% (5.9 million euros) of the total investment was used as a value of energy saving investment, which was an estimate from similar kinds of investment materialized earlier, the cost of the investment was remarkably positive (617 euros/tC). The former example describes the difficulties to value energy savings as part of a larger investment, 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 investment the use of

energy increased. In that particular investment the result was identical to electricity, where annual consumption rose by 16,000 MWh. However, the annual consumption of heat decreased by 55,000 MWh, so the net saving was 39,000 MWh per year.

In addition to an increase in the capacity of one paper machine, two other energy saving investments with negative costs were the use of secondary heat in the pulp drying process (cost -9 euro/tC) and in the pulp bleaching (-24 euro/tC). These objects were obvious energy saving investments, and also extremely profitable ones. In the first investment the period of repayment was 0.7/year, and in the second one 0.3/year. Both investments have already been made independently or as part of another technical renovation. The next two objects led to positive marginal costs of 69 euro/tC (use of secondary heat in handling frozen wood) and 77 euro/tC (use of secondary wood in heating mill buildings). In these cases the periods of repayments were 2.9 and 3.1 years. The last object (adjustment of the electrostatic precipitator of one energy boiler) caused marginal costs of 181 euros per tC, which made it too expensive to implement.

### **3.1.3 The cost curve of Mill C**

Wood bark and black liquor from a chemical cooking process were used as the main fuels in a cogeneration power plant producing both heat and electricity for the process. The proportion of bark was 41% and that of black liquor 59% of the total energy use of renewable fuels (2,000,600 MWh on average in 1995–2001). Heavy fuel oil was used in a lime sludge reburning kiln and in start-ups and shutdowns of the main energy boilers. It covered 30% of the total energy use produced with fossil fuels (314,700 MWh on average in 1995–2001). In mechanical pulping, spruce was used both as a round wood in the production of groundwood pulp and as chips in refined mechanical pulp (TMP) production. Grinders and refiners powered by electric motors produced mechanical pulp for the production of publication papers. This pulping process required considerable electricity, which was purchased mainly from energy companies outside the mill. The proportion of purchased electricity was 72% of all electricity production (1,037,600 MWh on average in 1995–2001). In 1995–2001 the production of electricity at the mill was, on average, 286,700 MWh. Other fuels used for energy production at the mill were peat, coal and recycled waste from cardboard manufacturing. In 1995–2001, the proportion of fossil or semi-fossil (peat) fuels was as follows: peat 31%, coal 24% and recycled waste 15% of the total energy use of fossil fuels (on average 2,000,600 MWh).

According to the energy saving report of Mill C, carbon emissions resulting from energy savings were calculated. In the case of this mill, the efficiency of burning in the main solid-fuel boiler, where e.g., coal and peat are combusted, was 91%. It was calculated that in the cogeneration process of the mill, the energy conversion coefficient from fuel to produced heat was 81% and further to produced electricity 19%. In order to obtain the amount of saved heat, the ratio of input fuel was calculated first. When the proportion of heat was marked with 1, the ratio of heat was 0.81, and the boiler efficiency in coal burning was 0.91, the proportion of input fuel was thus 0.89 [= (1/0.81)/0.91]. This ratio was multiplied by the energy amount of saved heat (unit MWh). In six cases of all eight energy saving objects, both heat and electricity were saved. Thus, CO<sub>2</sub> emissions of both heat and electricity savings were calculated in these cases. In order to get gross CO<sub>2</sub> emissions from coal burning, the energy amount was

transformed to CO<sub>2</sub> by multiplying it by the coefficient of 340,533 [= 94.6/(0.2778/1000), unit g/MWh]. The CO<sub>2</sub> emission coefficient factor for coal is 94.6 g CO<sub>2</sub>/MJ, and 0.2778 is the transformation factor between GJ and MWh. Finally, in order to get Mg CO<sub>2</sub> as a unit, the whole calculation formula was divided by 10<sup>6</sup>.

The CO<sub>2</sub> emissions of saved electricity were calculated by multiplying the coefficient in the former paragraph by 0.19, which is a coefficient factor for the electricity production. In the end, the CO<sub>2</sub> emissions of heat and electricity production were added in order to get total CO<sub>2</sub> emissions. Because in all later calculations the unit of CO<sub>2</sub> emissions was tC (tonnes of carbon), CO<sub>2</sub> emissions were transformed to carbon by multiplying emissions by the factor of 12/44. At this mill two energy saving objects were included in which only electricity was saved (the grinding mill and the production of TMP pulp). CO<sub>2</sub> emissions were calculated by multiplying saved electricity by the coefficient of 340,533 [= 94.6/(0.2778/1000)]. The total CO<sub>2</sub> emissions of saved electricity were 7,197 tCO<sub>2</sub>.

Figure 3 illustrates the costs of eight energy saving objects. In four cases, the costs were negative ones. In other words, annual savings of those saving objects were larger than investment costs needed to achieve these savings. This also meant that costs, which were investment costs of a certain energy saving investment divided by achieved carbon reduction (unit euro/tC) as a result of the decreased use of fuels, were negative. The biggest negative value was -302 euros/tC, which was a result in the investment of the optimal run of grinder stones and improvements in maintenance at the grinding mill. In the production of thermo-mechanical pulp (TMP) great annual savings were also achieved with investment costs less than annual savings. In TMP production, both sedimentation and grinding of TMP pulp rejects and renovations of the main grinder and heat recovery units were energy saving measures, which resulted in the costs of -276 euros/tC. Negative marginal costs of -46 euros/tC resulted at the steam control of one paper machine producing fine papers. In addition, improvements to the automatic control and drying unit and renewal of steam measurement at one paper machine producing publication papers led to negative marginal costs of -37 euros/tC.

The costs of the other four energy saving objects were positive ones (Figure 3). At the other paper machine, which produces publication papers, improvements in steam control caused marginal costs of 169 euros/tC. Improvements in heat recovery at the other paper machine producing fine papers resulted in marginal costs of 186 euros/tC. At the chemical pulp mill, renovation of the lime sludge reburning kiln and efficiency improvements at the evaporating plant caused marginal costs of 400 euros/tC. Renovation of the debarking plant at the sawmill was not justified in terms of energy saving, because the costs of the investment were 1,413 euros/tC. The investment cost of the debarking plant was estimated to be 9.5 million euros, which might be the value of the whole investment, not only the energy saving investment. However, the previously mentioned and all other figures reported by the mill on its energy saving measures were included in the calculations, if better estimates could not be obtained.

Reduction in the use of coal at the sawmill led to the largest carbon emission reductions as a result of an increase in the dry matter content of wood waste (reduced moisture content of wood material). With this investment, it was possible to achieve a carbon emission reduction of 6,420 tonnes. At one paper machine producing publication

papers, savings in steam use caused the carbon emission reduction of 4,201 tonnes. At the chemical pulp mill and at one paper machine producing fine papers, carbon emission reductions were also remarkable. In the first energy saving object, the reduction in carbon emissions was 3,730 tonnes, and in the second the reduction was 3,020 tonnes. The total carbon emission reduction of energy saving investments was 21,778 tonnes (= 79,853 t CO<sub>2</sub>). In 1995–2001 at Mill C, average CO<sub>2</sub> emissions of fossil fuels (coal, peat, heavy and light fuel oil, reject) were 109,516 tonnes. In the same time period, average CO<sub>2</sub> emissions of both fossil and biofuels (bark, black liquor) were 900,502 tonnes. The reduction in the CO<sub>2</sub> emissions of energy saving investments was then 72.9% of the total fossil fuel emissions and 8.9% of the CO<sub>2</sub> emissions of all fuels used for energy production at Mill C.

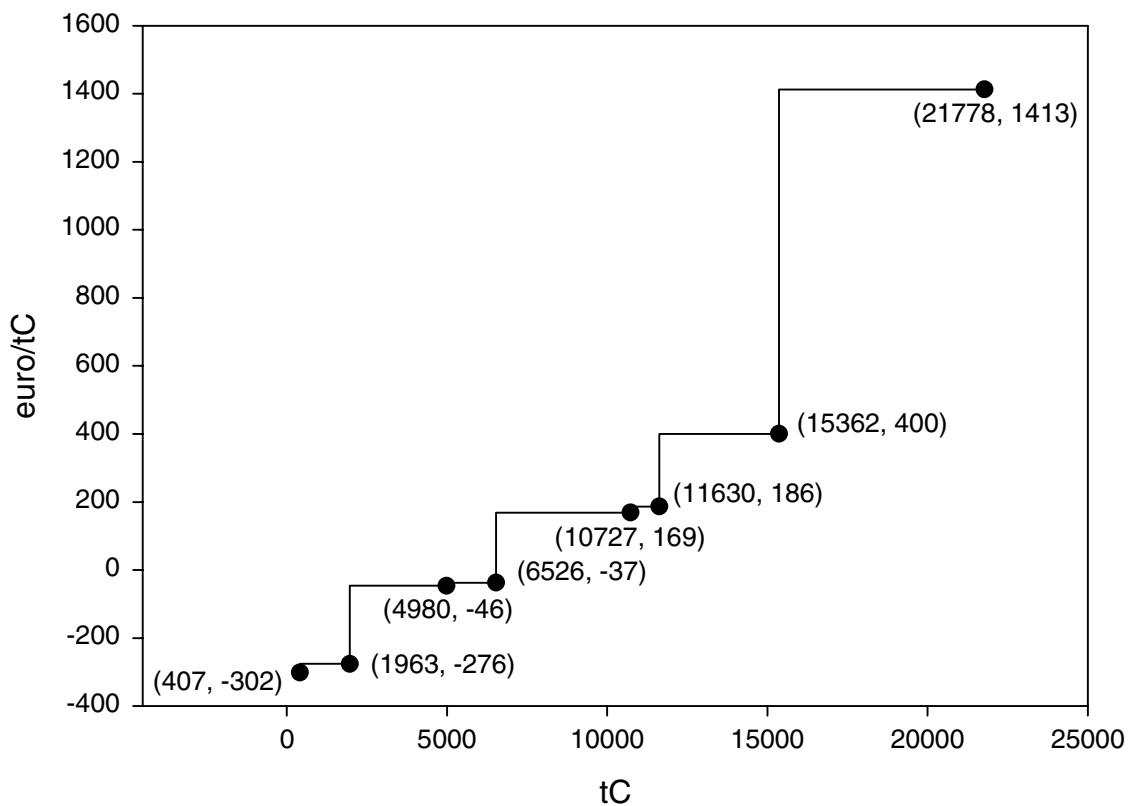


Figure 3: The cost curve (euro/tC) for Mill C as a function of the cumulative reductions of carbon emissions (tC).

### 3.2 Analysis of Different Carbon Trading Games

Carbon trading games illustrated in this study were first implemented in the summer of 2002 in Laxenburg, Austria during IIASA's Young Scientists Summer Program. Four different games were played, two bilateral trading games with open information and an individual target, one double auction with open information and an individual target, and a bilateral trading game with restricted information and an individual target. However, some improvements in the rules were necessary, and more subjects were needed. This was especially true in the double auction variation, which did not work well. For the above mentioned reasons, in November 2002 the games were repeated as

part of a course of economic control in nature conservation at the University of Joensuu, Finland. The game variations were identical to those variations played at IIASA, but all of the games were repeated and played simultaneously by two groups. This meant a total of 12 games and 18 subjects. One group of three subjects played two games so that the gaming arrangements were identical in both rounds. This gave subjects an opportunity to learn from those practices they met at the first round. Students were chosen randomly for each of the six groups. The subjects were also randomly divided into three categories: Mill A, Mill B, and Mill C. Here, the results of these 12 games are analyzed more thoroughly.

A total of 12 games were investigated by calculating optimal solutions for each mill. An effectiveness of each subject was compared to this optimum. The best performance of different game variations resulted when the total costs were the lowest. This meant that the mill had achieved profit by trading and thus diminished its costs compared to the situation where it made a total investment without trading.

Basically, two viable alternatives for carbon trading could be analyzed according to the cost curves and constraints given to the mills. These alternatives were as follows: either Mill A made an investment and sold extra carbon reduction licenses to Mills B and C, or Mill B made an energy saving investment and sold extra licenses to Mill C. In the latter case, Mill A made its energy saving investments independently up to its constraint, 17,500 tC. The cost for Mill A to make an energy saving investment was  $[(19,773 \text{ tC} - 16,857 \text{ tC}) * 75 \text{ euro/tC}]$ , which made 218,700 euros. After Mill A had covered its constraint, it could sell 2,273 tC to Mills B and C. 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 C would buy 1,370 tC from Mill A in the price range of [0, 400], and Mill B would buy 406 tC in the price range of [0, 69] (see Figure 4). In Figure 5 carbon reductions are marked cumulatively. Thus, the amount of 406 tC is the difference between 1,776 tC and 1,370 tC.

In the second case Mill C would buy 1,370 tC from Mill B in the price range [0, 400] (Figure 5). Then Mill B made an energy saving investment, which gave 1829 tC for sale. The total cost for Mill B was the area  $[(18,829 \text{ tC} - 16,594 \text{ tC}) * 69 \text{ euro/tC}]$ , which resulted in 154,215 euros. Mill A fulfilled its constraint by making an energy saving investment independently, because it could not buy enough licenses from B.

In the first case, expected prices for trades between Mills A and C were 200 euros/tC and between Mills A and B 34.5 euros/tC. In the second case, the expected price for the trade between Mills B and C was 200 euros/tC. The expected costs for Mill C were thus 274,000 euros ( $= 200 \text{ euros/tC} * 1,370 \text{ tC}$ ), for Mill B 14,007 euros ( $= 34.5 \text{ euros/tC} * 406 \text{ tC}$ ), and for Mill A -69,307 euros ( $= 218,700 \text{ euros} - 274,000 \text{ euros} - 14,007 \text{ euros}$ ). In the second case, where Mill B sold its surplus to Mill C, the expected costs for Mill C were 274,000 euros ( $= 200 \text{ euros/tC} * 1,370 \text{ tC}$ ), for Mill B -119,785 euros ( $= 154,215 \text{ euros} - 274,000 \text{ euros}$ ), and for Mill A 218,700 euros ( $= 2,916 \text{ tC} * 75 \text{ euros/tC}$ ). The total expected costs for each mill were the average of case one and two. These were for Mill A 74,696.5 euros  $[( -69,307 + 218,700)/2]$ , for Mill B -52,889 euros  $[(14,007 - 119,785)/2]$ , and for Mill C 274,000 euros  $[(274,000 + 274,000)/2]$ . The individual effectiveness (%) of each mill at a particular round was calculated by the formula:

$$[(\text{calculated costs at the particular round} - \text{optimum})/\text{optimum}] * 100 .$$

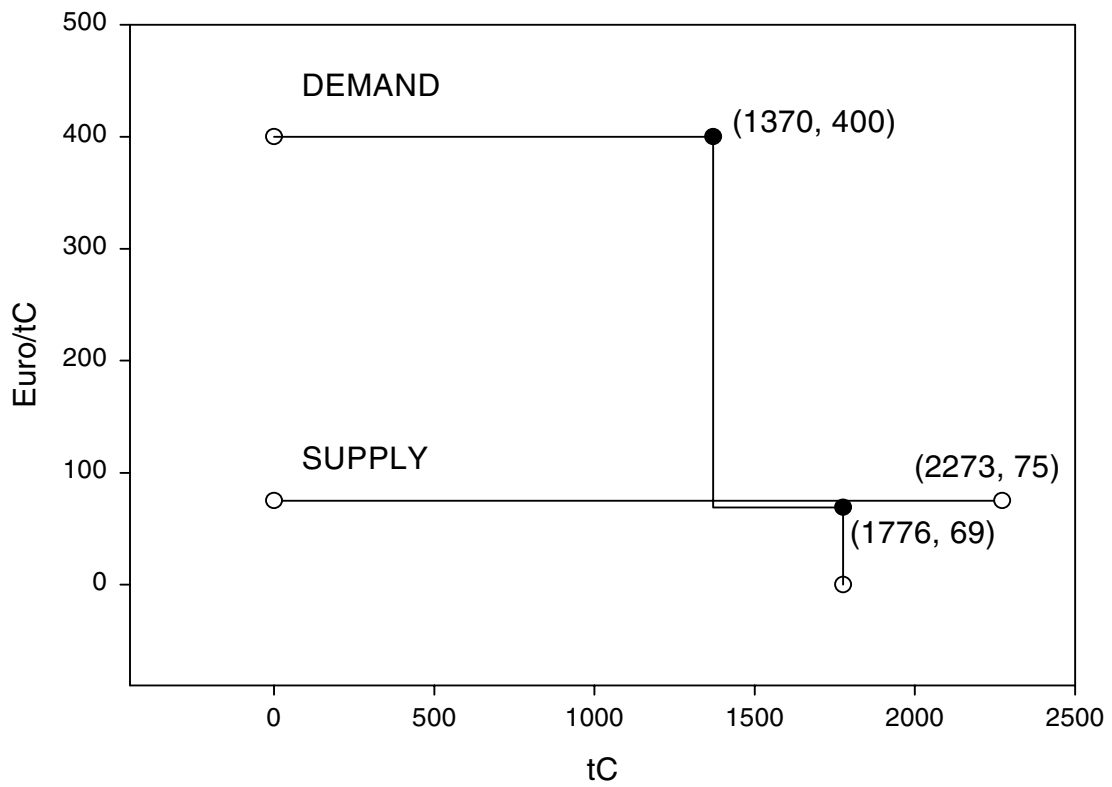


Figure 4: Supply and demand curves for carbon trading between Mills A, B, and C.

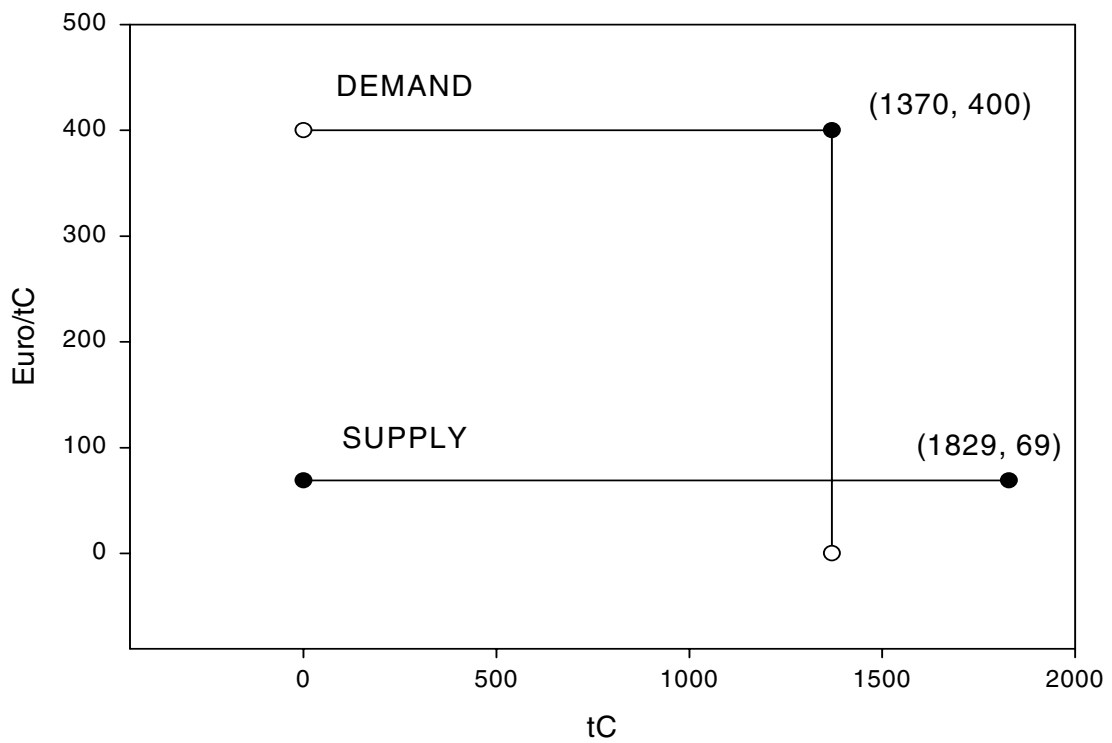


Figure 5: Supply and demand curves for carbon trading between Mills B and C.



Calculated costs at different rounds were calculated from trading records. It was possible for subjects to act as buyers or sellers. In the case of a buyer, costs were directly amount \* price. If a buyer could not fulfill his constraint, or he bought too few licenses, he 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 amount \* price.

The gaming effectiveness of different mills was basically positive (see Table 2). This indicated that subjects were not very effective, because their costs were more than the optimum. When costs were negative, subjects could surpass the optimum. Thus, trading had decreased the total costs of some mills. This was true for Mill C in bilateral trading with open information and for both mills of A in bilateral trading with restricted information. However, the subjects at both mills of A were different, although the game variation was similar. The largest cost savings originated from Mill B2 in bilateral trading with open information. In the first round, savings were almost 700%, and on average at both rounds over 270% compared to expected costs.

*Table 2:* Effectiveness of different mills in different game variations in the first and second round and, on average, in both rounds (trading with more info = bilateral trading with open information; trading with less info = bilateral trading with restricted information).

	Mill A1	Mill B1	Mill C1	Mill A2	Mill B2	Mill C2
<b>Trading with more info</b>						
1st round	+13%	+291%	-32%	+230%	-697%	+100%
2nd round	+47%	+153%	-50%	+254%	+151%	+418%
Average	+30%	+222%	-41%	+242%	-273%	+259%
<b>Trading with less info</b>						
1st round	-53%	+408%	+429%	-49%	+209%	+466%
2nd round	-77%	+359%	+443%	-48%	+151%	+421%
Average	-65%	+383%	+436%	-49%	+180%	+443%
<b>Double auction</b>						
1st round	-63%	+184%	+10%	+160%	+146%	+445%
2nd round	+235%	-191%	+0.7%	+245%	+392%	+431%
Average	+86%	-4%	+5%	+203%	+269%	+438%

When different trading methods were compared, it was found that bilateral trading with open information was the most efficient. The average effectiveness of six games was 73%, while the average effectiveness of double auction games was 166%, and in bilateral trading with restricted information it was 221%. In the first mentioned game method, namely bilateral trading with open information, the information given to subjects before the actual game process was the most comprehensive. They had a graphical description on the cost curves of each mill put into the same figure. This made actual trading easier, because a subject could more accurately decide whether he/she would act as a buyer or a seller. In bilateral trading with open information, there was one very profitable trade for Mill B. In that operation Mill B sold 1,370 tC to Mill C at a

price of 400 euros/tC. This indicated that Mill B could get the maximum profit in one trade, and Mill C did not profit at all. The costs for Mill C would have been the same, if it had made the energy saving investment without trading.

In the ranking of different trading methods a double auction was the second. The actual trading went well, but for Mills A and B it was difficult to buy the whole number of licenses in order to fulfill their constraints. The reason for expensive trades by those mills was that they actually made an investment themselves, and the costs of unlucky trades were added to their total costs. In the first case, Mill A could not buy all of its constraints, because Mill B was unable to sell enough licenses. In the second case, Mill B did not buy enough from Mill C, although it would have been possible. Among three methods, bilateral trading with restricted information gave the smallest trading effectiveness. The main reason for this was that Mill B could not get half of the price from trades with Mill C. Mill C also tried to sell to other mills, even though its costs were the highest. The method mentioned earlier was typical for the expensive trades of Mill C in other trading methods, too. And that indicated high positive values over the optimum. However, the most expensive for Mill C was the role as buyer, when it was actively trading but could not fulfill its constraint. This happened to Mill C2 in the first round of bilateral trading with restricted information. Totally refraining from trading with other mills was also expensive for Mill C (C2, double auction, first round). It can be concluded that the more detailed pre-information may have helped subjects to play more efficiently in the game variations of bilateral trading with restricted information and double auction with restricted information.

## 4 Discussion

The main results of this study were:

- In some cases energy saving was very profitable. This was especially evident for those objects where the costs of an energy saving investment were lower than annual savings achieved through these investments. This indicated negative costs of energy saving (see Figures 1, 2 and 3). Objects with negative costs could be found at all mills. At Mill A the number of objects with negative costs was three, at Mill B also three, and at Mill C four.
- The CO<sub>2</sub> emissions abatement achieved with energy saving was almost identical at the three mills. At Mill A the reduction was 21,430 tC (=78,577 t CO<sub>2</sub>), at Mill B 19,612 tC (=71,911 t CO<sub>2</sub>), and at Mill C 21,778 tC (=79,853 t CO<sub>2</sub>). It is important to note that a reduction in CO<sub>2</sub> emissions was mainly directed to wood at Mill A. Only external electricity was to be purchased from power plants fuelled by fossil fuel, namely coal. Basically, wood fuels are a sink of CO<sub>2</sub> emissions, not the source to the atmosphere, as is the case for fossil fuels, i.e., coal, oil, natural gas or partly fossil peat. This is obvious in circumstances where the growth of CO<sub>2</sub> absorbing biomass is larger than the drain due to natural mortality and fellings. In Finland, the above mentioned matter is true, because the growth of the Finnish forests has exceeded the drain since the 1970's (FFRI, 2000). In that sense the use of wood for energy purposes in order to replace fossil fuels favors CO<sub>2</sub> abatement from the atmosphere in Finland.

- Carbon trading based on CO<sub>2</sub> abatement through energy saving was profitable for the mills. This indicated negative percentage values of effectiveness. Thus a participant in a certain game variation could pass a theoretical optimum calculated for this game and save his/her mill's abatement costs by trading instead of investing to abatement technology himself. In principle, this was quite difficult for participants, but in the gaming variation of bilateral trading with open information, this happened twice — also twice in bilateral trading with restricted information. A slight under swing of the optimum was also possible in the double auction variation, but the difference was not great.
- Carbon trading was most efficient, when more detailed information on CO<sub>2</sub> abatement costs was available during the gaming process. This indicated the best result in bilateral trading with open information, where participants could utilize information on the cost curves of the other participants. Naturally, this information was not as detailed as their own information, containing also a numerical description of the cost curve. However, enough additional information was available to give participants an opportunity to plan their own game strategy more thoroughly before the actual process.

Energy saving with negative costs is interesting and thus requires more attention. As mentioned earlier, 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 emphasizes 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 two years, are usually profitable and are realized (Siitonen and Ahtila, 2002; Möllersten and Westermark, 2001). However, compared to lifespan, e.g., bark or recovery boiler in a pulp mill, the requirement for a payback period is very short. Normally, the above-mentioned energy investments are made for 25–40 years, which do not require such strict requirements for a payback period as energy conservation investments do. Besides, the need for capital is often much lower in energy conservation projects than in large investments in the 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 strategic improvements in capacity for pulp and paper production, other financing alternatives are needed for energy conservation projects. One solution is an Energy Service Company (ESCO), which develops, installs and finances energy conservation projects aimed at reducing both energy and operating costs. ESCO can finance projects with a payback period over four years, thus making them more attractive to companies requiring shorter payback periods. An ESCO gains its revenues from the company that has profited from the energy saving investment. The paid revenue is linked to a monetary value of the saved energy. Normal payback period to an ESCO project is 2–6 years (Kilpeläinen *et al.*, 2000).

Outscoring is another tool for promoting energy saving in the pulp and paper industry (Möllersten and Westermark, 2001). In this alternative, another company — usually an energy company — owns a complete part of the production system, e.g., a biofuel-fired

CHP plant in a pulp mill. Outsourcing enables exempting 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 outsourced part of the production line and takes care of an operation of the production line thereafter. As a bonus, there is the potential to save energy, according to Swedish estimations, 10%.

Reductions in CO<sub>2</sub> emissions with the assistance of energy saving investments covered 64% of the average CO<sub>2</sub> emissions of fossil fuels used for energy production at the three mills in 1995–2001. In addition, wood covered one third of the total CO<sub>2</sub> emission reductions resulting from energy saving investments at the mills. Thus, fossil fuel was not saved because — in the context of atmospheric warming — wood is a carbon neutral fuel. In summary, both improvements in energy efficiency and fuel switching to carbon neutral fuels are the elements that should be taken into consideration in the pulp and paper industry for controlling GHG emissions.

In the Finnish pulp and paper industry, the production of process steam and electricity is widely based on CHP production. The power-to-heat ratio is an important parameter in CHP production. There is a continuously increasing need for electricity in the pulp and paper industry due to requirements for paper quality and, quite surprisingly, in environmental protection. For example, improved treatment of waste water and cleaning of flue gas require more electricity in the 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, lower heat consumption, which makes mills more dependent on the procurement of external electricity (Siitonen and Ahtila, 2002).

To increase electricity production at mills, both efficiently targeted research and development and subsidies to commercialization of new technology are needed. Ways to improve power-to-heat-ratio and thus produce more electricity are, for example, the following: raising of steam pressure and temperature in Kraft recovery boilers; fuel gasification; fuel drying of moist 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 nearby society (Siitonen and Ahtila, 2002). The technology of fuel gasification is based on gasification of fuel in a gasifier and, after cleaning, the use of this product gas in a gas turbine for electricity production. In the future the gasification of wood-based fuels and black liquor will offer better power-to-heat-ratio in power production, when some technical problems, such as the cleaning of gas produced and corrosion of materials, have been eliminated. Better integration of heat use for industry and society enables higher heat loads in industry and thus more electricity, while society can utilize more district heat to heat buildings. The pulp and paper industry is a capital-intensive branch of industry. To obtain useful experience, commercialization of new technologies requires pilot plants of industrial size. This is especially true in applications of new energy technology. At that time, external financial support, e.g., from public financing organizations, gives a positive signal for the investment decision, when other major elements for the investment have been fulfilled.

Fuel switching in the sense of environmental conservation means replacement of fossil fuels with renewable ones. Wood is already much used in the Finnish pulp and paper industry. However, one clear target for fuel switching is lime kilns, where heavy fuel is

still used as the main fuel. From the technical standpoint, a wood gasifier producing product gas for calcium-oxide (CaO) production in a lime kiln can be commissioned (Siitonen and Ahtila, 2002). For example, in this study Mill A would be almost completely run by biofuels if heavy fuel oil were replaced by, e.g., sawdust, in a lime kiln. Of course, other possibilities for fuel switching still exist. The previously mentioned fuel drying of bark 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, environmental legislation, secure supply chain of main fuels and the available energy technologies.

Combining CO<sub>2</sub> trading and energy saving offers a rational way to control GHG emissions. It is also ethical in the sense that the basis for tradable emission licenses originates from the actual efficiency improvements of the mill's own production, rather than merely purchasing emission licenses from producers with lower abatement costs. The only evident solutions for GHG abatement are fuel switching to renewable energy sources and more efficient use of input resources throughout the whole production chain. Emission licenses form a property lot for its owner. If the value of one emission license is 20 euros/tCO<sub>2</sub> on the internal market of the European Union, the total value of three mills' emission licenses is then 3.0 million euros for the quantity of 152,095 tCO<sub>2</sub> (=331+71,911+79,853). At Mill A the emissions of purchased electricity (331 tCO<sub>2</sub>) originating from a coal condensing power plant were included in the tradable emission licenses, but all other CO<sub>2</sub> emission reductions (78,246 tCO<sub>2</sub>) were targeted to wood and were not calculated in the quantity of 152,095 tCO<sub>2</sub>. If the value of one emission license changes to 50 euros/tCO<sub>2</sub>, the total value of emission licenses of three mills increases to 7.6 million euros. At the moment, all price estimates are only tentative, because bids made on the real trading markets are lacking. The total investment costs needed at the three mills to obtain energy savings were 21.3 million euros, when 95,867 euros of Mill A's investment costs (in total 1,695,000 euros) were targeted to fossil coal. Then the possible value for emission licenses owned by the mills varied from 14% (20 euros/tCO<sub>2</sub>) to 36% (50 euros/tCO<sub>2</sub>) of the total investment costs.

The costs of carbon trading depend on the countries included in the trading scheme (see Haaparanta *et al.*, 2002). According to estimates made by the EU member states, if Russia ratifies the Kyoto Protocol, there will be more trade at the inexpensive price. Owing to economic reconstruction, Russia's CO<sub>2</sub> emissions are now at a much lower level than those for the base year 1990, which will dictate the number of emission licenses issued. The same situation also exists in other economies in transition in Eastern Europe, but the number of tradable emission licenses is not as abundant. The above mentioned indicates that in future carbon trading will take place between the EU, new member states joining in the EU and other eastern European countries, and perhaps Russia. Then the economic burden for Annex 1 countries will not be too heavy to be adapted. However, after carbon trading is actualized in 2008–2012, it will be extremely important to secure the competitiveness of domestic abatement actions, not at the expense of international trading, but as a complementing tool. This guarantees possibilities to invest in domestic energy saving and fuel-switching projects.

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