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Studies on Life Cycle Assessment of Sugi Lumber

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Life Cycle Assessment (LCA) is an environmental assessment method that has come into wide use. The LCA method has been used to assess the environmental impact of various products from domestic articles like plastic trays to large buildings. However, few LCA studies on domestic lumber have been conducted because of regional and other differences in forestry methods, distribution, etc. In this study, to obtain basic knowledge on the environmental impact of sugi lumber products, we investigated energy consumption, amount of waste, and volume of product in processes from felling to sawmilling. From the obtained data, emissions of environmental load substances were quantified and evaluated by LCA. The main results obtained are as follow:

CO_2, CO, NOx, and SO_2 were emitted in large quantities from the sawmill subprocess. This is probably due to the large electricity consumption of sawmill equipment. The amount of CO_2 emissions depends on the yield of the sawmill and the distance from market of the sawmill. Therefore, effective means to reduce the CO_2 emissions were suggested as follow: the sawmill equipment can be rationalized to improve the yield in sawmill subprocess, and the sawmilling line can be made more highly effective; in addition, it is important to plan construction of sawmills so that the distance from the sawmill to the market will be shortest. Global warming and acidification comprise almost the entire result of the impact assessment of both sawmills. The substances that contributed to global warming and acidification were CO_2, NOx, SO_2, and CH_4, and each substance was emitted most in the sawmill subprocess. Overall, this study showed that the sawmill subprocess has the greatest role in the environmental load of lumber products.

INTRODUCTION

The Kyoto Protocol has come into effect in February 2005, and related concerns about the environment have increased. Each country has a national reduction target value for emissions of greenhouse gases include carbon dioxide (CO_2). Japan has to reduce its emissions by 6%, of which 3.9% is allowed to be reduced from the atmosphere by forests; therefore, appropriate forest management and the promotion of domestic lumber products can be predicted. However, in the production of lumber products, a lot of resources and energy are consumed; the generation of both wastes and environmental load substances cannot be avoided. Therefore, a quantitative analysis of the environmental impact of the production of lumber products is needed.

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Life Cycle Assessment (LCA) is an assessment method that has recently come into wide use. Full-scale LCA studies were launched in Japan in the 1990s. The LCA method has been used to assess the environmental impact of various products from domestic articles like plastic tray (Kurayoshi and Terashima, 1992) to large buildings. As for lumber products, there have been some studies on LCA abroad, e.g., Energy Audit of Wood Harvesting System (Klavac *et al*, 2003) or Life Cycle Assessment of Flooring Materials (Jönsson *et al*, 1997). However, there have been very few studies on domestic lumber production because of regional and other differences in forestry methods, distribution, etc., which make it difficult to obtain all data of the processes involved, from felling to sawmilling.

In this study, to obtain the basic knowledge on the environmental impact of lumber products, we surveyed energy consumption, amount of wastes and volume of product in processes from felling to sawmilling. From the obtained data, emissions of environmental load substances were quantified and evaluated using LCA.

OUTLINE OF INVESTIGATION

Object of investigation

Sugi (*Cryptomeria Japonica* D.Don) lumber (timber, board, and scantling) was chosen as the object of this investigation. Hita city and Hita district (Oita prefecture) comprise a prominent area for forestry in Japan. Many sawmills are located there, and many sugi logs are sold. The half of the investigation covering felling to market was conducted under the auspices of the Hita forestry guild in Hita city; the rest of the investigation was conducted in two sawmills (sawmill I and sawmill II) in Hita district. In sawmill I, the sawing pattern and transportation of lumber between machines was determined by the operator. On the other hand, in sawmill II, the sawing pattern was controlled by computer, and all the processes until drying were composed of one line. Other differences between sawmill I and II are shown in Table 1.

Table 1. Details of sawmills.

	Sawmill 1	Sawmill 2
Volume of products(m^3/day)	16	100
Number of machines	12	18
Yields at sawmilling process(%)	40	60
Distances from market to sawmills(km)	35	1

Method of investigation

Scoping

The scoping of this investigation covered felling to sawmill production. The distribution channel by which logs are felled and transported to the market was first analyzed. The distribution channel is divided into five processes: felling, transportation I, market, transportation II, and sawmill, as shown Figure 1. In the market, logs are classified by

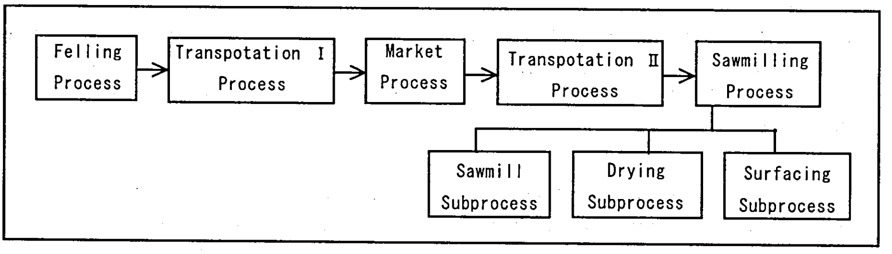

Fig. 1. Flow chart of the distribution channel.

diameter and from there are transported to sawmills. The sawmill process is subdivided into three subprocesses: sawmill, drying, and surfacing.

Inventory data

The following data were investigated in accordance with the processes shown in Table 2. In this study, dust means soot dust which generated in burning diesel oil.

Table 2. Inventory data.

Processes	Inventory data
Felling	Average age of the logs, Clear–cut or thinning, Type of machine, Working hours, Type of fuel, Fuel consumption
Transportation	Type of transportation, Type of fuel, Fuel consumption, Mileage.
Market	Type of machine, Working hours, Volume of product, Type of fuel, Fuel consumption, Electricity consumption.
Sawmill	Type of machine, Working hours, Volume of product, Type of fuel, Fuel consumption, Electricity consumption, Yield of sawmilling, Yield of drying, Yield of surfacing.

Description of the model

・Felling

Logs consist of 60% clear–cut (50 year–old sugi) and 40% thinning (30 year–old sugi). Clear–cut trees are felled 375 m^3/ha. Thinned trees are felled 40 m^3/ha, and a road 220 m in length is created. Lubricating oils for machines (Chain saw, Processor and Scraper) are not evaluated and other articles of consumption of machines except for fuel are omitted.

・Transportation I

Logs are transported 30 km from the felling place to the market by a 10 t truck. The load capacity of a 10 t truck is set at 10 m^3. The mileage of the truck is 3 km/liter.

・Market

Two types of machine (Forklift and Grapple) are used for carrying logs. The log sorter classifies 225 m^3 of logs per day. It is assumed for the calculations that there is no recycling of wastes. However, the transportation of wastes is calculated and included in the market process.

· Transportation Ⅱ

Distances from the market to sawmill Ⅰ and Ⅱ are 35 km and 1km, respectively. A 10 t truck is used to transport to sawmill Ⅰ, while a 10t truck and trailer are used to transport to sawmill Ⅱ. The load capacities of the 10t truck and trailer 10 m^3 and 30 m^3, respectively. Both mileages are set at 3 km/liter.

· Sawmill

A forklift is used for carrying logs into the sawmills. The volume of products is 10 m^3 per day in sawmill Ⅰ. The energy source of drying is kerosene in sawmill Ⅰ. In sawmill Ⅱ, the volume of products is 70 m^3. The energy source of drying is heavy oil. Wood chips generated from the sawmill are often used as an alternative energy source for drying. However, wood chips are not included in the inventory because of lack of data. Both sawmills use electricity for sawmilling and surfacing. Yield of surfacing is set to 100% in both sawmills.

Analysis

The functional unit used in this study was cubic meters (m^3).

The database software named JEMAI–LCA ver.1.0 developed by Japan Environmental Management Association was used for analysis. Table 3 shows impact categories and environmental load substances.

Table 3. List of impact categories and environmental load substances.

Impact categories	Environmental load substances
Global warming	CO_2, N_2O
Acidification	NO_x, SO_2
Eutrophication	NO_x
Winter smog	CxHy
Summer smog	dust, SO_2
Toxins for human body	dust

Inventory analysis

In the inventory analysis, energy consumptions, resource consumptions and emissions of each environmental load substances of each process in the life cycle were calculated.

Impact assessment

The inventory results were classified, characterized and evaluated using two impact assessment methods as follow,

· Ecoindicator 95 method

This method was developed in Europe. The data is based on research in Europe.

· National Institute for Resource and Environment Dt method (Dt method)

This method was developed in Japan. The data is based on research in Japan. However, due to lack of data about emissions to water, fewer impact categories could be evaluated with this method.

Table 4 and Table 5 show characterization factors, standard values and weighting factors used in the two assessments.

Table 4. Characterization factors, standard values and weighting factors (Ecoindicator 95 method).

	Global warming	Acidification	Eutrophication	Winter smog	Summer smog
CO_2	1				
CxHy					0.398
dust				1	
N_2O	270				
NOx		0.7	0.13		
SO_2		1			
Standard values	6.50E+12	5.60E+10	1.90E+10	4.70E+10	8.90E+09
Weighting factors	2.5	10	5	5	2.5

Table 5. Characterization factors, standard values and weighting factors (Dt method).

	Global warming	Acidification	Toxins for humans
CO_2	1		
dust			1
N_2O	310		
NOx		0.7	
SO_2		1	
Standard values	1.36E+12	2.21E+09	2.21E+09
Weighting factors	1.14	1	0.127

RESULTS AND DISCUSSION

The results of inventory analysis are shown in Table 6 and Table 7. Four substances (CO_2, CO, NOx and SO_2) are emitted in large quantities in the sawmill subprocess of both sawmills. This is probably due to the large electricity consumption of sawmill equipment. In addition to the above–mentioned substances, dust was also emitted most in sawmill subprocess in sawmill II. This is probably due to the fuel consumption of forklifts in sawmill I. The other substances are emitted most in the transportation II process. Different tendencies were shown in sawmill II. The influence of kerosene consumption in transportation was more remarkable because sawmill I is located further away from the market.

In terms of the total emissions of each substance for each process, CO_2 showed the highest value of all substances, regardless of which sawmill. Next were NO_X and SO_2. The CO_2 emission of sawmill I and II were ca 260 kg and ca 105 kg, respectively. According to data of the Hiroshima prefecture forestry guild federation, 1 m^3 of sugi lumber can fix ca 200 kg of CO_2. Thus, 75% of CO_2 emissions in sawmill I and 100% of CO_2 emissions in sawmill II are canceled out by the CO_2 that the lumber itself fixes. Wood is known as the sole renewable material that can fix CO_2. However, these results suggest that much depends on the process of conversion to product form.

Table 6. Results of inventory analysis (Sawmill Ⅰ).

Environmental load substances(kg)	Felling	Transportation Ⅰ	Market	Transportation Ⅱ	Sawmilling			Total
					Sawmill	Drying	Surfacing	
CO_2	7.346	23.774	1.771	4.128	55.764	10.943	1.198	104.923
CO	0.001	0.005	0.000	0.001	0.007	0.001	0.000	0.015
C_XH_Y	0.001	0.003	0.000	0.001	0.001	0.001	0.000	0.006
dust	0.001	0.000	0.000	0.000	0.003	0.003	0.000	0.008
N_2O	0.002	0.005	0.000	0.001	0.001	0.002	0.000	0.011
NO_x	0.013	0.025	0.002	0.004	0.040	0.024	0.001	0.109
SO_2	0.004	0.012	0.001	0.002	0.041	0.006	0.001	0.067

Table 7. Results of inventory analysis (Sawmill Ⅱ).

Environmental load substances(kg)	Felling	Transportation Ⅰ	Market	Transportation Ⅱ	Sawmilling			Total
					Sawmill	Drying	Surfacing	
CO_2	7.346	23.774	1.771	86.678	116.617	12.971	9.988	259.144
CO	0.001	0.005	0.000	0.017	0.020	0.001	0.001	0.045
C_XH_Y	0.001	0.003	0.000	0.011	0.009	0.001	0.000	0.026
dust	0.001	0.000	0.000	0.001	0.002	0.004	0.000	0.009
N_2O	0.002	0.005	0.000	0.018	0.014	0.003	0.000	0.041
NO_x	0.013	0.025	0.002	0.092	0.098	0.028	0.006	0.263
SO_2	0.004	0.012	0.001	0.042	0.071	0.007	0.008	0.144

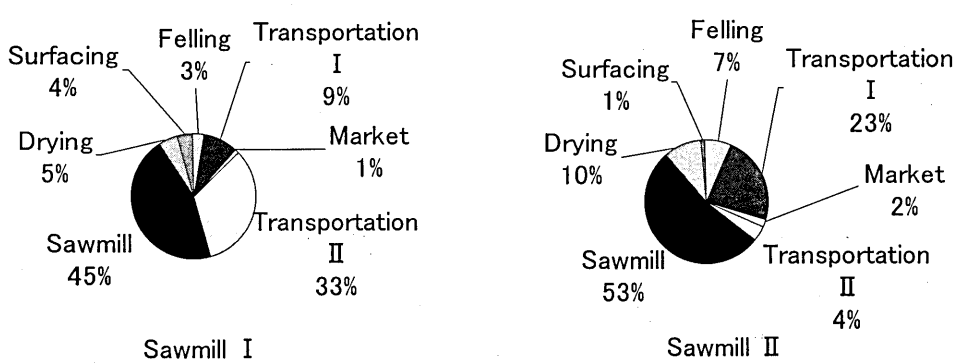

Fig. 2. Details of CO_2 emission.

Figure 2 shows details of CO_2 emissions of each subprocess for sawmill I and II. The sawmill subprocess made up nearly 50% in both results. Nevertheless, there are differences in actual values between the results of the two sawmills, not only in the sawmill subprocess but also in the other processes, especially transportation. The difference in sawmill subprocesses is probably due to the respective yields of the sawmills, originating in the differences in sawmill equipment and the sawmilling lines. The difference in transportation II is due to the difference in the distance from market of the two sawmills.

From these results, effective means for reducing CO_2 emissions are suggested as follow: the sawmill equipment can be rationalized to improve the yield in the sawmill subprocess, and the sawmilling line can be made more highly effective; in addition, it is important to plan construction of sawmills so that the distance from the sawmill to the market will be shortest.

Impact assessment

Ecoindicator 95 method

The results of impact assessment in both sawmills by the Ecoindicator 95 method are shown in Figure 3. From this figure, global warming has the largest rate among all impact categories. Acidification, eutrophication, summer smog and winter smog follow, in that

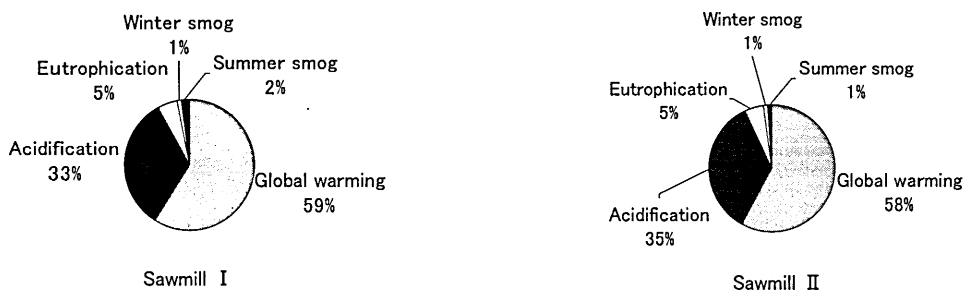

Fig. 3. Results of impact assessment (Ecoindicator 95 method).

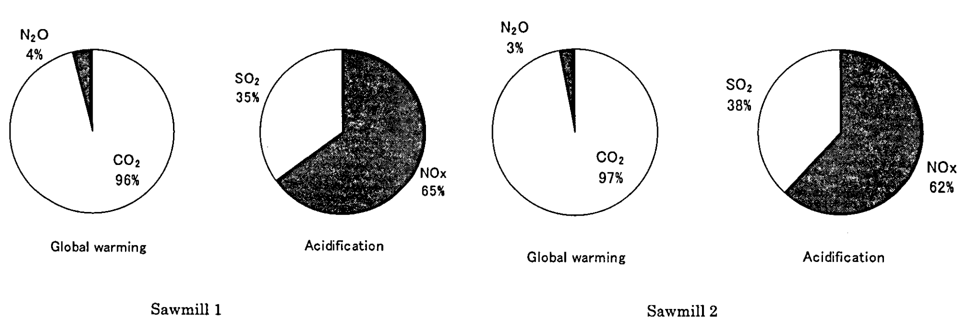

Fig. 4. Details of global warming and acidification (Ecoindicator 95 method).

order.

The details of global warming and acidification in both sawmills are shown in Figure 4. CO_2 made up 96% of the factors for global warming and NOx made up 63% of the factors for acidification.

National Institute for Resources and Environment Dt method (Dt method)

The results of impact assessment in both sawmills by the Dt method are shown in Figure 5. As with the Ecoindicator 95 method, global warming was shown to have the largest rate. Acidification and toxins to humans followed.

The details of global warming and acidification are shown in Figure 6. In the Dt method, CO_2 made up 95% of the factors responsible for global warming, and NOx made up 50% of the factors responsible for acidification.

From the above-mentioned results of impact assessment using both Ecoindicator 95 and Dt methods, it became clear that global warming and acidification comprise almost the entire impact. The major substances that contributed to global warming and acidification were CO_2, NOx, SO_2 and CH_4. The contribution to global warming by CO_2 was especially remarkable. Furthermore, the results of inventory analysis clarified that each substance was emitted most in the sawmill subprocess. Overall, this study showed that

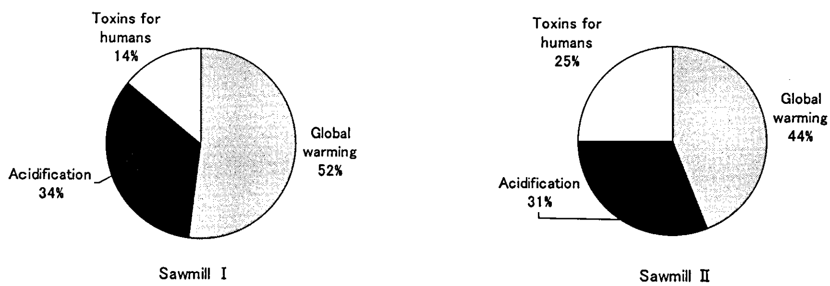

Fig. 5. Results of impact assessment (Dt method).

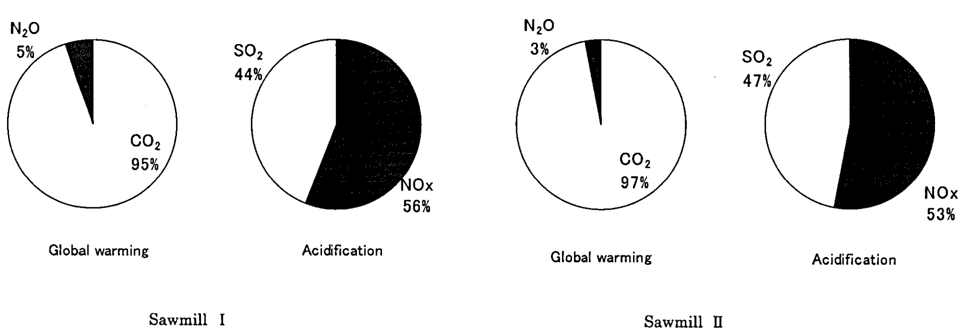

Fig. 6. Details of global warming and acidification (Dt method).

the sawmill subprocess has the greatest role in the environmental load of lumber products.

CONCLUSIONS

In this study, to obtain basic knowledge of the environmental impact of lumber products, we surveyed energy consumption, amount of wastes, and volume of product in the related processes from felling to sawmilling. From the obtained data, emissions of environmental load substances were quantified and evaluated using LCA. The main results were as follow:

1) CO_2, CO, NOx, and SO_2 were emitted in large quantities from the sawmill subprocess. This is probably due to the large electricity consumption of sawmill equipment.
2) The amount of CO_2 emissions depends on the yield of the sawmill and the distance from market of the sawmill. Therefore, effective means to reduce the CO_2 emissions were suggested as follow: the sawmill equipment can be rationalized to improve the yield in sawmill subprocess, and the sawmilling line can be made more highly effective; in addition, it is important to plan construction of sawmills so that the distance from the sawmill to the market will be shortest.
3) Global warming and acidification comprise almost the entire result of the impact assessment of both sawmills. The substances that contributed to global warming and acidification were CO_2, NOx, SO_2, and CH_4, and each substance was emitted most in the sawmill subprocess. Overall, this study showed that the sawmill subprocess has the greatest role in the environmental load of lumber products.

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