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Title

Life cycle assessment of woody biomass energy utilization: case study in Gifu Prefecture, Japan

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Abstract

This paper discusses the effectiveness of a woody biomass utilization system that would result in increased net energy production through wood pellet production, along with energy recovery processes as they relate to household energy demand. The direct environmental load of the system, including wood pellet production and utilization processes, was evaluated. Furthermore, the indirect load, including the economic impact of converting the existing fossil-fuel-based energy system into a woody-biomass-based system, on the entire society was also evaluated. Gifu Prefecture in Japan was selected for a case study, which included a comparative evaluation of the environmental load and costs both with and without coordination with the wood pellet production process and the waste-to-energy of municipal solid waste process, using the life cycle assessment

methodology. If the release of greenhouse gases from the combustion of wood pellets is included in calculations, then burning wood pellets results in unfavorable environmental consequences. However, when the reduced indirect environmental load due to the utilization of wood pellets versus petroleum is included in calculations, then favorable environmental consequences result, with a net reduction of green house gases emissions by 14 060 ton-CO_{2eq}.

1. Introduction

Greenhouse gas (GHG) emissions in Japan were approximately 1 209 million ton-CO_{2eq} in 2009 [1]. Approximately 89% of these emissions are derived from primary energy utilization, which implies that conversion of the existing fossil-fuel-based energy system to more environmentally benign systems is an important approach for efficiently reducing GHG emissions. The utilization of renewable energy holds promise not only from the viewpoint of reducing GHG emissions but also from that of conserving fossil fuel. On the basis of this concept, energy recovery using renewable resources is now being pursued worldwide, including Japan. Let us take woody biomass as an example of such a renewable energy source. The land area of Japan is dominated by forests, which account for approximately 68.2% of its land. This high percentage is comparable to that of Sweden (66.9%) and Finland (73.9%) [2]. For this reason, research and development on the utilization of the energy of this woody biomass is being actively pursued in a number of local municipalities in Japan [3,4]. The Investors Group on Climate Change (IIGCC) [5] notes that Japan aims to reduce GHG emissions in developed countries by 20%–45% of the 1990 level by 2020 and further reduce that figure by 80%–95% by 2050. The amount of woody biomass in Japan that is potentially utilizable in such forms as unused lumber and wood waste from construction sites and lumber mills is 20.1 million tons per year [6]. If this biomass is entirely utilized to make electricity, it has the potential to reduce GHG emissions in Japan by 1.3%. This statistic shows why woody biomass offers one of the most effective options for reducing GHG emissions.

The focus of the actions of local municipalities has been to set qualitative goals for the utilization of woody biomass. These actions include some quantitative considerations such as how to effectively utilize woody biomass to reduce the environmental load and what forms of energy demand can be met by effective substitutes for fossil fuel. The promotion of biomass energy utilization must also be addressed from various social, economic, and environmental perspectives. If the economic and environmental viewpoints are focused on, the following three issues are of primary concern. The first issue is the importance of system design from the perspective of life cycles. Although storage stability and usage are increased if biomass is processed as pellets or liquid fuel, the energy consumed by such processing is also increased, along with the processing cost [7, 8]. Japan in particular has a great deal of mountainous area in proportion to its huge forested area, thereby turning costly operations such as tree trimming and transportation into a severe obstacle [9-11]. As a consequence, the total cost and energy consumption tend to be larger from the perspective of life cycles. That said, technological development in energy utilization and investigations into cost reduction have been carried out in many Japanese municipalities [12, 13]. Many studies have also been conducted on transportation, technologies for energy utilization, and optimization of regional environmental utilization systems from the viewpoints of economics and the environment [14-20]. No studies, however, have sought to investigate how to design a system to meet the demand for energy at lower cost and with higher efficiency.

The second important issue is the indirect impact of the introduction of a new energy system. If the direct environmental effect is defined as the reduction in environmental load achieved by fossil fuel savings, the reduction in the indirect environmental load achieved by converting the existing fossil-fuel-based energy system into a biomass-based system can be defined as an indirect environmental effect. To take the case of heating oil, CO_2 is emitted not only in its burning (direct CO_2 emission) but also in its production (indirect CO_2 emission). This implies that a strategy for saving fossil fuel contributes to a reduction in both direct and indirect CO_2 emissions. Transformation of the existing fossil-fuel-based energy system offers the possibility of converting the social activities of related businesses such as these in the future. For this reason, it is important to evaluate both these effects. Studies of biomass energy utilization, however, have been primarily focused on the direct effects, with few studies addressing the combination of direct and indirect effects [19, 21-22]. There is also an apparent lack of investigation into the degree of impact that woody biomass can have on the conversion of the energy system of the entire society.

The third important issue is the question whether the utilization of biomass is a carbon neutral process. The burning of biomass is said to be carbon neutral due to a canceling out process in nature, but CO_2 is emitted by the process itself, if biomass is burned as a fuel. With regard to this point, Rabl *et al*. [23] assert that the emission and removal of CO_2 should be specifically measured at each stage of the life cycle. Johnson [24] also indicates that biomass fuels are not always carbon neutral and claims that they can even be far more carbon positive than fossil fuels. It is therefore important to evaluate the effectiveness of the utilization of woody biomass energy without presuming carbon neutrality.

The aim of this study was to design a woody-biomass-based energy system to replace the existing fossil-fuel-based system and thus reduce both costs and the environmental load. In this study, a system for recovering energy from woody biomass using wood pellets for household heating was designed. Furthermore, an energy recovery complex that is based on coordination with a municipal solid waste (MSW) management system to reduce the energy consumed in the production of wood pellets with the energy generated by the incineration of wood waste was also designed. Using life cycle assessment (LCA), the cost and direct environmental load of the generation of wood biomass, the production of wood pellets, and the associated energy recovery in households were first evaluated. Then, the indirect environmental load of partially converting the existing fossil-fuel-based energy system to a biomass-based system was evaluated. The environmental impact from the perspectives of environmental loads and resource conservation was also evaluated. In this paper, the effectiveness of introducing a biomass-based energy system is discussed.

2. Materials and methods

2.1. Case study area

For our case study, Gifu Prefecture in Japan was selected, whose geographical location is shown in Figure 1. Gifu Prefecture is located roughly in the center of Japan and had a population of approximately 2.1 million in 2006. Its land area is approximately 10 598 km^2, with the forest area accounting for 82% of that area [25]. This ratio of forest area to land area is second largest among Japanese prefectures. In this area, 16 450 thousand ton-CO_{2eq} was emitted in 2008 [26]. In this area, heating and hot-water supply in households in this area is 2.3 times (39%) the mean value for Japan. Because the central and north regions of this area have a cold climate, energy consumption of heating oil for household is greater than the mean value of consumption in Japan. Reduction of CO_2 emission derived from energy demand is severe problem, and an energy utilization of woody biomass can therefore be highly effective in this area.

Figure 1 Location of case study area

2.2. System boundaries

Figure 2 shows the system boundaries considered in this study. In this system, unused lumber and wood waste were targeted as sources of woody biomass. Unused lumber includes lumber that is not utilized for construction or other industrial materials such as thinned wood and the roots of soft wood. The production and utilization of wood pellets from such lumber involves processes such as tree trimming, transportation, pellet production, and energy recovery. The utilization of wood pellets is assumed to contribute to the conservation of heating oil. Wood waste comprises branches and leaves from households and industrial waste from construction sites, lumber mills, and the like. These materials are collected, transported, and incinerated together with MSW in incineration plants. Electricity produced by incineration plants contributes to savings in the system's electricity consumption. System electricity and heating oil are usually the utilities employed for wood pellet production. In the energy recovery complex, steam and electricity from incineration plants are assumed to replace heating oil in the dehydration process and system electricity in pellet mills because of energy savings in the entire system. Then, the system that is combined wood pellet production and MSW incineration for energy savings is named as “coordination” system. On the contrary, the system that is not combined is named as “no coordination” one.

Figure 2 System boundaries

2.3. Evaluation method

To carry out a comparative evaluation of systems between coordination system and no coordination one, three cases for evaluation was considered, as shown in Table 1: C-1 represents the case of no coordination, with the energy for producing wood pellets provided by heating oil and the system's electricity. C-2 and C-3 represent cases in which there is coordination, and the energy for producing wood pellets is replaced with steam and electricity from incineration plants. In cases C-1 and C-2, unused lumber is utilized for the production of wood pellets. Then, unused lumber indicates that does not harvest and does not be used. To compare the three cases on the LCA basis, the production of heating oil is accounted for in cases C-2 and C-3. The environmental load of the heating oil in used in the manufacturing process is also accounted for in the evaluation. Additionally, in case C-3, unused lumber and mature lumber are utilized. C-3 was defined in order to elucidate the maximum wood pellet production if mature lumber that grows in the case study area is not used. In this area, although approximately 2 000 thousand m^3 of mature lumber is annually grown, 29% of the mature lumber that is possible to process for construction and paper manufacture is utilized only to meet those industrial demands, and imported lumber is used to fulfill the remaining demand for other needs [25, 26]. Mature lumber continues to be grown in a sustainable manner each year is utilized to fulfill this demand and that the lumber that exceeds the industrial demand is utilized for wood pellet production. On the basis of this assumption, approximately 46% of the mature lumber can be utilized as wood pellets.

Table 1 Evaluation cases

The environmental load that was targeted included GHGs (CO_2, CH_4, and N_2O), NO_x, SO_x, and final disposal. Total environmental loads excluding final disposal are calculated by following formulas.

$$E_i = e_{pi} + e_{wi} + e_{ri} \quad (1)$$

$$e_{pi} = W_p \times \sum_x u_{pxi} \quad (2)$$

$$e_{wi} = W_w \times \sum_y u_{wyi} \quad (3)$$

$$e_{ri} = (I - (I - M)A)^{-1} \times F \times U_{ri} \quad (4)$$

where,

E: total environmental load,

e_p: environmental load derived from wood pellet production and utilization,

e_w: environmental load derived from waste wood incineration,

e_r: environmental load derived from economic ripple effect,

W_p: amount of wood pellet,

W_w: amount of waste wood,

u_p: unit environmental load of wood pellet production and utilization,

u_w: unit environmental load of waste wood incineration,

I: unit matrix,

M: import matrix,

A: matrix of coefficients,

F: vector of final disposal,

U_r: vector of unit environmental load,

i: environmental load (CO_2, CH_4, NO_2, NO_x and SO_x),

x: processes of wood pellet production and utilization (tree trimming, transportation of lumber, chipper, pulverizer and dehydrator, pellet mill, transportation of wood pellets, heating of households and burning of biomass),

y: unit environmental load of waste wood (incineration of wood waste and energy recovery).

Life cycle inventory data about each process from both the literature and surveys were collected, as shown in Figure 2 [13, 27-30]. Although these life cycle inventory data is based on case study in Japanese local area, to validate whether these data is valid in total Japan is difficult because the few related data is published. Therefore, sensitivity analysis was conducted after life cycle inventory analysis. The functional unit employed is the environmental load emission for the transportation, production, and energy recovery of 1 ton of wood pellets or 1 ton of wood waste. Calculation of the life cycle inventory data accounted for not only the processes shown in Figure 2 but also the manufacture of trucks, chippers, pulverizers, and pelletizers and packing of wood pellets and so on. The wood pellets were assumed to be manufactured, packed, and then consumed immediately; that is, and the process storage was not taken into account.

Table 2 lists the unit cost and unit environmental load for each process. The direct environmental load by multiplying the annual generation of unused lumber or wood waste disposal and the unit environmental load of each process was calculated. The direct environmental load was also calculated by multiplying the annual wood waste disposal and the unit environmental load of each process. The environmental load was calculated not only in terms of transportation, production, and energy recovery, but also in terms of the construction of incineration plants and the manufacture of trucks and equipment for wood pellet production. The cost was calculated by multiplying the annual generation of unused lumber or wood waste disposal and the unit cost.

Table 2 Unit cost and unit environmental load for each process

The unit environmental load of Table 2 was calculated by multiplying the life cycle inventory data based on literature survey and unit environmental load by applying JEMAI-LCA Pro, an LCA software program for Japan. And these loads were summed up to obtain the total direct environmental load. GHGs were evaluated by weighting in the CO_2 equivalent using the factor of global warming potential for a time horizon of 100 years—CO_2: 1, CH_4: 25, and N_2O: 298 [30]. Acidification gases were also evaluated by weighting in SO_2 equivalents using the factor of deposition-oriented acidification potential, SO_x: 1, NO_x: 0.72 [32]. The calculations also accounted for environmental load reduction derived from savings in heating oil and system electricity at power stations and form the substitution of chemical fertilizers with the ash generated from wood pellet incineration, which is an organic fertilizer. In this study, the gross CO_2 emissions, including CO_2 derived from wood pellet burning, were calculated. The life cycle inventory data of energy recovery by waste to energy (WTE) were assumed to utilize for actual incineration plants in the case study area, where the WTE process is already conducted at several incineration plants. Therefore, additional production of steam and electricity and the environmental load emissions derived from wood waste were allocated.

Next, the indirect environmental load was calculated by applying economic ripple effect of the input-output table. The input-output analysis is possible to evaluate the ripple effect if the interindustry transactions were changed because of change of industry structure or economic fluctuation. This economic ripple effect is possible to convert to the environmental load basing on LCA methodology. In this manuscript, the economic ripple effect by changing the structure of existed energy industries by introducing new industry based on renewable energy was applied for calculation of indirect environmental load. For this calculation, industrial activities such as oil production and power generation were assumed to change by the substitution of woody biomass for heating oil and system electricity. These changes in activity are converted into an indirect environmental load by multiplying the economic ripple effect of the input-output table [33] and the unit environmental load emission database of each industry (3EID [34]).

Finally, a comparative evaluation of the direct and indirect environmental loads was carried out in three cases. A life cycle impact analysis was also carried out from the viewpoint of environmental loads and resource conservation using LIME (lifecycle impact assessment method based on endpoint modeling). LIME is a method for life cycle impact analysis that virtually evaluates the degree to which humans and the ecosystem suffer environmental impacts in monetary terms [35]. Indicator value of LIME method is calculated by following formula.

$$I = \sum_z E_{impz} \times \alpha_z \qquad (5)$$

where,

I: indicator value,

E_{imp}: environmental impact,

α: unit environmental impact,

z: environmental impact (GHG, acidification and final disposal).

Global warming in the emission of GHGs that do not take into account carbon neutrality, acidification in acidification gases, change in land use involving landfill construction (final disposal), and resource consumption (heating oil and heavy oil savings) were the target environmental impacts.

2.4. Geographic information data

The annual generation of unused lumber was estimated from the forested area and its annual growth rate [25]. Figure 3 shows the spatial distribution of unused lumber (each square in the mesh represents an area of 1 km^2). To avoid the inclusion of costly tree trimmings, unused lumber from national parks or from areas steeper than 35° was not considered. As a result, the annual generation of unused lumber was estimated as 104 400 tons, from which 65 780 tons of wood pellets can be produced. The annual generation of unused lumber and mature lumber that exceeds industrial demand was estimated at 300 740 tons, from which 189 470 tons of wood pellets can be produced. At present, the annual energy recovered from unused lumber in the case study area is 12 400 tons, and the annual generation was calculated by subtracting this annual energy recovery from the annual production of wood pellets. Incidentally, 38 790 tons of wood waste is estimated to be lost each year by being sent directly to landfills and incineration facilities with no attempt at energy recovery. This amount corresponds to approximately 24% of the annual disposal of wood waste in the case study area. Four wood pellet production plants are assumed to locate next to the incineration plants, as shown in Figure 3. Each plant collects unused lumber in a 40-km buffer range, and the minimum road transportation distance from the trimming areas to the plants was calculated. The municipal government of each city administers the transportation of wood waste to the plants and uses the minimum road transportation distances obtained from the Google Maps API and MappleX Ver. 9 (Shobunsha Publications, Inc.).

Figure 3 Spatial distribution of lumber and wood pellet production plants

The recovery of energy from wood pellets in residential areas presents difficulties because of the smoke and air pollution caused by pellet stoves. This would not present a difficulty in areas with a low population density (150 per km^2), since scores of local governments in Japan have offered financial incentives for the use of pellet stoves. Wood pellets were assumed to be transported to 12 wood pellet utilization areas in a cold region, as shown in Figure 4. In addition, one centrally located wood pellet production plant in the case study area would double as the utilization area. The minimum road transportation distance from the plants to the demand area was also assumed.

Figure 4 Wood pellet utilization area and transportation of wood pellets

3. Results and discussions

3.1. Life cycle inventory analysis

Figure 5 shows the results of a life cycle inventory analysis of each process. In Figure 5, bar graph indicates the result of GHG emission and cost of each process calculated by formula (1) to (3). And line graph indicates the total of GHG emission and cost. The total of GHG emission was classified to the result including carbon neutrality or excluding carbon neutrality. The case of no coordination signifies that heating oil and system electricity are utilized for wood pellet production, and the case of coordination signifies that steam and electricity from an incineration plant are utilized.

Figure 5 Result of unit GHG emission and unit cost

First, the results of unit GHG emissions were focused on. If carbon neutrality of burning woody biomass was taken into account, the total GHG emissions are in the range of -1 029 to -1 337 kg-CO_2eq/ton-pellet due to the greater effect of the substitution of heating oil in households. On the other hand, if carbon neutrality of burning woody biomass was not taken into account, GHG emissions are in the range of 135 to 438 kg-CO_2eq/ton-pellet. Thinking of carbon neutrality is applied in broad research field concerning climate change prevention. Nevertheless, the fact that so much GHG is emitted by the burning of woody biomass burning should be recognized.

A slight amount of GHG is emitted in the transportation process. And a relatively large amount is emitted by dehydrators and pellet mills in the case of no coordination, due to the utilization of heating oil and system electricity in these processes. On the other hand, total GHG emissions are reduced by approximately 70% in the case of coordination, as opposed to no coordination. This result indicates process improvement in the pulverizer and dehydrator and the pellet mill processes is quite important to reduce total GHG emission.

The sensitivity analysis was conducted to investigate an influence of the result when value of unit environmental load was changed. In this analysis, no coordination case including carbon neutrality was picked up. Then, change of total unit GHG emission was investigated if unit GHG emission of tree trimming, transportation of unused lumber, chipping, pulverizer and dehydrator, pellet mill and transportation of wood pellet. Figure 6 indicates the result of sensitivity analysis. In Figure 6, line graph indicates the total unit GHG emission. As the result, total unit GHG emission was changed to positive value when increasing rate of unit environmental load of each process is exceeded 250%. Pulverizer and dehydrator and pellet mill processes have big influences This result indicates that an advantage by wood pellet utilization keeps till unit environmental load increases 3.5 times from original value.

Figure 6 Result of sensitivity analysis

Next, the results of unit cost were focused on. Unit cost is in the range of 93 to 591 USD/ton-pellet. This cost reduces by approximately 86% in the case of coordination, as opposed to that of no coordination. Although the substitution of heating oil usage was taken into account, these cases nonetheless incur a cost due to the utilization of system electricity and the fuel costs of wood pellets. This is not to say, however, that wood pellets should not be utilized for energy recovery. The “2050 Japan Low-Carbon Society” scenario team [36] has estimated that the corresponding average reduction costs are in the range of 25 000 JPY/ton-C to 39 900 JPY/ton-C (87 to 140 USD/ton-CO_2). If the CO_2 emissions generated by burning woody biomass were not taken into account, the cost reduction is in the range of 70 to 644 USD/ton-CO_{2eq}. This implies that the utilization of wood pellets with coordination case is in fact advantageous in reducing GHG emissions.

3.2. Evaluation including direct and indirect environmental load emissions

Table 3 shows the results for annual direct and indirect environmental load emissions with the introduction of a woody-biomass-based energy system in the evaluation cases calculated by formula (1) to (4). The results for GHG emissions show that in case C-1, 21 100 ton-CO_{2eq} is emitted, which is an undesirable value compared with those in cases C-2 and C-3. In case C-2, emissions are reduced by 3 470 ton-CO_{2eq}, and in case C-3, they are reduced by 14 060 ton-CO_{2eq}. Indirect GHG emissions are reduced by 9 680–34 280 ton-CO_{2eq}. It is worth noting that in all cases, NO_x and SO_x emissions are reduced, though the reduction is greater in cases C-2 and C-3 than in case C-1. On the other hand, 2 140 tons of final disposal derived from the incineration ash of wood waste are discharged in all cases. The wood waste, however, is sent directly to landfills and is incinerated without the expenditure of energy resources. This increase in final disposal is not, therefore, a severe problem.

Table 3 Results for the evaluation cases

3.3. Environmental impact analysis

Finally, the environmental impacts of introducing a biomass-based energy system were evaluated from the viewpoint of its comprehensive environmental effects. Figure 7 shows the results of environmental impacts using the LIME method calculated by formula (5). In Figure 7, bar graph indicates the result of indicator value of each environmental impact. And line graph indicates the total of indicator value. The results are negative if the indicator value is positive and vice versa. The results thus indicate that case C-1 has a rather negative result because its impact on global warming is greater than its other impacts. Cases C-2 and C-3, on the other hand, have positive results, because their impact on global warming shifts to a negative value. Resource consumption is the main positive indicator in all cases, which implies that the conversion of a fossil-fuel-based energy system has significance not only in the prevention of global warming but also in resource conservation.

Figure 7 Results of environmental impact

4. Conclusions

In Japan, a number of local municipalities plan to make greater use of renewable energy sources, including woody biomass. Although the goals of such energy utilization are set in qualitative terms, there are few quantitative goals that would effectively reduce the environmental load by taking into account concrete methods to utilize biomass in their regions. To resolve this problem, an energy recovery complex that combines energy recovery from woody biomass and MSW incineration was proposed, taking into account the reduction in energy utilization in each process that is involved and its energy demand impact on households. The environmental effectiveness of this complex as applied to Gifu Prefecture in Japan was also evaluated.

Our results indicate that the proposed energy recovery complex offers the advantages of reduced environmental loads, costs, and environmental impacts. If the release of greenhouse gases from the combustion of wood pellets is included in calculations, then burning wood pellets results in unfavorable environmental consequences. However, when the reduced indirect environmental load due to the utilization of wood pellets versus petroleum is included in calculations, then favorable environmental consequences result, with a net reduction of green house gases emissions by 14 060 ton-CO_{2eq}.

The utilization of the energy of wood pellets is advantageous from the viewpoint of the cost of reducing GHG emissions. Future areas of investigation include an evaluation of the potential reduction in GHG emissions by considering the acceptability of biomass energy utilization in households and an evaluation of a combination of other biomass energy technologies to elucidate what constitutes optimal biomass energy utilization, by taking into account several forms of energy demand.

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Figure 1 Location of case study area

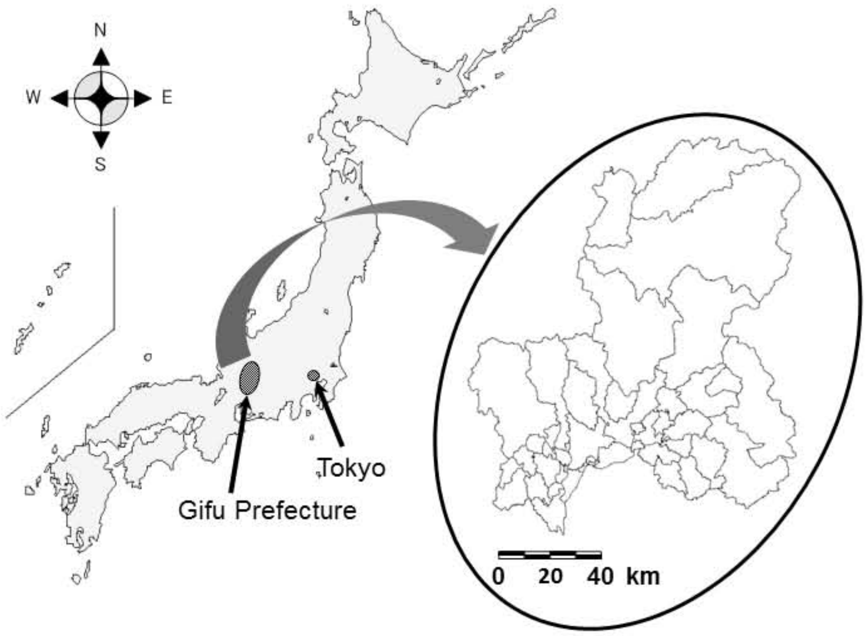


Figure 2 System boundaries

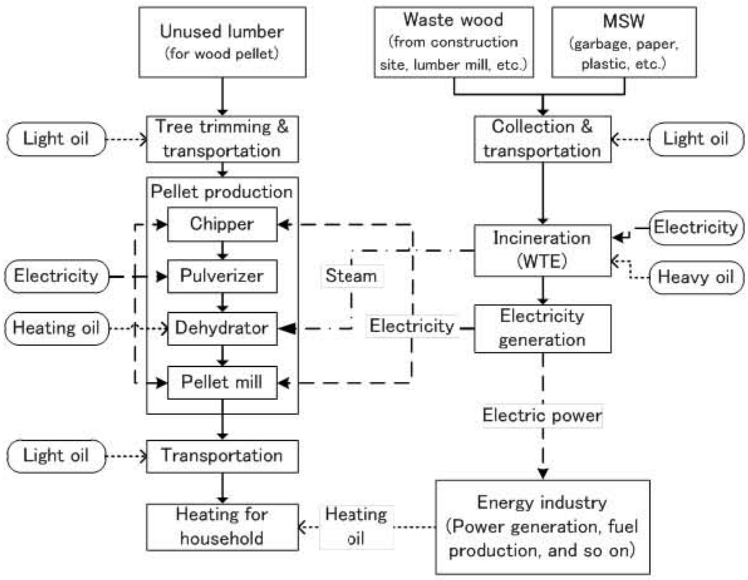


Figure 3 Spatial distribution of lumber and wood pellet production plants

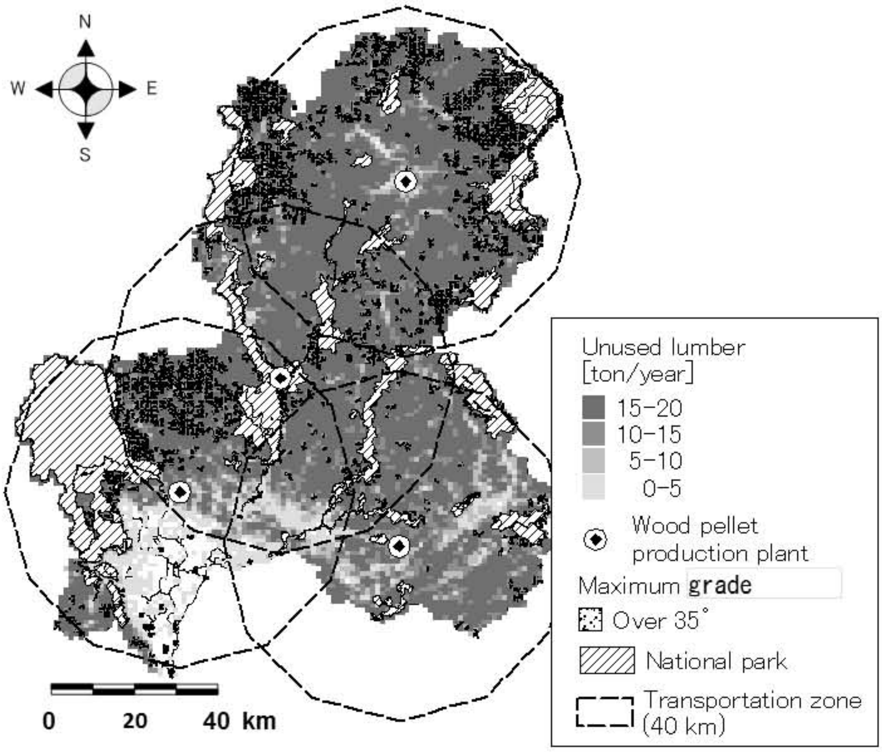


Figure 4 Wood pellet utilization area and transportation of wood pellets

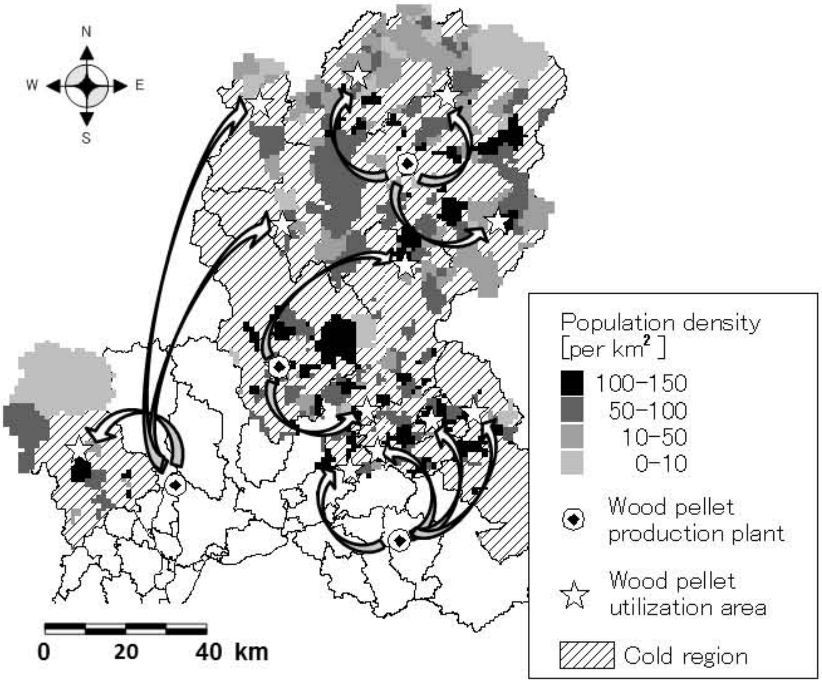


Figure 5 Result of unit GHG emission and unit cost

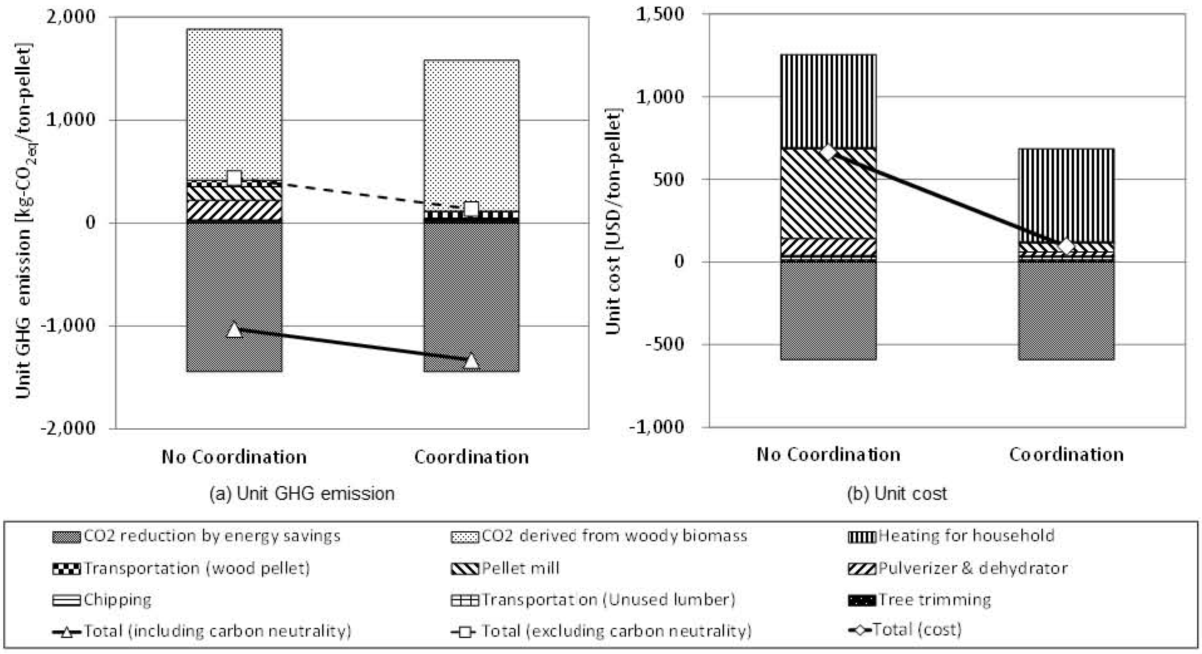


Figure 6 Result of sensitivity analysis

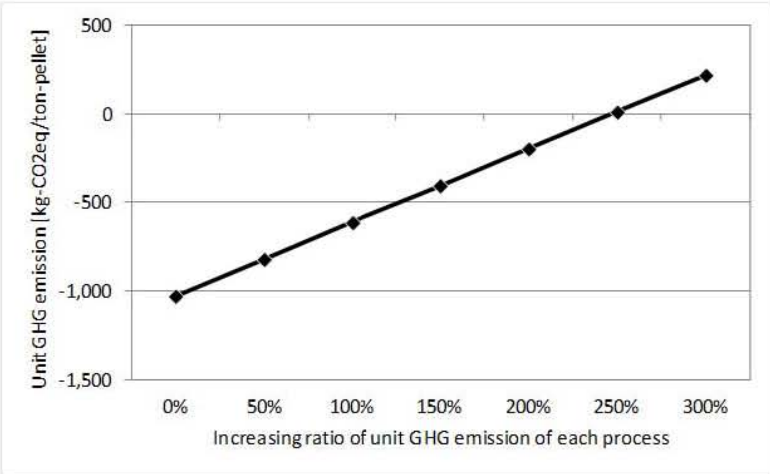
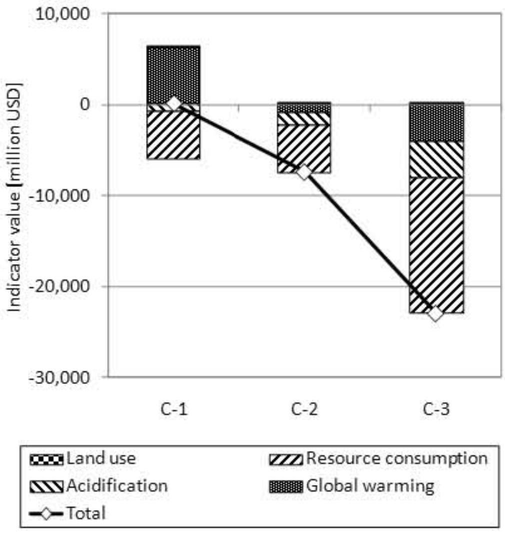


Figure 7 Results of environmental impact



C-1: No coordination (Unused lumber), C-2: Coordination (Unused lumber), C-3: Coordination (Unused lumber and mature lumber exceeded industrial demand)

Table 1 Evaluation cases

	Descriptions	Energy supply for wood pellet production	Materials for wood pellet production
C-1	No coordination	Heating oil and system electricity	Unused lumber
C-2	Coordination	Steam and electricity from WTE plant	Unused lumber
C-3	Coordination	Steam and electricity from WTE plant	Unused lumber and mature lumber (Exceeded industrial demand in the case study area)

Table 2 Unit cost and unit environmental load for each process

	CO_2	CH_4	N_2O	NO_x	SO_x	Ash	Cost**
Unit of donation *	kg-CO_2	g-CH_4	g-N_2O	g-NO_x	g-SO_x	kg-residue	USD
Tree trimming [*/ton-pellet]	13.41	0.45	0.26	7.55	4.92	-	12.31
Transportation of lumber [*/ton-pellet]	7.34	0.10	0.059	8.25	5.09	-	19.50
Chipper [*/ton-pellet]	0.52	0	0	0.67	0.41	-	2.86
Pulverizer & Dehydrator [*/ton-pellet]	8.20	0	0	7.33	4.48	-	25.85
Pellet mill [*/ton-pellet]	12.06	0	0	15.69	9.55	-	54.14
Transportation of wood pellets [*/ton-pellet]	16.99	0.48	0.27	12.23	7.79	-	8.68
Heating for households [*/ton-pellet]	2.73	0	0.024	79.98	34.40	80	561
CO_2 derived from burning of biomass [*/ton-pellet]	1,467	-	-	-	-	-	-
Environmental load reduction through utilization of biomass energy [*/ton-pellet]	-1,445	-49.86	-28.36	-760	-521	-	-591
Incineration of wood waste [*/ton-wood waste]	167	0	0	140	59.41	7,295	-
Environmental load reduction from utilization of WTE [*/ton-wood waste]	-163	0	0	-21.57	-14.38	0	-

**1 USD = 77.93JPY (12/5/2011)

Table 3 Results for the evaluation cases

	GHG emission [ton-CO_{2eq}/year]			Acidification [ton-SO_{2eq}/year]			Final disposal of ash [ton/year]		
	C-1	C-2	C-3	C-1	C-2	C-3	C-1	C-2	C-3
Environmental load derived from wood pellet production and utilization	34,282	9,677	17,896	-18	-33	-102	0	0	0
Environmental load derived from incineration of waste wood incineration	-1,762	-1,761	-1,761	4	4	4	2,137	2,137	2,137
Environmental load derived from Economic ripple effect	-11,390	-11,381	-30,198	-26	-26	-72	0	0	0
Total	21,130	-3,466	-14,063	-40	-55	-170	2,137	2,137	2,137