Economic, societal, and environmental evaluation of woody biomass heat utilization: A case study in Kobe, Japan

Zhou, J.

Tabata, T.

(Citation)
Renewable Energy,188:256-268

(Issue Date)
2022-04

(Resource Type)
journal article

(Version)
Accepted Manuscript

Title

Economic, societal, and environmental evaluation of woody biomass heat utilization: A case study in Kobe, Japan

Author names and affiliations

Zhou, J. [1], Tabata, T.[1, *]

[1]Graduate School of Human Development and Environment, Kobe University, Japan

*Corresponding author details, tabata@people.kobe-u.ac.jp

Present address

3-11 Tsurukabuto, Nada-ku, Kobe 657-8501 JAPAN

Highlights

- Evaluation model for the heat utilization of woody biomass was developed.
- A woody biomass–heated hot bath facility was assumed at Mt. Rokko, Japan.
- Societal value regarding tourist consciousness was estimated using CVM.
- Cost difference of fuels (wood chip and fossil fuels) was evaluated.
- GHG emissions from fossil fuel substitution in wood chips were evaluated.

Abstract

This study aims to develop a model for the integrated evaluation of woody biomass heat utilization considering the environment, economy, and society. Herein, a woody biomass heat utilization business was virtually operated at Mt. Rokko, Kobe, Japan. In the societal impact assessment, a questionnaire survey was conducted to clarify tourist opinions regarding the hypothetical hot bath facility, and its societal value was estimated using the contingent valuation method. The total benefit estimated based on the willingness to pay was 5.92 million USD. In the economic evaluation, an economic model was constructed using life cycle cost. If kerosene was added to the wood chips, the optimum scale of the wood chip boiler installed was 687 kW, and the fossil fuel substitution rate reached 95.9%. The difference between the annual cost was −126.74–100.12 thousand USD. In the environmental impact assessment, a life cycle assessment was conducted to clarify how the use of woody biomass heat may change the environmental impact of the hypothesized hot bath facility. The net greenhouse gas emissions per 1 GJ were −69.9 kg-CO_{2eq}/GJ in kerosene.

Keywords

Woody biomass; heat utilization; regional revitalization; contingent valuation method; life cycle assessment; life cycle cost

Abbreviations

3EID: Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables
CHP: Combined Heat and Power
CVM: Contingent Valuation Method
FIT: Feed-in Tariff
FY: Fiscal Year
GHG: Greenhouse gas
IDEA: Inventory Database for Environmental Analysis
JANRE: Japan Agency for Natural Resource and Energy
JFA: Japan Forest Agency
LCA: Life Cycle Assessment
LCC: Life Cycle Cost
MWTP: Marginal Willingness to Pay
RHI: Renewable Heat Incentive
WTP: Willingness to Pay

1. Introduction

Japan has abundant forest resources, accounting for approximately 70% of the total land area. According to the Japan Forest Agency (JFA) [1], the forest stock reached 5.2 billion m^3 in 2017, which is nearly 2.7 times that in 1966. After World War II, timber demand expanded rapidly owing to the recovery and development of the country. The national government promoted forestation and forestry development. However, as timber was imported into Japan with a high price advantage, the market share of domestic timber gradually declined, and the supply volume of domestic timber dropped sharply. Due to the loss of competitiveness of domestic timber, large forest areas were left unattended, and forest area increased rapidly. In 1960, the self-sufficiency rate of domestic timber was approximately 89% [1]. The self-sufficiency rate decreased to 19% in 2002. Since 2002, the self-sufficiency rate has gradually recovered, reaching 36% in 2017 [1]. One reason that the self-sufficiency rate has recovered is the decrease in the supply of imported timber owing to the decrease in the total demand for timber. Since 1990, forest stocks have been increasing at a rate of 78 million m^3 per year. The supply of domestic timber in 2017 was approximately 30 million m^3, which is less than one-third of the annual increase in forest stock [1].

In recent years, woody biomass represented by forest resources has been attracting attention in Japan as a renewable energy source and is widely used for both power generation and heat utilization. With regard to power generation, the Feed-in Tariff (FIT) scheme was introduced in Japan in 2012, and the total output of national woody biomass power generation plants was 1,147 MW in FY2016[1] [2]. Compared with power generation, heat utilization is low [3]. The energy utilization of woody biomass is expected to expand more rapidly in the future.

To build a sustainable society, it is necessary to consider the environment, economy, and society together [4]. The energy utilization of woody biomass may satisfy three aspects from the viewpoint of the aforementioned ecosystem services. There are many studies on the energy use of woody biomass, focusing on the three aspects. In terms of the economic aspects, Yanagita et al. [5] clarified the relationship between the raw material procurement price and the break-even point in the woody biomass power generation business. Kuboyama et al. [6] developed a profitability evaluation tool for CHP projects that use woody biomass and the conditions for establishing the combined heat and power (CHP) project. Moon et al. [7] conducted an empirical study on the impact of expanding woody biomass use on the local economy. The supply and utilization potential of woody biomass based on procurement cost was also evaluated [8], [9], [10], [11].

In terms of the environmental aspect, Japan Wood Energy [12] estimated greenhouse gas (GHG) emissions during the woody biomass fuel procurement process, and clarified that woody biomass fuel has a lower environmental impact than fossil fuels. Kayo et al. [13] clarified the GHG emission reduction effect of a woody biomass district heat supply system. Tabata et al. [14] clarified the GHG reduction effect by evaluating the difference in the co-firing method of thinned timber.

In terms of the social aspect, Mamada et al. [15], [16] conducted a survey of

[1] FY means Japanese fiscal year. For example, FY2016 starts from April 2016 and ends to March 2017.

local residents on their intention to use woody biomass. Ahl et al. [17] conducted an interview survey with stakeholders in the supply chain to investigate the success factors influencing businesses using woody biomass for power generation. Hodges et al. [18] conducted a survey of private forest landowners in the southeastern United States regarding their attitudes and consciousness toward forest energy use. Campbell et al. [19] clarified the Marginal Willingness to Pay (MWTP) for electric power utilization of thinned timber from public forests.

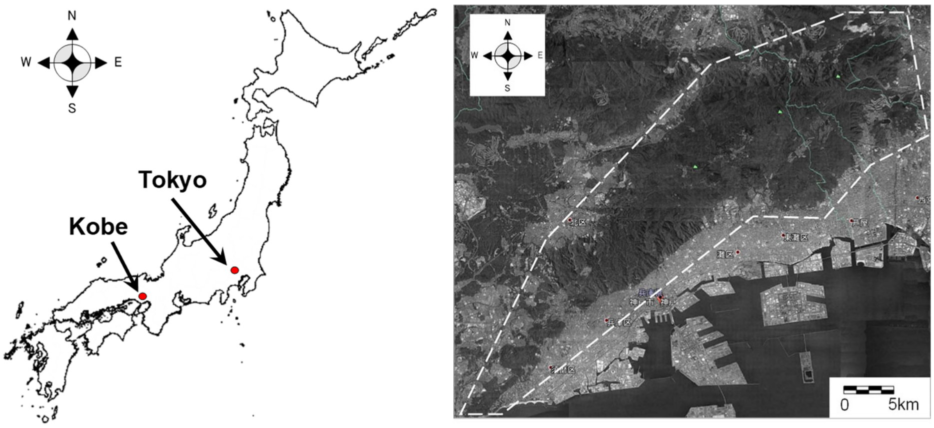
In terms of both the economic and environmental aspects, Jåstad et al. [20] analyzed the use of woody biomass in the Nordic thermal and electric power sector in 2040; they found that GHG emissions from the electric power and thermal sector might be reduced by 4% to 27%. Komata et al. [21] clarified the environmental performance of power generation and a CHP system using only woody biomass and external cost reduction. Tabata and Okuda [22] evaluated the environmental and economic impacts of replacing fossil fuels with woody biomass for household heating. Jackson et al. [23] identified the economic and environmental implications of introducing the woody biomass industry to rural US. Kishita et al. [24] predicted the environmental burden and economic viability of future woody biomass power generation projects through a scenario analysis considering uncertainties. Focusing on both the economy and society, Bowda et al. [25] analyzed the reasons for the failure of the woody biomass pellet projects in Sub-Saharan Africa in terms of cost, technique, skill, and human resources.

Most previous studies have analyzed power generation, whereas few studies have evaluated heat utilization. In addition, most studies evaluated the environment, economy, or society separately or considered only two factors. Since woody biomass use is a significant consideration in climate change and regional revitalization, it is necessary to integrate environmental, economic, and societal analyses to identify their relationships and joint effects. Cambero and Sowlati [26] reviewed the energy and product use of woody biomass and conducted a comprehensive environmental, economic, and societal analysis. They discuss job creation as a representative societal factor. While job creation is important, discussing consumer awareness of woody biomass to promote its effective use is equally important. This study aims to develop a model for the integrated evaluation of the woody biomass heat utilization business from three aspects: environment, economy, and society. For this purpose, we conducted studies focusing on the reduction of GHG from the environmental perspective, the evaluation of business feasibility from the economic perspective, and the awareness of heat users from the societal perspective. The authors have conducted studies on the estimation of woody biomass potential and the awareness of the citizens of Kobe regarding the heat utilization business of woody biomass in Kobe [27]. This study extends a previous study which evaluated a woody biomass heat utilization business from the comprehensive perspective of the environment, economy, and society.

2. Materials and methods

2.1 Case study area

Figure 1 illustrates the case study area. The total land area of Kobe is 557 km^2. The estimated population is 1.52 million (in 2020) [27][28]. Mt. Rokko is the generic name of a mountain range stretching 30 km from east to west. The Kobe coastal urban area is close to Mt. Rokko, which is famous for sightseeing, and where there are recreational facilities such as observation decks, botanical gardens, ski resorts, and athletic facilities at the top of the mountain. Approximately 1.87 million tourists visited Mt. Rokko in 2018 [28].



(a) Kobe (b) Kobe and Mt. Rokko.

Figure 1 Location of case study area

Note: The dotted line is the area of Mt. Rokko, and the urban area of Kobe is on the south side of Mt. Rokko.

2.2 Model of this study

A model consisting of societal, economic, and environmental impact assessments was developed (Figure 2) to evaluate the woody biomass heat utilization business in Kobe and Mt. Rokko. Although no woody biomass heat utilization business was operated at Mt. Rokko as of January 2022, this study assumed that a hot bath facility that utilizes woody biomass for heat is virtually operated at Mt. Rokko. A hot bath facility was used, as it is familiar to Japanese people [29]. In the societal impact assessment, a questionnaire survey was conducted to clarify tourist consciousness regarding the facility, and its societal value was estimated using the Contingent Valuation Method (CVM). Nakahara et al. [29] clarified citizen awareness of a woody biomass heat utilization business in Kobe and Mt. Rokko using the CVM. This study combines the results of citizens and tourists to estimate the benefits of using woody biomass at Mt. Rokko. An economic model was constructed using the life cycle cost (LCC) model. This analysis clarified how the use of woody biomass affects the economic efficiency of a facility. In the environmental impact assessment, an Life Cycle Assessment (LCA) was conducted to clarify how the use of woody biomass heat would impact the surrounding environment. By integrating the three aspects of environment, economy, and society, we comprehensively examined the effects of the hypothesized hot bath facility on forest maintenance and regional revitalization. Finally, we constructed a methodology for the development of an environmentally, economically, and socially sustainable community considering use of woody biomass.

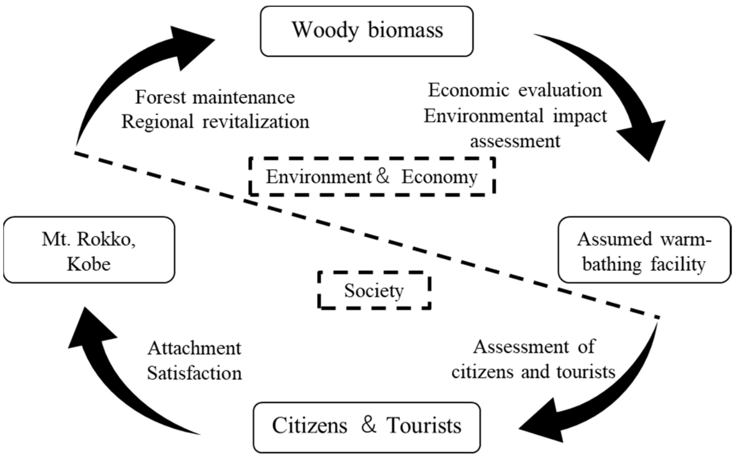


Figure 2 Environmental, economic, and societal evaluation model framework

2.3 Societal impact

2.3.1 Questionnaire survey

The questionnaire survey comprised a face-to-face survey conducted with 201 tourists at the site of the recreation facility on Mt. Rokko on November 24 and 25, 2018. The number of valid responses was 194, with a valid response rate of 96.5% after excluding incomplete responses. The questionnaire is shown in Table 1. Respondents were asked about their awareness of Mt. Rokko and the likelihood of using the hypothesized hot bath facility. Questions regarding awareness reflected those used in a questionnaire survey of 522 Kobe citizens on December 12 and 13, 2017 by Nakahara et al. [29] to compare with results of citizens and tourists. The questionnaire survey for citizens of Kobe was conducted online. In this study, we examined how WTP results obtained with CVM differ between Kobe citizens and tourists.

Table 1 Questionnaire survey items

Composition of questionnaire	Question
Questions about basic attributes	Age, sex, residence, number of visitors, number of visits, visitor composition, purpose of visit, travel time, and trigger for visit
Questions about awareness	
Intention to use hypothesized hot bath facility Note: Same questions as Nakahara et al. [29]	Imagine that a day-trip bathing facility equipped with facilities to warm water using woody biomass harvested at Mt. Rokko will be built at the foot of Mt. Rokko. The usage fee of this bathing facility is 800 JPY (7.60 USD[2]) per adult. In this bathing facility, a contribution to support the growing and maintaining of the forest of Mt. Rokko is added to the usual usage fee at 200 JPY (1.90 USD) per adult. At this time, would

[2]The exchange rate applied was 0.0095 USD = 1 JPY (as of 13 February 2021).

	you consider paying the contributions in addition to the use fee for bathing facility? *If answer was "Yes," the same question was asked again with a charge of 300 JPY (2.85 USD) **If answer was "No," the same question was asked again with a charge of 100 JPY (0.95 USD)

2.2.2 CVM

Based on the results of the questionnaire survey, CVM was applied to estimate the Willingness to Pay (WTP) of tourists. "Excel for CVM Version 4.0" was applied to calculate the WTP [30]. The total benefit of the hypothesized hot bath facility (the total benefit of tourists and citizens of Kobe as a result of the project being implemented) is calculated by multiplying the WTP of households in Kobe with the number of tourists by the total number of households in Kobe and the number of tourists [27], [28].

2.4 Economic impact

2.4.1 Evaluation model

To evaluate the economic and environmental impacts of woody biomass heat utilization, two heat utilization systems using wood chips (target system) and fossil fuels (original system) are assumed. City gas, heavy oil, and kerosene were considered fossil fuels. The systems were compared in terms of their economic and environmental impacts (Figure 3). The original system consists of a fuel procurement process, heat utilization process, and boiler introduction process. The target system consists of a fuel procurement process, heat utilization process, boiler introduction process, and waste disposal process. This study assumed that no ash was generated in the original system. Wood chips were selected because they can be applied for large-scale heat utilization in a cost-effective manner [31]. Japan Wood Energy [32] also proposed using wood chips and fossil fuels together because the wood chip boiler has a high initial cost, and it is difficult to control the output promptly. This disadvantage may be overcome by integrating a fossil fuel boiler.

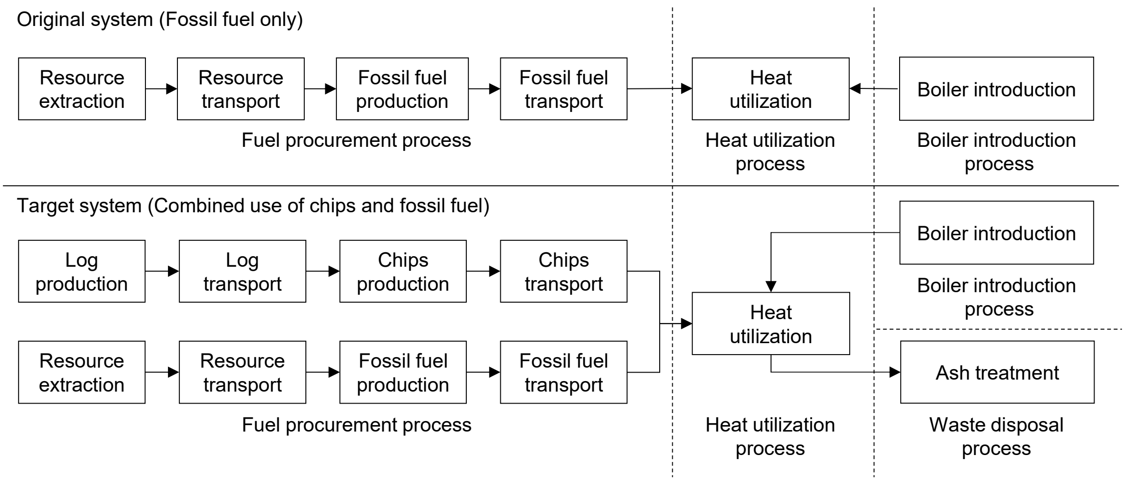


Figure 3 Heat utilization system comparison

Table 2 lists the cost items considered for the economic evaluation. The cost required for utilizing woody biomass heat is divided into the initial and running costs. The initial cost of the target system is divided into the introduction costs of wood chips and fossil fuel boilers. The initial cost of the original system is only the introduction cost of the fossil fuel boiler. Although the initial cost of woody biomass boilers is higher than that of fossil fuel boilers, the fuel cost of woody biomass is lower [32]. Therefore, the total cost of the target system may be lower than that of the original system in terms of its life cycle. In this study, the difference in annual costs between woody biomass and fossil fuel use for heat utilization in the hypothesized hot bath facility based on the life of the boiler was used as an index for economic evaluation.

Table 2 Cost items for economic evaluation

	Target system (Combined use of wood chips and fossil fuel)	Original system (Fossil fuel only)
Initial cost	Costs of introducing the wood chip boiler and the fossil fuel fired boiler	Cost of introducing the fossil fuel fired boiler
Running cost	Fuel, property, and operating costs	Fuel, property, and operating costs

2.4.2 Basic economic evaluation data

The size of the hot bath facility affects boiler output and fuel consumption. It was necessary to determine the scale of the facility before conducting an economic evaluation. Nakahara et al. [29] estimated the scale of the corresponding hot bath facility based on the energy potential of the woody biomass of Mt. Rokko. Based on the results, we selected an existing hot bath facility in Kobe and used a similar scale. An interview survey was conducted to determine the basic data of the hypothesized hot bath facility. The interview survey gathered basic information such as the facility area and operating status of the boiler, such as fuel consumption. Table 3 shows the basic data for economic evaluation. The boiler scale and annual heat demand of the hypothesized hot bath facility were calculated from the results of the survey. Because the original system uses only fossil fuels, the heat supply of the fossil fuel boiler is the same as the annual heat demand of the interviewed facility. In the case of the target system, the scale of the boiler and annual heat demand are estimated from the regression formula between the heat supply of the wood chip boiler and the output of the boiler obtained from the interview survey.

The calculation procedure for the scale of the boiler and annual heat demand is as follows:

a) The average heat demand per hour is calculated by Equation (1).

$$D_h = \frac{D_m}{h} \tag{1}$$

where D_h is the average heat demand per hour, D_m is the monthly heat demand of the hot bath facility obtained from the interviews, *and* h is the operating hours of the hot bath facility.

b) The average heat demand per hour was compared with the output of the wood chip boiler. If the wood chip boiler output was high, the monthly heat supply was calculated using Equation (2). If the wood chip boiler output was low, the monthly heat supply was calculated using Equation (3).

$$H_{wm} = h \times D_h \quad (2)$$

$$H_{wm} = h \times O_w \quad (3)$$

where H_{wm} is monthly heat supply, O_w is wood chip boiler output.

c) The annual heat demand was calculated using Equation (4). In this study, the heat supply of the wood chip boiler was assumed to remain steady throughout the year.

$$D_y = H_{wm} \times 12 \quad (4)$$

where D_y is annual heat demand. 12 indicates 12 months.

d) The regression formula between the output and annual heat supply was calculated. Then, the output scale is assumed to vary within 50 kW of the maximum value of the average per-hour heat demand.
e) The annual heat supply of the fossil fuel boiler was calculated by subtracting the annual heat supply of the wood chip boiler from the annual heat demand of the facility.

$$H_{fy} = \frac{H_{wy}}{D_y} \quad (5)$$

where H_{fy} is the annual heat supply of the fossil fuel boiler and H_{wy} is the annual heat supply of the wood chip boiler.

Table 3 Basic data for economic evaluation

Item		Unit	Factor and setting conditions
Hypothesized hot bath facility			
O_t	Total boiler output of heat utilization system	[kW]	
H_t	Total heat supply of heat utilization system	[MJ/year]	
Fuel price			
P_w	Price of wood chips	[JPY/MJ]	

P_f	Price of fossil fuel	[JPY/MJ]	
Original system (Fossil fuel only)			
O_{f1}	Fossil fuel fired boiler output	[kW]	$O_{f1}=O_t$
C_{fb1}	Fossil fuel fired boiler cost	[JPY]	$C_{fb}=8090.6O_{f1}$ [1]
H_{f1}	Heat supply form fossil fuel fired boiler	[MJ]	$H_{f1}=H_t$
Target system (Combined use of wood chips and fossil fuel)			
O_w	Wood chip boiler output	[kW]	
C_{wb}	Wood chip boiler cost	[JPY]	$C_{wb}=63047O_w+10^7$ [2]
H_w	Heat supply form wood chip boiler	[MJ]	
O_{f2}	Fossil fuel fired boiler output	[kW]	$O_{f2}=O_t-O_w$
C_{fb2}	Fossil fuel fired boiler cost	[JPY]	$C_{fb}=8090.6O_{f2}$ [1]
H_{f2}	Heat supply form fossil fuel fired boiler	[MJ]	$H_{f2}=H_t-H_w$

1: regression formula of Figure 4 was adopted. 2: regression formula derived from [31] was adopted.

To create the regression formula between the heat supply and output of the wood chip boiler, the wood chip price, fossil fuel price, and wood chip boiler output were set as explanatory variables. This was done because the price of fossil fuels varies by type and time, the ratio of the wood chip and fossil fuel boiler outputs in the target system is difficult to determine, and the price of fuel and the ratio of output of the boiler in the target system significantly influences the annual cost. The price of the fossil fuel boiler was calculated using the regression formula between the boiler output and price (Figure 4). The price of the fossil fuel boiler was determined using data from six companies via an online survey. The price of the wood chip boiler is calculated from the regression formula between the output of the boiler and the price of the boiler, which was published by Japan Wood Energy [32]. The Boiler efficiency and expected lifetime of the boiler were set as 90% and 15 years, respectively [32].

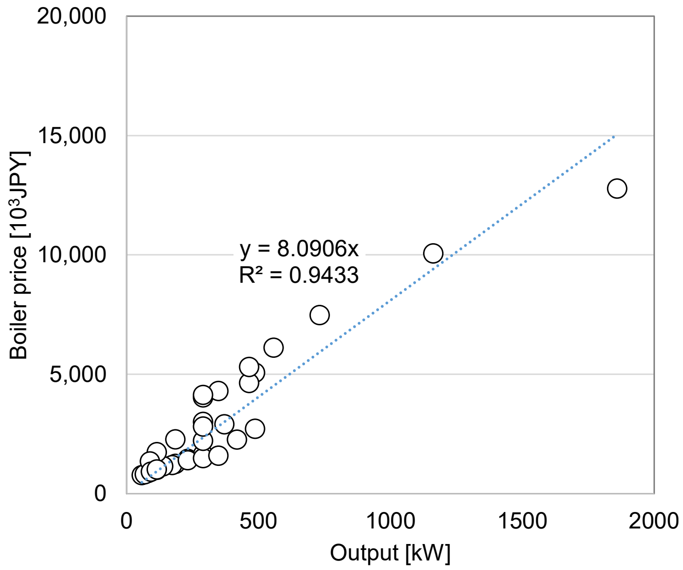


Figure 4 Cost of fossil fuel boiler

Table 4 shows the estimation method for each cost of the original system.

The depreciation cost is set at a residual value of 1 JPY (0.0095 USD) based on the guidelines of the Japan National Tax Agency [33]. As the running cost, the property tax was calculated as the average value for 15 years by setting to 1.4% of the initial cost remaining value [32]. The fuel cost was calculated by multiplying the annual heat demand by the fossil fuel price.

Table 4 Estimation method for each cost of the original system

Item		Unit	Factor and setting conditions
Initial cost			
C_{tf1}	Total cost of introducing fossil fuel fired boiler	[JPY]	C_{tf1}=8090.6O_{f1} [1]
C_{i1}	Summation	[JPY]	C_{i1}=C_{tf1}
C_{d1}	Depreciation expense of initial cost	[JPY/year]	C_{d1}=(C_{i1}−1)/15 [2]
Running cost			
C_{o1}	Operating cost	[JPY/year]	
C_{p1}	Property tax	[JPY/year]	$C_{p1}= \sum_{n=0}^{14}[0.014(C_{i1}-nC_{d1})]/15$ [3]
C_{f1}	Fuel cost	[JPY/year]	$C_{f1}=H_{f1}\cdot P_f$
C_{r1}	Summation	[JPY/year]	$C_{r1}=C_{o1}+C_{p1}+C_{f1}$
C_{a1}	Annual cost of original system	[JPY/year]	$C_{a1}=C_{d1}+C_{r1}$

1: Regression formula of Figure 4 was adopted. 2: 15 years is the expected lifetime of the boiler [32]. 3: 1.4% is the initial cost remaining value [32].

Table 5 presents the estimation method for each cost in the target system. As the initial cost, the installation cost is estimated from the price of the boiler by applying the ratio of various costs to the wood chip boiler installation cost [31]. As the running cost, the property tax is estimated using the same method as the original system. The operation and maintenance costs vary greatly depending on the operating conditions of the hot bath facility. In this study, the increase in operation and maintenance costs owing to the introduction of the wood chip boiler was set to 2.5% of the initial cost, referring to the implementation example [34]. The fuel cost is calculated by multiplying the annual heat supply of each boiler by the fuel price; 50% subsidies were introduced because there are many cases in which subsidies were applicable [31].

Table 5 Target system cost estimation method

Item		Unit	Factor and setting conditions
Initial cost			
C_{tw}	Total cost of introducing the wood chip boiler	[JPY]	C_{tw}=2.5C_{wb} [1]
C_{tf2}	Total cost of introducing the fossil fuel fired boiler	[JPY]	C_{tf}＝8090.6O_{f2} [2]
C_{i2}	Summation	[JPY]	$C_{i2}=C_{tw}+C_{fb}$
C_{d2}	Depreciation expense of initial cost	[JPY/year]	C_{d2}=(C_{i2}−1)/15 [3]
Running cost			

C_{o2}	Operating cost	[JPY/year]	$C_{o1} - C_{o2} = 0.025C_{i2}$ [4]
C_{p2}	Property tax	[JPY/year]	$C_{p2} = \sum_{n=0}^{14}[0.014(C_{i2} - nC_{d2})]/15$ [5]
C_{f2}	Fuel cost	[JPY/year]	$C_{f2} = Hw \cdot P_c + H_{f2} \cdot P_f$
C_{r2}	Summation	[JPY/year]	$C_{r2} = C_{o2} + C_{p2} + C_{f2}$
C_{a2}	Annual cost of original system	[JPY/year]	$C_{a2} = 0.5C_{d2} + C_{r2}$ [6]

1: total cost of introducing the wood chip boiler is 2.5 times of wood chip boiler cost [31]. 2: regression formula of Figure 4 was adopted. 3: 15 years is the expected lifetime of the boiler [32]. 4: introduction of the wood chip boiler is set to 2.5% of the initial cost [34]. 5: 1.4% is the initial cost remaining value [32] and 15 years is the expected lifetime of the boiler [32]. 6: 50% is subsidies [31].

Based on the evaluation model, the difference in annual costs owing to the replacement of city gas, heavy oil, and kerosene with wood chips were estimated. Table 6 lists the characteristics and prices of each fuel. Data from the Japan Wood Energy [35], All Japan Wood-recycle Association [36], and Japan Woodchip Manufacture's Association [37] were used to determine the costs of wood chip. To determine fossil fuel costs, data from the Japan Agency for Natural Resource and Energy (JANRE) [38], [39] were used. Since the price of fossil fuels fluctuates yearly, it is necessary to understand the impact of price reductions on fossil fuels on the economics of the hypothesized hot bath facility. In this study, the fuel price in 2018 and the lowest price in 2016 since the oil shock in 2014 were used. The optimal scale and cost difference of the wood chip boiler were estimated using the fossil fuel price in 2018 and the maximum wood chip price (11.5 JPY (0.11 USD)). Next, the fluctuation range of the difference in annual costs was calculated using the fossil fuel price in 2016 based on the calculated scale of the introduction of the wood chip boiler. The fuel price of city gas in 2018 was collected from an interview survey conducted in a hot bath facility. Since the price of the city gas is lower than the price after 2000 announced by JANRE [40], it was assumed that the city gas price does not change.

Table 6 Characteristics and prices of each fuel

Item	Unit	Factor and setting conditions
Wood chips		
Moisture content of wood chips (wet basis)	[%]	$MC=40$ [1]
Lower heating value	[MJ/kg]	$LHV_w=10.6$ [2]
Price (2018)	[JPY/kg]	8.5–11.5 [3]
	[USD/kg]	0.081–0.11
City gas (13A)		
Higher heating value	[MJ/m^3]	$HHV_c=45.0$ [4]
Lower heating value	[MJ/m^3]	$LHV_c=0.90HHV_c$ [4]
Price (2018)	[JPY/m^3]	71.68 [5]
	[USD/m^3]	0.68
Heavy oil		
Higher heating value	[MJ/L]	$HHV_h=38.9$ [4]
Lower heating value	[MJ/L]	$LHV_h=0.95HHV_h$ [4]

Price (2018)	[JPY/L]	81.83 [5]
	[USD/L]	0.78
Price (2016)	[JPY/L]	57.29 [5]
	[USD/L]	0.54
Kerosene		
Higher heating value	[MJ/L]	HHV_k=36.5 [4]
Lower heating value	[MJ/L]	LHV_k=0.95HHV_k [4]
Price (2018)	[JPY/L]	100.08 [5]
	[USD/L]	0.95
Price (2016)	[JPY/L]	72.73 [5]
	[USD/L]	0.69

1: [35]. 2: [36]. 3: [37]. 4: [38]. 5: [39].

2.5 Environmental evaluation

2.5.1 Evaluation model

Using the above results, the annual GHG emissions of the heat utilization system were estimated when each fuel was used. The system boundary of the evaluation was the same as that constructed in the economic evaluation (Figure 3). The system boundary of the original system is separated into the following three processes: fossil fuel procurement, heat utilization, and boiler introduction. The system boundary of the target system also consisted of four processes: wood chip and fossil fuel procurement, heat utilization, combustion ash disposal, and boiler introduction. Each process, such as transportation, repair, and disposal of the equipment used for the heat utilization system were excluded from the evaluation target. GHG emissions were used as the evaluation index. The evaluated GHGs included CO_2, CH_4, and N_2O. The functional unit is the annual GHG emissions of the heat utilization system. The CO_2, CH_4, and N_2O results were converted into GHGs using the global warming potential factor for a time horizon of 100 years (CO_2: 1, CH_4: 25, and N_2O: 298) [41].

2.5.2 Basic data of environmental evaluation

The GHG emissions for the three processes of fuel procurement, heat utilization, and waste disposal was calculated by multiplying input raw materials/energy and GHG emission coefficients listed in Japanese LCA databases “Inventory Database for Environmental Analysis (IDEA) v2.2” [42]. The GHG emissions for the boiler introduction process were calculated by the multiplying production value of the boilers and GHG emission coefficients listed in Japanese LCA databases “Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID)” [43]. It is assumed that CO_2 is avoided when wood chips are burned using the concept of carbon neutrality. Table 7 shows the basic data for environmental impact assessment. The output of the boiler is calculated from the relational expression between the output and power consumption (Figure 5 and 6), which was created based on the data obtained from the online survey. The hypothesized hot bath facility was assumed to be built on Mt. Rokko. The transportation distance was calculated using the actual road distance to the wood chip factory and incineration plant closest to the facility, as obtained from Google Maps.

Table 7 Basic data for environmental impact assessment

	Item	Unit	Factor and setting conditions
P	Density of wood chips	[t/m^3]	ρ=0.26 [1]
AC	Ash content of wood chips (dry basis)	[%]	*AC*=1 [1]
CP	Chip production volume from logs	[m^3-chip/m^3-log]	*CP*=3 [1]
RP_w	Rated power of wood chip boiler	[kW]	$RP_w=0.3402O_w^{0.4831}$ [2]
RP_f	Rated power of fossil fuel fired boiler	[kW]	$RP_f=0.0171O_f^{0.7109}$ [3]
HHV_f	Higher heating value of fossil fuel	[MJ/m^3 or MJ/L]	
LHV_f	Lower heating value of fossil fuel	[MJ/m^3 or MJ/L]	
D_w	Wood chip transportation distance	[km]	D_w=15.5 [4]
D_a	Ash transportation distance	[km]	D_a=16.7 [4]

1:[31], [34]. 2: regression formula of Figure 5 was adopted. 3: regression formula of Figure 6 was adopted. 4: actual road distance to the wood chip factory and incineration plant closest to the facility.

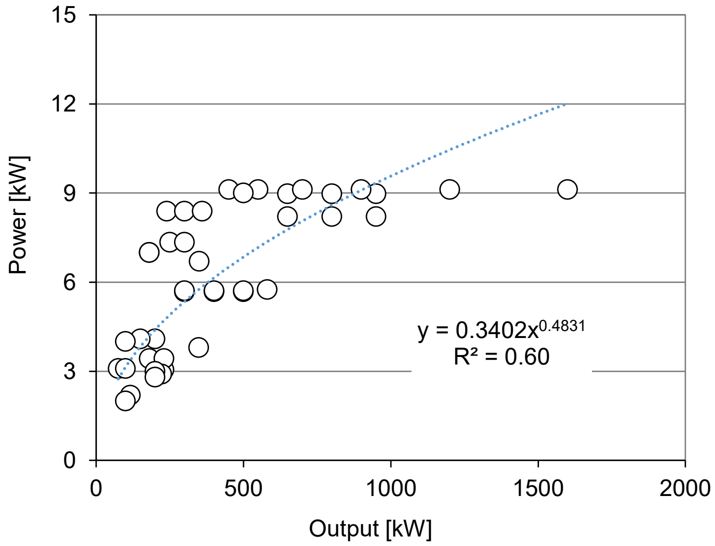


Figure 5 Rated power of wood chip boiler

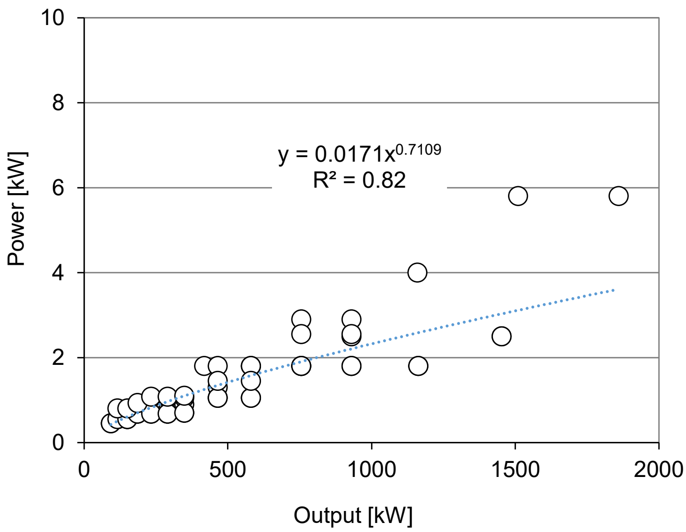


Figure 6 Rated power of fossil fuel boiler

Table 8 lists the input data for each process of the original system. Fossil fuel production was estimated based on the annual heat demand of the hypothesized hot bath facility during the fuel procurement process. The amount of fossil fuels used was considered the same as the amount of fossil fuel produced during the heat utilization process. The annual power consumption of the fossil fuel boiler was calculated by multiplying the power consumption by the annual operating hours. Table 9 lists the input data for each target system process. The amount of wood chips was calculated by dividing the amount of heat supplied by the wood chip boiler by the lower heating value of the wood chips in the fuel procurement process. Similarly, the amount of fossil fuel produced was calculated. The log production volume was estimated as one-third of the wood chip production volume [32]. The basic unit of log production is the transportation process. The amount of chips and fossil fuel used were assumed to be the same as the amount of each production during the heat utilization process. The annual power consumption of the wood chip boiler was calculated by multiplying the power consumption of the boiler by the annual operating hours. The fossil fuel boiler is an auxiliary when the heat demand exceeds the output of the wood chip boiler and is not always in operation. Therefore, the power consumption corresponding to the heat supply of the fossil fuel boiler was estimated. Each cost of wood chip boiler introduction was calculated by multiplying the ratio of various costs by the wood chip introduction cost by the JFA [31] at the heat utilization process.

Table 8 Input data for each process of the original system

Item		Unit	Factor and setting conditions
Fuel procurement process			
PV_{f1}	Fossil fuel production volume	[m^3/year or L/year]	$PV_{f1}=H_t/LHV_f$
Heat utilization process			
U_{f1}	Usage of fossil fuel	[m^3/year or L/year]	$U_{f1}=PV_{f2}$
EP_{f1}	Electric power usage of fossil fuel fired boiler	[kWh]	$EP_{f1}=(0.278RP_f{\cdot}H_t)/O_t$ [1]
Fossil fuel fired boiler introduction process			

C_{fb1}	Fossil fuel fired boiler cost	[JPY]	$Cf_{b1}=8090.6O_t$ [2]

1: [35]. 2: regression formula of Figure 4 was adopted.

Table 9 Input data for each process of the target system

Item		Unit	Factor and setting conditions
Fuel procurement process			
PV_w	Wood chip production volume	[m^3/year]	$PV_w = H_w/(LHV_w{\cdot}\rho)$
PV_l	Log production volume	[m^3/year]	$PV_l = PV_w/CP$
D_w	Wood chips transportation distance	[km]	$D_w = 15.5$ [1]
PV_{f2}	Fossil fuel production volume	[m^3/year or L/year]	$PV_{f2} = H_f/LHV_f$
Heat utilization process			
U_w	Usage of wood chips	[m^3/year]	$U_w = PV_w$
U_{f2}	Usage of fossil fuel	[m^3/year or L/year]	$U_{f2} = PV_{f2}$
EP_w	Electric power usage of wood chip boiler	[kWh/year]	$EP_w = (0.278RP_w{\cdot}H_w)/O_w$ [2]
EP_{f2}	Electric power usage of fossil fuel fired boiler	[kWh/year]	$EP_{f2} = (0.278RP_f \cdot H_f)/O_f$ [2]
Waste disposal process			
AG	Ash generation amount	[t/year]	$AG = U_w{\cdot}\rho{\cdot}(1-MC){\cdot}AC$
D_a	Ash transportation distance	[km]	$D_a = 16.7$ [1]
Fossil fuel fired boiler introduction process			
C_{fb2}	Fossil fuel fired boiler cost	[JPY]	$C_{fb2} = 8090.6O_f$ [3]
Wood chip boiler introduction process			
C_{wb}	Wood chip boiler cost	[JPY]	$C_{wb} = 63047O_w+10^7$ [4]
C_{ms}	Construction cost of machine room and silo	[JPY]	$C_{ms} = 0.32C_{tw}$ [5]
C_{or}	Other related construction costs	[JPY]	$C_{or} = 0.23C_{wb}$ [6]
C_{ot}	Other costs	[JPY]	$C_{ot} = 0.05C_{wb}$ [7]

1: actual road distance to the wood chip factory and incineration plant closest to the facility. 2: [35]. 3: regression formula of Figure 4 was adopted. 4: regression formula derived from [31] was adopted. 5: [31].

3. Results and discussion

3.1 Societal impact

3.1.1 Questionnaire survey responses

Table 10 shows the questionnaire results. Most respondents were aged 20–39 years. Approximately 40% of the respondents visited Mt. Rokko for the first time. Regarding the contribution fee, the positive responses were as follow: 48% (300 JPY; 2.85 USD), 34% (200 JPY; 1.90 USD), and 14% (100 JPY; 0.95 USD).

Table 10 Responses for questions

Age	Below 19	6	Purpose of visit	Leisure	187
	20-29	60		Work	1
	30-39	43		Extracurricular class	0

	40-49	29		Volunteer activities	1
	50-59	29		Miscellaneous	5
	60-69	18	Travel time	Below one hour	40
	70-79	7		From one to two hours	95
	80+	2		From two to three hours	25
Sex	Male	80		Above three hours	33
	Female	114	Trigger of visit	Saw flyers and/or guidebooks	42
Residence	Kobe	42		Introduced by friends and/or acquaintances	47
	Outside of Kobe	152		Visited websites	32
Number of visitors	One person	4		Saw social media posts, such as on Twitter and Facebook	12
	Two persons	100		Miscellaneous	61
	Three persons	44	(3) Intention to use hypothesized hot bath facility		
	Four persons	19			
	Five persons or more	27			
Number of visits	First time	78	YY (300 JPY (2.85 USD))		94
	Second to third time	63	YN (200 JPY (1.90 USD))		66
	Fourth to ninth time	25	NY (100 JPY (0.95 USD))		26
	Tenth time or more	28	NN (0 JPY (0 USD))		8
Visitor composition	Individual	4	Note: YY: first and second questions were "YES". YN: first question was "Yes" and second question was "No". NY: first question was "No" and second question was "Yes" and NN: first and second questions were "No."		
	With friends	39			
	With partner	39			
	With family (without children)	39			
	With family (with children)	65			
	Miscellaneous	8			

3.1.2 CVM Results

Figure 7 shows WTP for contributions. The WTP of the respondents was 298 JPY (2.83 USD) as a median value, 345 JPY (3.28 USD) as an average value, and 254 JPY (2.41 USD) with hedging at the maximum offer amount. The calculated median WTP was nearly equal to the maximum proposed amount (300 JPY (2.85 USD)) set in this study.

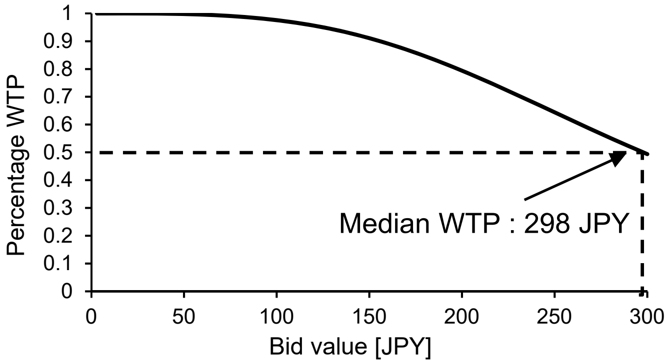


Figure 7 WTP contributions

Nakahara et al. [29] conducted the same questionnaire survey in 2017 for the citizens of Kobe. In this study, the result the WTP of tourists was compared with the WTP of citizens. Table 11 shows comparison result of tourists and Kobe citizens. As a result, the WTP of the citizens of Kobe was relatively low compared with that of tourists; where 21% of the Kobe citizens answered 0 JPY, while only 4% of tourists answered 0 JPY.

Table 11 Response comparison of tourists and Kobe citizens

Item	Analysis results	
	Tourists	Kobe citizens [27]
Number of respondents	196	522
Answers regarding contributions		
300 JPY (2.85 USD)	48%	36%
200 JPY (1.90 USD)	34%	27%
100 JPY (0.95 USD)	14%	16%
0 JPY (0 USD)	4%	21%
WTP		
Median WTP [JPY] ([USD])	298 (2.83)	237 (2.25)
Mean WTP [JPY] ([USD])	254 (2.41)	210 (2.00)
Total benefit [million JPY] ([million USD]	474.98 (4.51)	148.14 (1.41)

The total benefits of the assumed business was estimated to be 474.98 million JPY (4.51 million USD) and 148.14 million JPY (1.41 million USD), respectively by multiplying total number of households in Kobe in 2015 (705,459) and the number of tourists in Mt. Rokko area in 2018 (1.87 million) by each average value of WTP [27], [28]. The benefits from tourists were approximately three times that of the Kobe citizens. The total benefit of the assumed business is 623.12 million JPY (5.92 million USD). The annual forest maintenance cost of Mt. Rokko is approximately 400 million JPY (3.8 million USD) [44]. This total benefit corresponds to approximately 1.5 times the aforementioned annual forest maintenance cost. This result revealed that the forest maintenance of Mt. Rokko might be covered by utilizing the benefits obtained from the heat utilization business of woody biomass.

As a limitation of this study, the questionnaire survey for tourists was conducted only once in late autumn, and there were few respondents. If surveys were conducted in different seasons, the results may change. To ensure the validity of the survey results, it is necessary to refine the CVM results through year-round surveys. In addition, the questionnaire survey conducted by Nakahara et al. [29] for the citizens of Kobe also comprises a low number of respondents; nevertheless the number of respondents in consideration of the gender and population composition of Kobe City was secured. Therefore, further surveys are required to ensure the representativeness of the Kobe citizens.

3.2 Economic evaluation

3.2.1 Result of interview survey

The hot bath facility selected for the interview survey uses three fossil fuel boilers with outputs of 930 kW (total output of 2,790 kW). The fuel used was 13A city gas, and the annual fuel consumption was 266,880 m^3. The annual heat demand calculated based on the annual fuel consumption was 10,808,640 MJ, using the lower heating value of city gas. Based on the survey, the boiler scale of the hypothesized hot bath facility was set at 2,790 kW, and the annual heat demand was set at 10,808,640 MJ. The heating equipment of this hot bath facility was operated for 17 h every day, except for five days in February. Fuel consumption fluctuated seasonally, and the maximum fuel consumption in winter was approximately four times that in summer. Figure 8 shows the calculated monthly average heat demand of the facility. Figure 9 also shows the relationship between the calculated annual heat supply and the output of the wood chip boiler based on the average heat demand per hour.

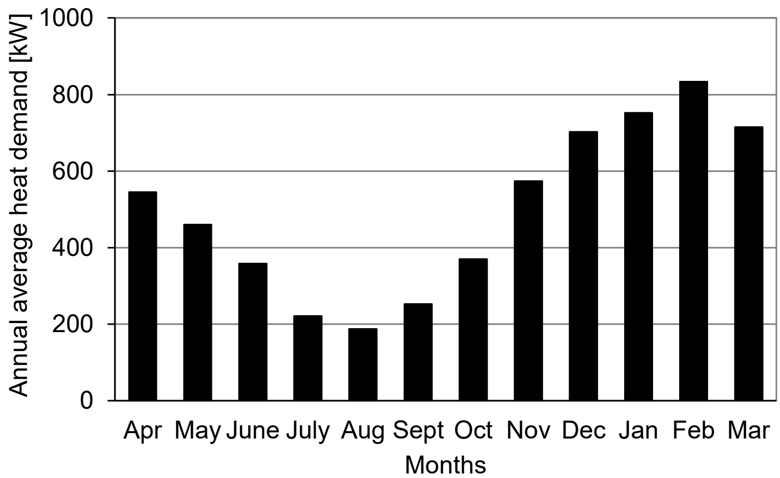


Figure 8 Monthly average heat demand

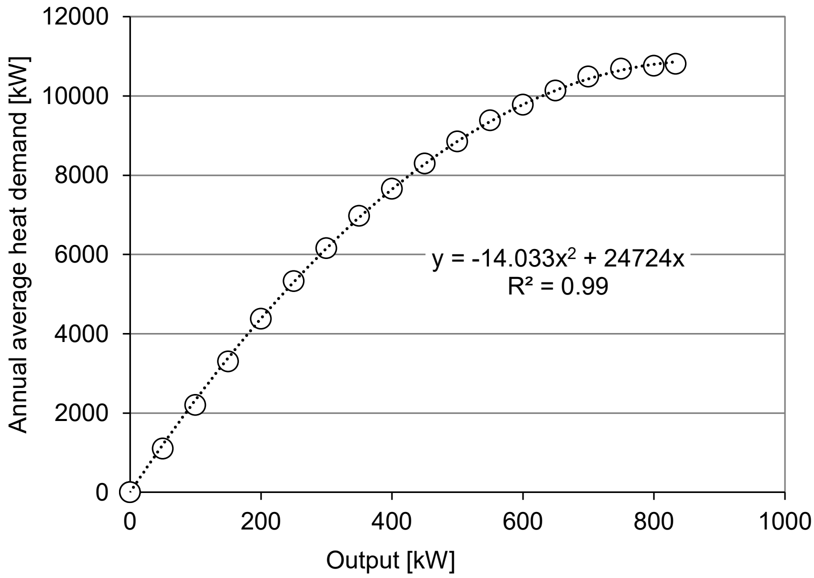


Figure 9 Annual wood chip boiler heat supply

3.2.2 Heat results of the evaluation model

The difference between the annual costs of the target system and the original system is expressed by the following formulas: Equation (2) expresses the price difference between the target system and the original system using the regression formula derived in Figure 9, and

$$C = -14.033PO_w{}^2 + (24724P + 9838.87)O_w + 1456893.5292 \quad (2)$$

$$P = P_w - P_f \quad (3)$$

where C is the difference in annual costs, O_w is the output of the wood chip boiler, P is the difference in fuel price, P_w is the price of the wood chip, and P_f is the price of the fossil fuels. 9838.87 in Equation (2) represents the price difference between the running costs of the target system and the original system calculated from the setting conditions in Tables 4 and 5. 1456893.5292 in Equation (2) also represents the difference between the initial cost of the target system and the original system calculated from the setting conditions of Tables 4 and 5.

Figure 10 shows the relationship between the price difference of fuel, minimum cost difference, and wood chip boiler output. This result revealed that the smaller the fuel price difference, the smaller the cost difference and wood chip boiler output. If C_{min} is 0, P is −0.705 when $O_w \in [0,833]$. In other words, when the price difference of fuel is greater than 0.705 JPY/MJ (0.0067 USD/MJ), the use of woody biomass is not economical.

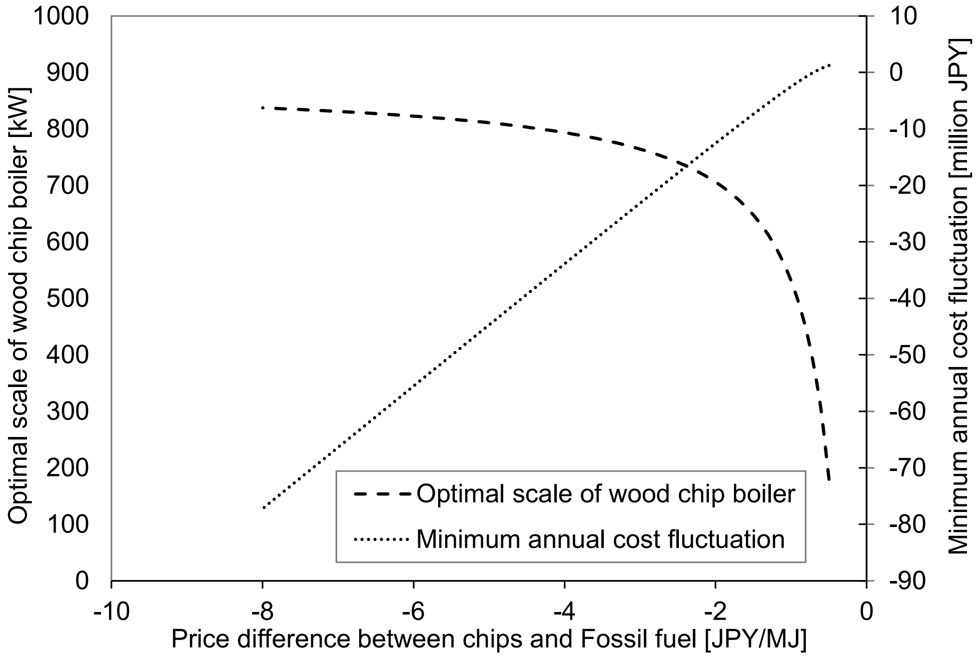


Figure 10 Relationship among fuel price difference, minimum cost difference, and wood chip boiler output

3.2.3 Results of cost fluctuation of each fuel

Table 12 shows annual cost fluctuation of each fuel. The difference between the annual cost is calculated by subtracting the annual cost of the original system from the annual cost of the target system. A negative value indicates cost reduction, and a positive value indicates cost increase. If city gas was added to the wood chips, the optimum scale of the wood chip boiler was 373 kW, and the fossil fuel substitution rate reached 67.2%. Then, the difference between the annual cost was −1.92–0.11 million JPY (−18.28–1.05 thousand USD). This result revealed that a lower cost increase may not hinder the implementation of the assumed business, although the hypothesized hot bath facility may not be economical. In the case of substitution of heavy oil A and kerosene, the optimum wood chip boiler installation scales are 571 kW and 687 kW, respectively, and the substitution rate was 88.3% and 95.9%, respectively. Then, the difference between the annual cost was −6.38 – −3.71 million JPY (−60.60 – −35.23 thousand USD) and −13.34 – −10.54 million JPY (−126.74 – 100.12 thousand USD), respectively. If the price of the fossil fuel reaches the price in 2016, the difference between the annual cost of heavy oil A and kerosene could be −0.086 – −2.59 million JPY (−0.82 – −24.56 thousand USD) and −5.23 – −2.33 million JPY (−49.70 – −22.14 thousand USD), respectively. Kerosene substitution may support cost reduction even if the price of the fossil fuel drops. Heavy oil A substitution may induce cost increase. However, the total benefit of the hypothesized hot bath facility estimated by the societal impact assessment was approximately 600 million JPY (5.7 million USD). If this were the actual income, there is a surplus of approximately 200 million JPY (1.9 million USD), even if the forest maintenance cost of Mt. Rokko [44] is excluded. This surplus may be used to amortize the annual cost increase of the hypothesized hot bath facility and the subsidies used in the initial installation. Based on the above results, the economic efficiency of the assumed project is considered good.

Table 12 Annual cost fluctuation of each fuel

Replaced fuel	Optimal scale of wood chip boiler [kW]	Substitution rate of Fossil fuel [%]	Annual cost fluctuation [Million JPY] ([Thousand USD])	
			2018	2016
City gas	373	67.2	−1.92 – −0.11 (−18.28 – −1.05)	–
Heavy oil	571	88.3	−6.38 – −3.71 (−60.60–−35.23)	−0.86 – −2.59 (−0.82 – 24.56)
Kerosene	687	95.9	−13.34 – −10.54 (−126.74 – 100.12)	−5.23 – −2.33 (49.70 – 22.14)

3.3 Environmental evaluation

3.3.1 Net GHG emission

Figure 11 shows the annual GHG emissions for each fuel. In the original system, the dominant GHG emission process is the heat utilization process. This process corresponds to 83‐87% of the total GHG emissions. The GHG emissions of city gas, heavy fuel oil A, and kerosene in the original system were 834.9, 1,012.4, and 943.8 t-CO_{2eq}/year, respectively. In the target system, the dominant GHG emissions process is still the heat utilization process, but the emission rate drops to 41%‐67%. The waste disposal process produces minimal emissions. The combination of wood chips and kerosene yielded the highest substitution rate of fossil fuel, resulting in the lowest GHG emissions of 225.4 t-CO_{2eq}/year. When heavy oil A was substituted, GHG emissions exhibited the largest reduction (726.4 t-CO_{2eq}/year). Figure 12 shows the net GHG emissions of each fuel. The net GHG emissions derived from wood chips per 1 GJ was −60 kg-CO_{2eq}/GJ for city gas, −76.3 kg-CO_{2eq}/GJ for heavy oil A, and −69.9 kg-CO_{2eq}/GJ for kerosene, respectively. If the GHG emissions become negative, the operation of the target system is considered to produce a fossil fuel substitution effect. In the case of a positive value, the net GHG emissions increased with continued operation.

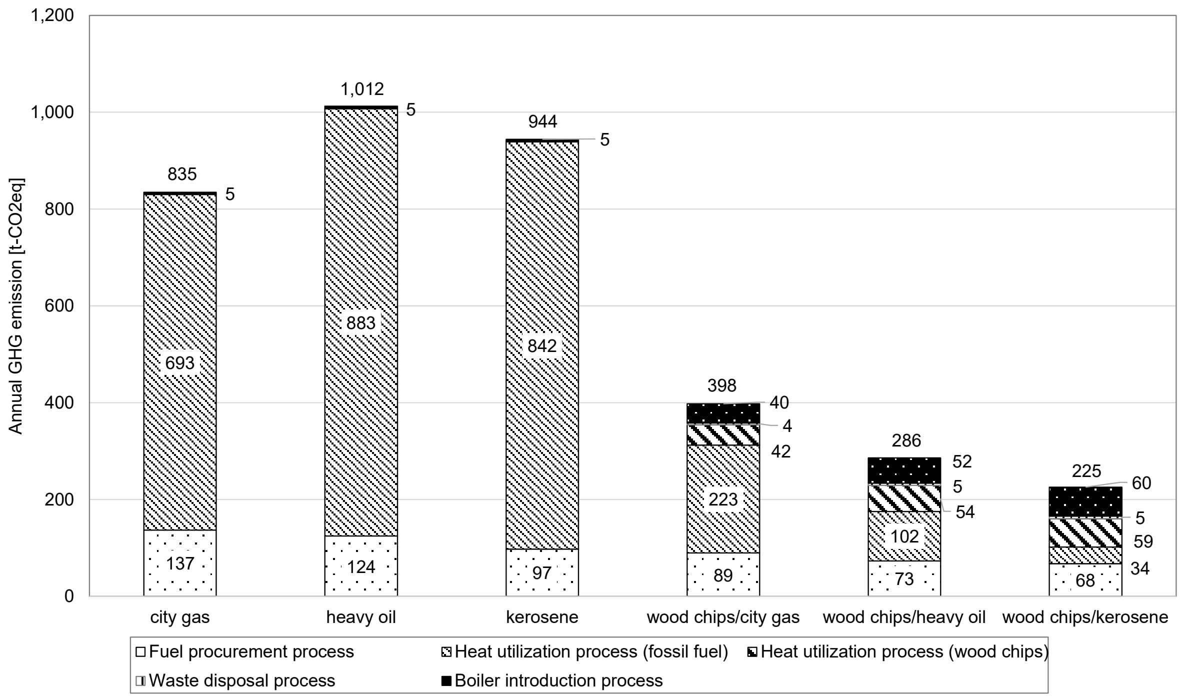


Figure 11 Annual GHG emissions of each fuel

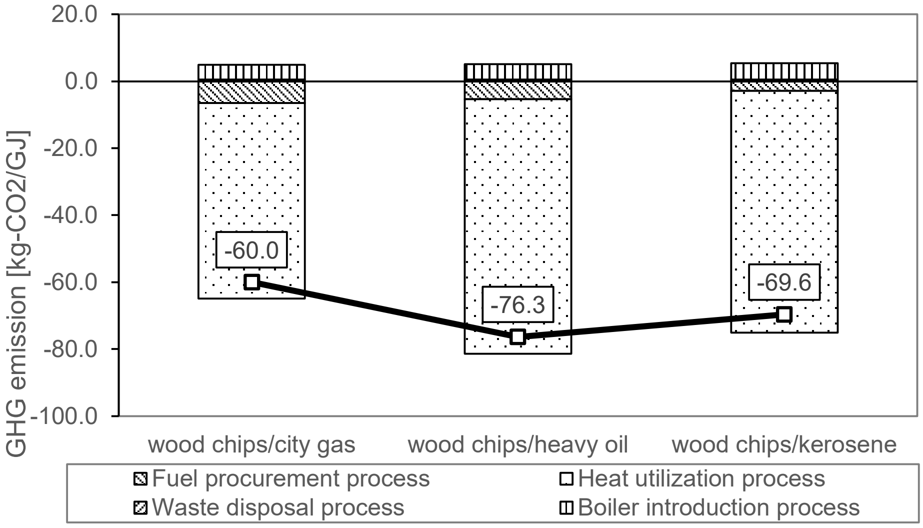


Figure 12 Net GHG emissions of wood chips for each fuel

3.3.2 Validity of the evaluation result

To verify the validity of our results, the results obtained were compared with those of previous studies. Because few studies have employed LCA to evaluate woody biomass heat in hot bath facilities, the results were compared with a case study targeting district heat supply and power generation. As a case study on district heat supply, Kayo et al. [13] elucidated the GHG emission reduction effect of a woody biomass district heat supply system. When liquefied petroleum gas was considered for substitution, the net GHG emissions were −21.6 kg-CO_{2eq}/GJ (with 29% thermal efficiency) and −65.3 kg-CO_{2eq}/GJ (with 75% thermal efficiency). Because the hypothesized hot bath facility is assumed to have high thermal efficiency and 90% boiler efficiency, the net GHG reduction was larger than the district heat supply. Studying power generation, Tabata et al. [14] explained the GHG reduction effect by evaluating the difference in the co-firing method of thinned timber. They reported that the net GHG emissions were −75 kg-CO_{2eq}/GJ with coal substitution. These results are consistent with the results obtained in this study. Our results agree with those of previous case studies, indicating that they are valid.

4. Conclusions

This study developed a model for evaluating a business utilizing woody biomass for heat from an integrated perspective of the environment, economy, and society. A hot bath facility using woody biomass at Mt. Rokko was assumed, and the environmental, economic, and societal outcomes of the assumed business were evaluated. The main findings are as follows:

(1) In the societal impact assessment, a questionnaire survey was conducted to clarify tourist consciousness regarding the facility. Its societal value was estimated using the CVM. The WTP of the respondents for a contribution fee was 298 JPY (2.83 USD; median).

(2) The total benefit of the hypothesized hot bath facility estimated based on the WTP of tourists and citizens of Kobe was 623.12 million JPY (5.92 million USD). This total benefit corresponds to approximately 1.5 times the annual forest maintenance cost of Mt. Rokko.

(3) If city gas was substituted into the wood chips, the optimum scale of the wood chip boiler was determined to be 373 kW, and the fossil fuel substitution rate was 67.2%.

The difference between the annual cost was −1.92 – 0.11 million JPY (−18.28 – 1.05 thousand USD). When heavy oil A and kerosene were substituted, the optimum wood chip boiler installation scales were determined to be 571 kW and 687 kW, respectively, and the substitution rates reached 88.3% and 95.9%, respectively. The differences between annual costs were −6.38 – −3.71 million JPY (−60.60 – 35.23 thousand USD) and −13.34 – −10.54 million JPY (−126.74 – 100.12 thousand USD), respectively. Kerosene substitution is likely to maintain cost reduction, even if the price of fossil fuel declines.

(4) The GHG emissions of city gas, heavy fuel oil A, and kerosene in the original system were 834.9, 1012.4, and 943.8 t-CO_{2eq}/year, respectively, in the original system. The lowest GHG emissions were 225.4 t-CO_{2eq}/year in the target system. The net GHG emissions per 1 GJ were −60 kg-CO_{2eq}/GJ for city gas, −76.3 kg-CO_{2eq}/GJ for heavy oil A, and −69.9 kg-CO_{2eq}/GJ for kerosene, respectively.

If forest maintenance costs were offset by additional contribution fees from the hypothesized hot bath facility, forest maintenance on Mt. Rokko could be promoted. According to the estimation, new environmentally and economically friendly businesses could be constructed in the region using woody biomass harvested at Mt. Rokko. Although the price of fossil fuels greatly affects economic viability, the economic shortcomings can be compensated for by fully utilizing the total benefits of the assumed facility.

At present, most woody biomass heat utilization in Japan is limited to public facilities. Compared with heat utilization, power generation from woody biomass receives favorable treatment, which is one factor for the low popularity of woody biomass heat utilization in Japan. To promote heat utilization by private companies, the United Kingdom has implemented an RHI since 2011, which increased the price competitiveness of renewable energy by offsetting the cost difference between the production cost of heat from renewable energy and that of fossil fuel with government subsidies. The RHI is considered to be the heating equivalent of the FIT. As of the end of November 2019, the number of heat uses certified by the Renewable Heat Incentive (RHI) reached 19,793, with a total output of 4,970.6 MW [45]. This figure corresponds to approximately 55% of the certified amount of FIT-based biomass power generation in Japan [46]. Although measures such as the RHI have not been considered in Japan, the introduction of such measures could promote heat utilization by private companies.

Acknowledgements

This study was funded by the Research on Environmental Economics and Policy Studies, Japan Ministry of Environment, grant number Stage IV, No.7. The authors would like to thank the funding bodies.

References

[1] JFA, Annual report on forest and forestry in Japan (FY2018). https://www.maff.go.jp/e/data/publish/attach/pdf/index-176.pdf, 2018 (accessed 13 February 2021).

[2] Japan Woody Bioenergy Association, Woody biomass energy data book 2018. https://www.jwba.or.jp/database/woody-biomass-energy-2018/, 2018 (accessed 13 February 2021).

[3] JFA, Case report for woody biomass heat utilization and cogeneration. https://www.rinya.maff.go.jp/j/riyou/biomass/con_4.html, 2017 (accessed 13 February 2021) (in Japanese).

[4] JMOE, Basic environment plan 2018. https://www.env.go.jp/policy/kihon_keikaku/plan/plan_5/attach/ref_en-01.pdf, 2018 (accessed 13 February 2021).

[5] Yanagida, T., Yoshida, T., Kuboyama, H., Jinkawa, M., Relationship between fe

edstock price and break-even point of woody biomass power generation under FIT program, J. Jpn. Inst. Energy 94 (2015) 311–320. https://doi.org/10.3775/jie.94.311.

[6] Kuboyama, H., Komata, H., Yanagida, T., Conditions for establishing a combined heat and power station by using unutilized woody biomass, J. Jpn. For. Soc. 99 (2017) 226—232. https://doi.org/10.4005/jjfs.99.226.

[7] Moon, D., Isa, A., Yagishita, T., Minowa, T., The regional economic impacts on the development of wood chip utilization in Maniwa city, J. Wood Sci. 59 (2013) 321–330. https://doi.org/10.1007/s10086-013-1334-6.

[8] Kamimura, K., Kuboyama, H., Yamamoto, K., Woody biomass supply costs and potential for biomass energy plants in Japan, Biomass Bioenerg. 36 (2012) 107–115. https://doi.org/10.1016/j.biombioe.2011.10.020.

[9] Goerndt, M.E., Aguilar, F.X., Skog, K., Resource potential for renewable energy generation from co-firing of woody biomass with coal in the Northern U.S., Biomass Bioenerg. 59 (2013) 348–361. https://doi.org/10.1016/j.biombioe.2013.08.032.

[10] Kizha, A.R., Han, H.S., Montgomery, T., Hohl, A., Biomass power plant feedstock procurement: Modeling transportation cost zones and the potential for competition, Calif. Agr. 69 (2015) 184–190. https://doi.org/10.3733/ca.v069n03p184.

[11] He, L.X., English, B.C., Menard, R.J., Lambert, D.M., Regional woody biomass supply and economic impacts from harvesting in the southern U.S, Energy Econ. 60 (2016) 151–161. https://doi.org/10.1016/j.eneco.2016.09.007.

[12] Japan Wood Energy, Report on LCA for woody biomass utilization. http://www.mori-energy.jp/pdf/lca_hokokusho.pdf, 2012 (accessed 13 February 2021) (in Japanese).

[13] Kayo, C., Ojimi, R., Iwaoka, M., Yasuda, K., Greenhouse gas emission reductions in a district heating and cooling system by using woody biomass- A study in Shiwa, Iwate Prefecture, J. Jpn. Wood Res. Soc. 62 (2016) 172–181 (in Japanese).

[14] Tabata, T., Torikai, H., Tsurumaki, M., Genchi, Y., Ukegawa, K., Life cycle assessment for co-firing semi-carbonized fuel manufactured using woody biomass with coal: A case study in the central area of Wakayama, Japan, Renew. Sust. Energ. Rev. 15 (2011) 2772-2778. https://doi.org/10.1016/j.rser.2011.02.042.

[15] Mamada, M. and Tanaka, H., Evaluation for use of woody biomass by inhabitants- A case of Myoko City, Niigata Prefecture, J. Rural Planning 25 (2006) 407–412 (in Japanese). https://doi.org/10.2750/arp.25.407.

[16] Mamada, M., Hara, H., Tanaka H. A study on the use of biomass resources by inhabitant, J. Rural. Prob. 53 (2017) 37–42 (in Japanese). https://doi.org/10.7310/arfe.53.37.

[17] Ahl, A., Eklund, J., Lundqvist, P., Yarime, M., Balancing formal and informal success factors perceived by supply chain stakeholders: A study of woody biomass energy systems in Japan, J. Clean Prod. 175 (2018) 50–59. https://doi.org/10.1016/j.jclepro.2017.11.108.

[18] Hodges, D.G., Chapagain, B., Watcharaanantapong, P., Pudyal, N.C., Kline, K.L., Dale, V.H., Opportunities and attitudes of private forest landowners in supplying woody biomass for renewable energy, Renew Sust. Energ. Rev. 113 (2019) 109205. https://doi.org/10.1016/j.rser.2019.06.012.

[19] Campbell, R.M., Venn, T.J., Anderson, N.M., Social preferences toward energy generation with woody biomass from public forests in Montana, USA, Forest Policy Econ. 73 (2016) 58–67. https://doi.org/10.1016/j.forpol.2016.08.008.

[20] Jåstad, E.O., Bolkesjø, T.F., Trømborg, E., Rørstad, P.K., The role of woody bi

omass for reduction of fossil GHG emissions in the future North European energy sector, Applied Energ. 274 (2020) 115360. https://doi.org/10.1016/j.apenergy.2020.115360.

[21] Komata, H., Ishikawa, Y., Hondo, H., Assessment of life cycle environmental impacts and external costs for woody power generation and cogeneration, J. LCA J. 13 (2017) 73–83 (in Japanese). https://doi.org/10.3370/lca.13.73.

[22] Tabata, T., Okuda, T., Life cycle assessment of woody biomass energy utilization: Case study in Gifu Prefecture, Japan, Energ. 45 (2012) 944–951. https://doi.org/10.1016/j.energy.2012.06.064.

[23] Jackson, R.W., Ferreira, N.A.B., Erfanian, E., Woody biomass processing: Potential economic impacts on rural regions, Energ. Policy 115 (2018) 66–77. https://doi.org/10.1016/j.enpol.2018.01.001.

[24] Kishita, Y., Nakatsuka, N., Akamatsu, F., Scenario analysis for sustainable woody biomass energy businesses: The case study of a Japanese rural community, J. Cleaner Prod. 142 (2017) 1471–1485. https://doi.org/10.1016/j.jclepro.2016.11.161.

[25] Bowd, R., Quinn, N.W., Kotze, D.C., Guilfoyle, M.J., A systems approach to risk and resilience analysis in the woody-biomass sector: A case study of the failure of the South African wood pellet industry, Biomass Bioenerg 108 (2018) 126–137. https://doi.org/10.1016/j.biombioe.2017.10.032.

[26] Cambero, C. and Sowlati, T., Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives – A review of literature, Renew, Sust. Energ. Rev. 36 (2014) 62–73. https://doi.org/10.1016/j.rser.2014.04.041.

[27] Kobe city government. Statistics of Kobe. https://www.city.kobe.lg.jp/a89138/shise/toke/toukei/, 2020 (accessed 13 February 2021) (in Japanese).

[28] Kobe city government, 2018 Survey on number of visitors and trends in Kobe. https://www.city.kobe.lg.jp/documents/26929/20190815142003-1.pdf, 2019 (accessed 13 February 2021) (in Japanese).

[29] Nakahara, Y., Tabata, T., Ohno, T., Furukawa, Y., Inokuchi, K., Katagiri, K., Hirayama, Y., Discussion on Regional Revitalization using Woody Biomass Resources as Renewable Energy, Int. J. Energy Environ. Eng. 10 (2019) 243–256. https://doi.org/10.1007/s40095-019-0300-5.

[30] Kuriyama, K., CVM for Excel Ver.3.2. http://kkuri.eco.coocan.jp/research/workingpaper/WP1101CVM32.pdf, 2011 (accessed 13 February 2021) (In Japanese).

[31] JFA, Practical texts for introduction and operation of woody biomass boilers. https://www.rinya.maff.go.jp/j/riyou/biomass/pdf/250610biomass1.pdf, 2012 (accessed 13 February 2021) (In Japanese).

[32] Japan Wood Energy, Diagnosis survey manual for woody biomass boiler introduction. http://www.mori-energy.jp/img/biomas-sindan.pdf, 2017 (accessed 13 February 2021) (In Japanese).

[33] Japan National Tax Agency, Depreciation by straight-line method and declining balance method. https://www.nta.go.jp/taxes/shiraberu/taxanswer/shotoku/2106.htm, 2019 (accessed 13 February 2021) (In Japanese).

[34] Japan Wood Energy, Woody biomass boiler introduction diagnosis work report in Sakaemura Kitano Tenma Onsen. http://www.vill.sakae.nagano.jp/fs/1/5/2/2/1/_/h24report_woody-biomass.pdf, 2012 (accessed 13 February 2021) (In Japanese).

[35] Japan Wood Energy, Guideline of woody biomass boiler introduction. http://www.mori-energy.jp/pdf/lca_boilershishin.pdf, 2012 (accessed 13 February 2021) (In Japanese).

[36] All Japan Wood–recycle Association, Wood chip market price by region. http://www.woodrecycle.gr.jp/pdf/kakaku/kakaku-kako.pdf, 2019 (accessed 13 February 2021) (In Japanese).

[37] Japan Woodchip Manufacture's Association, Survey and analysis business report on the stable trade of papermaking chips and raw wood for chips. http://zmchip.com/houkoku1.html, 2012 (accessed 13 February 2021) (In Japanese).

[38] JANRE, List of standard calorific value by energy source. https://www.enecho.meti.go.jp/statistics/total_energy/pdf/stte_016.pdf, 2018 (accessed 13 February 2021) (In Japanese).

[39] JANRE, Survey on petroleum product price. https://www.enecho.meti.go.jp/statistics/petroleum_and_lpgas/pl007/results.html, 2020 (accessed 13 February 2021) (In Japanese).

[40] JANRE, Transition in city gas prices and LNG prices. https://www.enecho.meti.go.jp/about/whitepaper/2010html/2-1-4.html, 2010 (accessed 13 February 2021) (In Japanese).

[41] Intergovernmental Panel on Climate Change, Climate change 2007: The physical science basis. https://www.ipcc.ch/report/ar4/wg1/, 2007 (accessed 13 February 2021).

[42] National Institute for Advanced Industrial Science and Technology, IDEA (Inventory Database for Environmental Analysis) Ver.2.2. http://idea-lca.com/?lang=en, 2020 (accessed 13 February 2021).

[43] National Institute for Environmental Studies, 3EID (Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables). http://cger.nies.go.jp/publications/report/d031/eng/index_e.htm, 2013 (accessed 13 February 2021).

[44] Kobe city government, Strategy for Mt. Rokko's forest management. http://www.city.kobe.lg.jp.cache.yimg.jp/life/town/flower/rokkou/siryou1.pdf, 2012 (accessed 13 February 2021) (in Japanese).

[45] GOV.UK, RHI monthly deployment data: November 2019. https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-april-2019, 2019 (accessed 13 February 2021).

[46] JANRE, Information of the FIT scheme. https://www.enecho.meti.go.jp/category/saving_and_new/saiene/statistics/index.html, 2020 (accessed 13 February 2021) (In Japanese).