

Article

Assessing Retail Biomass Electricity Efficiency in Japan: Focus on Average Cost and Benefit

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Abstract: Biomass utilisation has been one of the most pertinent topics in the field of sustainability. An example of biomass resource usage is renewable electricity (REL) using bioresources (Bio-REL). Although Bio-REL is widely disseminated globally, existing research suggests that it may be less economically efficient than other REL sources. The cost of Bio-REL has not changed in recent years, but the cost of solar or photovoltaic (PV) REL has been significantly reduced. Some studies also assert that retail Bio-REL is preferred less than PV-REL. As this is not well established in the literature, this study analysed the average levelised costs of energy (LCOE) and preferences for retail Bio-REL and PV-REL while focusing on the case of Japan. The results indicate that the average LCOE of retail Bio-REL was 1.4 times greater than that of PV-REL, while the willingness to pay (WTP) for Bio-REL was about half. The analysis has considerable relevance for countries other than Japan with comparative cost and preference for both REL sources. The research raises an important issue regarding the efficiency of the strategy of REL dissemination and proposes that a comprehensive economic analysis of the social benefits of Bio-REL be conducted.

Keywords: biomass; photovoltaic; renewable electricity; efficiency; levelised cost of energy; willingness to pay (WTP); Japan



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1. Introduction

Many countries have gone to great lengths to develop new biomass resource and energy usage. This has been especially so because it may improve local sustainability by not only improving environmental performance, such as waste biomass utilisation or CO₂ emission reduction, but also local vitalisation in the course of new local industrial development. It could be argued that biomass utilisation has been one of the most relevant topics in the field of sustainability. One example of biomass resource usage is the use of bioresources (Bio-REL) for renewable electricity (REL). Bio-REL is produced by burning or gasifying diverse kinds of biomass resources. Although it has been argued that its usage has non-financial social benefits, in general it has been criticised for its excessive costs; thus, assessing its social benefits is important. To assess its efficiency, an analysis that focused on retail Bio-REL was carried out to obtain a snapshot of the current status in terms of economic efficiency of biomass resource usage with concrete figures in Japan. We believe our paper provides important insights for further undertaking biomass development to improve sustainability and is thus relevant to this journal.

Biomass power generation is generating electricity by directly burning or gasifying biomass. Currently, various biomasses are effectively used, and under the Japanese FIT (feed-in tariff) system, Bio-REL is classified as woody biomass (produced either from unused lumber, general wood, or construction material waste, etc.), biogas from methane fermentation, and that produced from general waste and other biomass. Biomass power generation derived from local resources is considered to have great regional ripple effects,

such as maintenance and activation of local agriculture, forestry and fisheries, environmental conservation, and improvement of people's lives by effectively utilising organic waste as resources [1]. For example, since the start of the FIT system, the operation of woody biomass power plants using mainly forest residue and thinned wood discarded in forests, use of unused woody biomass fuel, and output of tips for fuels have increased, with considerable economic effects for mountain village areas [2]. Therefore, in addition to financial gains, biomass power generation has a wide range of benefits beyond the scope of privately captured ones, such as greenhouse gas (GHG) reduction and regional promotion, and it is necessary to evaluate them appropriately [2].

The issues and risks in the biomass power generation business in Japan are as follows [1]. When various wastes such as livestock excrement, swill, sewage, and urine are mixed and used, cooperation and coordination with local government agencies and communities is indispensable, and it takes a considerable amount of time (1 to 3 years) to obtain the region's consent. Moreover, stable fuel procurement is sometimes difficult, as are fluctuations in prices and processing costs of fuel, by-products, and residues (digestion liquid, combustion ash, etc.) after the use of power generation, and dealing with equipment failures.

Although Bio-REL is widely used globally, the most recent research regarding the economics of Bio-REL and other REL sources, especially the popular solar or photovoltaic (PV) power (PV-REL), seems to reveal that retail Bio-REL may be less economically efficient than other sources, especially PV-REL. However, this unrecognised fact may have broad and serious implications for the global REL market and policy, which makes an investigation into the economic efficiency of REL a priority.

PV-REL is classified under the Japanese FIT system into residential (less than 10 kW) and industrial (10 kW or more). The latter includes mega-solar and some smaller industrial PV-REL such as agri-voltaic power facilities set in farming houses, and are typically sold to electricity companies under the FIT system. Residential PV-REL is typically set up on the rooftop of detached private houses and sold to electricity companies under the FIT system. Regarding waste treatment, PV-REL has the same issues as Bio-REL; however, in the case of the former there are many occasions where consensus with the region at the time of introduction is not necessary, and securing fuel and waste treatment during operation is not essential. Additionally, it has been noted that the use of imported biomass could be a global sustainability problem [3].

The economic efficiency of a REL source is assessed by whether and how much its total benefits exceed the total installation costs (Figure 1). The costs and benefits of a REL are the total value and disvalue of installation and usage. The value of REL includes private goods value, such as the value of electricity usage and spillover industrial effects of REL installation (often called "pecuniary externality" effects), plus the public goods value, such as the social value of waste biomass usage, biodiversity conservation that results from utilising waste biomass, and preservation of farmland. Some of these values are captured in the market through REL prices, whereas other values are not well captured if they are perceived as social benefits irrelevant to consumers (particular values captured in WTPs (WTP—willingness to pay) depend on specific cases, but usually, social benefits that do not directly accrue to individuals may be valued at less than actual perceived value, as consumers may adopt strategic or free-rider behaviours without higher WTP values for socially desirable aspects of REL. Thus, the social value of REL may need to be assessed not just as WTPs for REL of electricity consumers but also with respect to other settings.). The social disvalue or costs of the REL source include the costs of scarce resources used for installation as well as fuels to generate the REL. Both benefits and costs include non-financial ones; for example, fuel is included in REL production cost, but its usage also leads to increased environmental pollution generated by mining, transportation, and combustion, which has other social costs.

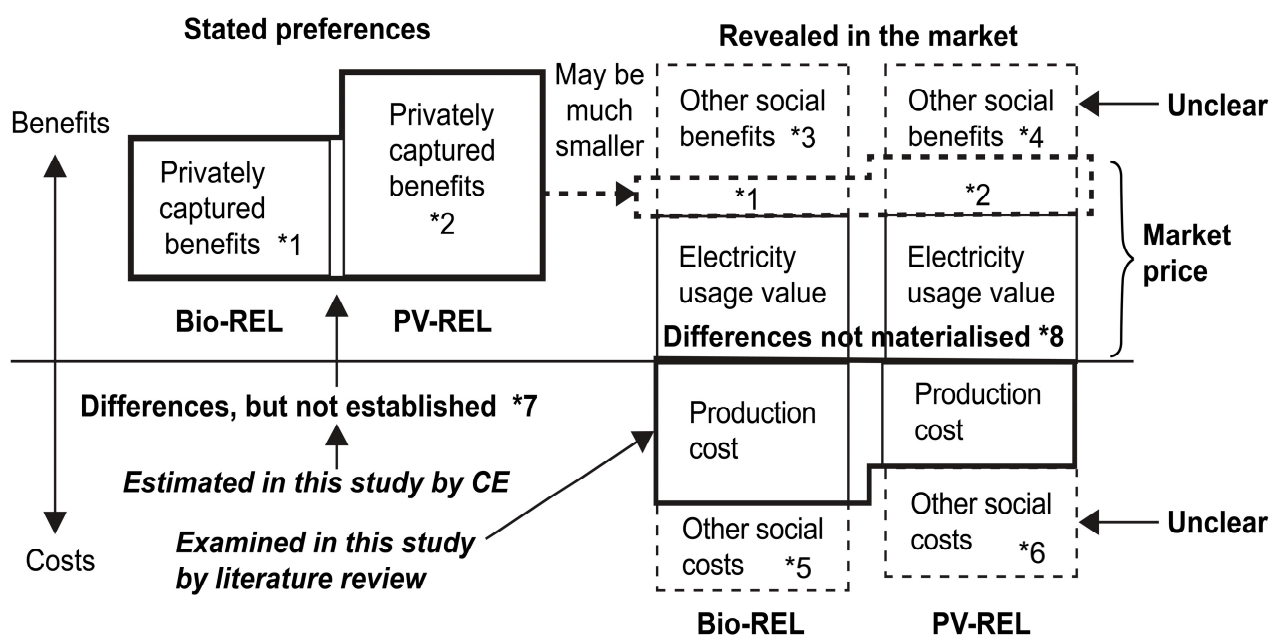


Figure 1. Economic efficiency assessment and the focus of this study. Notes: *1 Privately captured benefits particular to Bio-REL. *2 Privately captured benefits particular to PV-REL. *3 Other social benefits particular to Bio-REL. *4 Other social benefits particular to PV-REL. *5 Other social costs particular to Bio-REL. *6 Other social costs particular to PV-REL. *7 Some studies suggest that privately captured benefits are lower for Bio-REL than PV-REL, but these are not established in the literature. *8 Differences in benefits between Bio-REL and PV-REL have not materialised in the current market, even if there are such differences. Abbreviations: Bio-REL—renewable electricity using bioresources; CE—choice experiment; PV-REL—photovoltaic electricity.

Although REL benefits and costs differ by sources and sizes of the facilities producing it, efficiency can be compared in terms of the average net benefits (average benefits minus average levelised cost of energy or LCOE) of one kWh of Bio-REL or PV-REL. Efficiency analysis, which requires multisided consideration of both benefits and cost, is complicated, but revealed costs and stated individual preferences in the current literature suggest that retail Bio-REL may be less efficient than other retail REL sources, especially PV-REL, from the viewpoint of LCOE, reduction in the emission of GHG per kWh of electricity, and size of consumer preferences for REL. Preferences for REL can be estimated from stated preference studies of environmental economics, which estimate the WTP values perceived by consumers. Although these WTPs are sometimes larger than the actual prices in the market, the relative sizes of WTPs among different REL sources may be worth referencing (it has often been argued that the actual price premia of renewable energy are lower than predicted by research, especially studies conducted through revealing preferences methods. In Western countries, it has been reported that actual price premia for REL are negligible compared to conventional electricity prices.). If costs outweigh benefits, other net social benefits of Bio-REL, which are other social benefits minus social costs, should offset its lower net private economic benefits, thus economically justifying retail Bio-REL usage. In addition, conducting a private benefit/cost analysis is worthwhile because of its direct market implications for electricity companies making a profit or loss. Market implications are relevant to the energy-mix policies of governments, which usually aim to attain a low-carbon society with fewer subsidies for REL. Although the global trend of “energy mix” has promoted careful investigation of consumer preferences for electricity, surprisingly little research has been conducted on the differences in WTP values for each type of REL. This seems to be partly because of the relatively minor market implications of the differences in WTPs among different REL sources due to the current technical limitations to disentangle different REL sources in electricity grids after they are generated (REL of different sources are mixed after generation and consumers can

choose one of the energy-mix options. Therefore, although electricity consumers may be able to choose electricity companies, it would have often been technically difficult for them to use their preferred REL sources. Therefore, consumers' preferred REL sources have not been an issue for marketing or distributing REL.). However, when technologies enable consumers to select their preferred REL sources, market needs will materialise, with significant implications (consumer preferences may become much more pertinent in the near future with the development and adoption of novel technologies such as blockchains, which are expected to enable general consumers to select their preferred electricity sources. If electricity consumers can choose their preferred REL sources more accurately, price disparities among REL sources may accrue depending on the volume of preferences.).

This study compares the efficiency of retail Bio-REL with PV-REL in Japan, focusing on their private costs and benefits. We analyse the cost structures of both RELs by focusing on estimating the weighted average LCOE of one kWh of Bio-REL and PV-REL and the benefits of retail Bio-REL by estimating the WTP amounts. The analysis will be valuable to all electricity sellers and will also have significant implications for the application of energy-mix strategies and energy policies. To the best of our knowledge, this is the first study to analyse the comparative efficiency of Bio-REL and PV-REL. This analysis has considerable relevance for other countries where it is not well understood that Bio-REL has higher production costs and lower WTP value than other REL sources.

2. Materials and Methods

The workflow of this study is as follows. First, the relevant literature is reviewed in the global as well as Japanese contexts. Second, the analysis of a choice experiment (CE)—a stated preference method to estimate WTPs for products and services—is conducted using a survey, and its results are depicted. Third, the efficiencies of retail Bio-REL and PV-REL in Japan are analysed.

2.1. LCOE for Retail Bio-REL and PV-REL

It was previously estimated that the average LCOE of Bio-REL was lower than that of PV-REL. However, the cost of PV-REL globally has been rapidly decreasing in recent years [4]. According to IRENA [5], for newly commissioned projects, the global weighted-average LCOE of utility-scale solar PV fell by 82% over 2010–2019, from USD 0.378/kWh to USD 0.068/kWh, as the global cumulative installed capacity of all solar PV (utility-scale and rooftop) increased from 40 GW to 580 GW. Meanwhile, the global weighted average LCOE of bioenergy for power projects was USD 0.066/kWh, slightly higher than that of PV electricity. However, data from the IRENA Auction and PPA (power purchase agreement) Database indicate that solar PV projects that have won recent PPAs—to be commissioned in 2021—could have an average price of just USD 0.039/kWh [5], which means PV-REL has become much cheaper since 2019.

The above-mentioned cost structures were global, but in some developed European countries, the cost disadvantages of Bio-REL compared to PV-REL were clearly observed around 2019. For example, the production cost of Bio-REL (general wood with a capacity of 5000 kW) in Germany was JPY 12.7/kWh in 2017, which was higher than that in 2000. Meanwhile, in Germany, the average cost of PV-REL was JPY 60.7/kWh in 2000 but decreased to JPY 8.3/kWh in 2018. This cost reversal between Bio-REL and PV-REL was the same in France and Spain [6].

The LCOEs of Bio-REL and PV-REL were estimated as follows (Figure 2). First, capital cost, and operation and maintenance costs including fuel, were all totalled. In the case of Bio-REL, either the lower costs of procurement under the FIT system or the estimated LCOE of each Bio-REL were referred to as LCOE. Then, the weighted averages of LCOEs of both REL were estimated in terms of weighing the LCOEs from diverse types of renewable resources with varied sizes by the percentage of total power generation for each type of REL constituting Bio-REL and PV-REL.

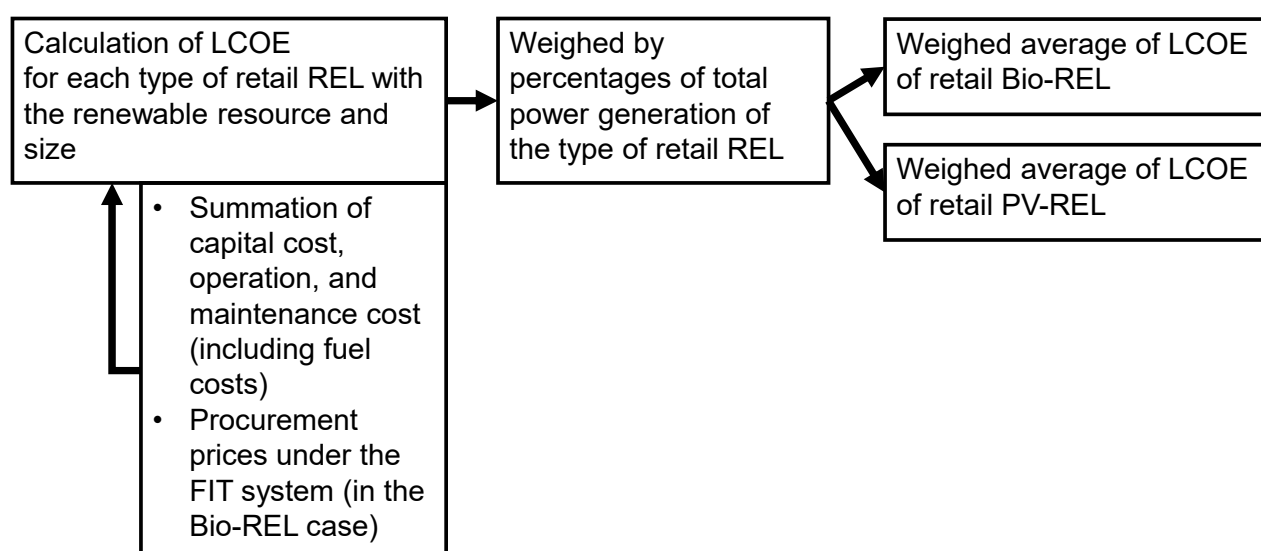


Figure 2. Process for the estimation of the LCOE of retail Bio-REL and PV-REL.

It is possible to estimate the average LCOE of retail Bio-REL in Japan based on the weighted average LCOE of retail Bio-REL produced from different kinds of biomass resources with different sizes of facilities operated through the FIT system. This is because the retail consumption of Bio-REL in Japan is almost exclusively purchased from electric power companies registered in the FIT system (systems other than FIT in Japan, including green power certificates, J-credits, and non-fossil certificates, allow companies to trade “environmental value,” but none of these are supposed to be purchased directly by general consumers.). For FIT-registered companies, the procurement price for Bio-REL is fixed for 20 years, and no businesses are expected to make negative profits at this procurement price under the FIT system. Therefore, it is considered that the LCOE of retail Bio-REL is lower than the FIT procurement price, which is regarded as closer to the average LCOE of REL because the price is set to cover the cost of efficient operation.

The difference between PV-REL and Bio-REL is that not only power generation companies but also individuals may produce PV-REL, such as on the roofs of their homes. In terms of individually installed PV-REL, the produced power is either sold through the FIT system or consumed in-house, for which there are no data on how much PV-REL is generated. Although retail PV-REL is purchased by commercial users through electric companies that install industrial solar power (>10 kW), this analysis calculates the weighted average LCOE of PV-REL consumed by citizens, which also considers the cost of self-procured PV-REL installed by citizens. Considering the cost of self-procured PV-REL leads to a higher weighted average LCOE because the cost of self-procured PV-REL is generally higher than that of industrial PV-REL facilities. In-house generation can be estimated by the amount of PV-REL sold through the FIT system because it is assumed that, in most cases, the surplus self-consumption of PV-REL is sold through the FIT system (in 2019, most of the in-house installers made their PV investment decisions with the power generation capacity covering both own consumption and selling surplus electricity through the FIT system because the procurement price in the FIT system was higher than the retail electricity prices charged by electric power companies in most places.).

The procurement prices of PV-REL in the FIT system may not necessarily represent its LCOE due to the financial uncertainty faced by individual PV-REL installers. Although the procurement period of PV-REL by individuals is 10 years, PV-REL can be produced after 10 years, which is sold through systems other than the FIT system with uncertain value. Therefore, it is not clear which PV-REL prices individuals had assumed when they decided to introduce their PVs, even as the LCOE of PV-REL depends on such an assumption. Meanwhile, the LCOE of PV-REL can be estimated from the capital cost and operation and maintenance cost data analysed by METI [6] in the same manner as the LCOE of Bio-REL.

2.2. The CE Method and Materials

A CE was conducted to estimate privately captured values of Bio-REL and PV-REL. The procedure of the CE follows (Figure 3). First, a questionnaire for a survey was developed based on the information obtained in the literature review and two focus groups and provided to respondents via a web page. Second, the obtained data were analysed by applying statistic models that would best represent the preferences of respondents regarding the use of Bio-REL and PV-REL. Third, WTPs and privately captured benefits for both REL and factors of such preferences were analysed.

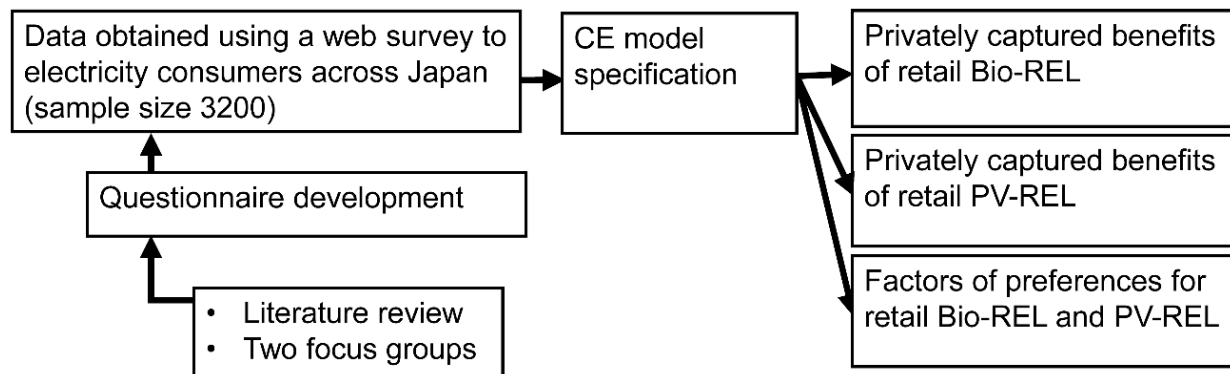


Figure 3. Model for the estimation of privately captured benefits and their factors perceived by electricity consumers for retail Bio-REL and PV-REL.

CE is the methodology used to determine the relative sizes of the utilities of two or more characteristics or attribute of a product or service [7,8]. The questionnaire asked each respondent to choose the most preferred type of electricity out of three alternatives, including REL and conventional electricity with different production methods and electricity costs (here, the cost of electricity is not production cost, but consumption cost.). CEs are based on the random utility model where goods and services utility comprises deterministic or systematic and observable (V) and stochastic components [7]. The behavioural model for a CE is

$$U_{nj} = V_{nj} + \varepsilon_{nj},$$

where n is a respondent, j is an option, and U_{nj} ($j = 1, \dots, J$) is the utility that respondent n obtains from option j (hereafter, this section employs Train's [9] methodology unless otherwise specified). V_{nj} is a systematic component of utility U_{nj} —a function of option j 's attributes and respondent n 's characteristics—and ε_{nj} is a random component that affects utility U_{nj} . If $U_{ni} > U_{nj} \forall j \neq i$ for respondent n , the respondent chooses i . Multinomial logit (MNL) and mixed logit (ML) CE models were built to explain the variables. MNL is the simplest choice experiment model. Generalised choice experiment models include the probit, nested, and ML models. The ML model, approximating any discrete choice model [10], has the following utility function:

$$U_{nj} = \alpha'x_{nj} + \mu_n'z_{nj} + \varepsilon_{nj},$$

where x_{nj} and z_{nj} are vectors of option j 's observable variables (specifically, option j 's attributes and respondent n 's characteristics concerning option j), μ_n is a vector of a random term with zero mean, and ε_{nj} is an independent and identically distributed (IID) Type-I (Gumbel) distribution. Once a suitable model is estimated, the marginal utility values and WTP values of the attribute parameters can be calculated. Suppose the utility values' systematic terms are

$$V_{nj} = \beta_1 x_{1nj} + \beta_2 x_{2nj} + \beta_3 p_{nj},$$

where p_{nj} is the price of option j . The first attribute x_{1nj} and the second attribute x_{2nj} of option j 's WTP values are β_1/β_3 and β_2/β_3 , respectively [11].

The CE study of this paper is an unpublished part of the research conducted from 2018 to 2019 concerning consumers' choice of REL sources. In this research, first, a comprehensive relevant literature review and two focus groups consisting of company professionals and citizens were implemented to extract stakeholders' understanding of the social impacts of introducing REL and the determinants of recognising such impacts. Second, two surveys with a small sample of 206 participants were conducted. Third, full surveys, including the survey presented in this paper, were undertaken. The CE questionnaire was developed with reference to the existing literature as well as previous research (in the questionnaire, first, a brief background to the survey was provided. It also provided information about renewable energy, including that it is a promising national energy and comparatively less popular in Japan than in other countries such as Germany and England, and about government policy and a formal definition. Second, it asked whether REL and other low-carbon electricity, such as PV power, had been produced and used at home. Third, it asked each participant four multiple-choice questions, having first briefly explained what Bio-REL and PV-REL are. Finally, it asked questions regarding socio-demographic values (SDVs) and opinions of the participants (relevant for analysing respondents' choices). As the provision for information may have affected the participant's responses, two questionnaires were prepared, one explaining the REL and another without any explanation.). The attributes and attribute levels of the CE are shown in Appendix A Table A1. To disentangle the values of Bio-REL (BIO) and PV-REL (PV), the attributes of an alternative included both BIO and PV. Additionally, the cost of electricity (COST), defined as the average monthly cost of electricity, was set as an attribute. The composition of electricity was set at 100% by adding up PV, BIO, and non-REL (electricity other than PV and BIO) (the WTP values for REL in the literature and national statistics regarding electricity consumption [12] were used to determine the monthly cost of electricity for average households for PV, BIO, and non-REL combined.). The experimental design was constructed by SAS Institute Inc. University Edition's "%ChoiceEff," which utilises a modified Fedrov algorithm to optimise the choice model variance matrix based on the largest D-efficiency and no prior assumption (the existing status quo alternative that each respondent used at the time of the survey was not included as an alternative, which may have led to forced choices and created a bias in the responses [13]. However, it was reported that the status-quo situation may have been erroneously remembered by the respondents, especially regarding the percentages of PV and Bio-REL, which would also trigger bias. Therefore, the lack of the status quo option was not expected to lead to a more biased result. In fact, some researchers have suggested that the lack of a status quo option may reduce status quo bias [14–16]. Although four to 16 questions are usually asked in environmental valuation CEs, only four questions were prepared in this study to avoid overburdening the participants [16].).

The questionnaire was used to conduct an Internet-based survey in March 2019, carried out by a professional survey company (MyVoice Communications Inc., Tokyo, Japan). Data were collected across Japan using stratified random sampling to understand the preferences of representative Japanese electricity consumers (Appendix A Table A2). The participants were aged between 20 and 79. Furthermore, their characteristics roughly corresponded to those of the Japanese population in terms of age, sex, and geographic area. Of the 10,161 questionnaires sent, 3429 (33.7%) responses were received. Of the 3429 responses, 229 were deemed dishonest and excluded. A total of 3200 responses were obtained, equally split between responses to the detailed questionnaire and to the less-detailed questionnaire. The sample population structure in terms of age, sex, and area of residence were very similar to those of the Japanese population (Appendix A Table A2). However, the percentage of respondents with at least a bachelor's degree was higher than that of the general population—48.3% vs. 23.1%, respectively), and so were household income (JPY 6,048,000 vs. JPY 5,523,000, respectively) and average monthly electricity bill (JPY 10,109 vs. JPY 9100, respectively). This indicates that the respondents were more

educated, earned a slightly higher income, and consumed a little more electricity than the average Japanese person.

The majority (81.0%) of respondents had not installed REL or other low-carbon electricity generation devices at home and instead bought all the electricity required. Two hundred and ten respondents (6.6%) had installed PV-REL for their own usage (these included cases where some surplus electricity was sold), whereas 51 (1.6%) had installed PV-REL facilities to sell the electricity produced to companies using the FIT system (i.e., they did not use the electricity). Sixty-five respondents (2.0%) installed fuel cells and gas engines using city gas and liquefied petroleum (LP) gas at home and used the electricity. The remaining 9% did not know whether REL had been installed, the type installed, or who had installed the other REL facilities.

Appendix A Table A3 summarises the features of the local areas of the respondents as recognised by the respondents themselves.

Appendix A Table A4 shows a summary of responses regarding lifestyle and attitudes, knowledge, values, and opinions of the respondents. Many stated that they had lived in their current places of residence for a long time and wanted to live there for longer. Many did not participate in activities in their local communities, such as public events. There were more respondents who considered themselves inadequately educated in terms of global environmental problems, energy, and renewable energy than those who considered themselves well-educated. Among the many values and opinions expressed, the most significant issue for the respondents was a stable supply of electricity (V28). Many expressed that they wanted to abide by local rules and societal norms, and agreed with the statement that global environmental problems, local employment, and environmental conservation are important.

The models were estimated using the free software R (v 4.0.3) and mlogit and RStan packages in its free software program. The MNL and ML models were estimated using the maximum likelihood estimation. As there was limited prior knowledge regarding model specification, linear-in-parameter MNL and ML models with the main effects and some cross effects were estimated. A main-effect model including the three attributes (PV, BIO, and COST) was generated as a base model. Next, additional explanatory variables (Appendix A Table A5) found to be relevant in the literature and previous research were then added one by one to the base MNL model depending on whether they improved the values of the Akaike information criterion (AIC). Models with cross effects between SDV variables were examined while focusing on the cross effects of sex and age and other SDV variables. Such cross effects were also assessed using their AIC values. The adopted model was then selected. A Bayesian model was also constructed to help understand the distribution of the estimates of the model.

3. Results

3.1. LCOE of Bio-REL and PV-REL in Japan

3.1.1. The LCOE of Bio-REL

Table 1 shows the procurement prices of Bio-REL under the FIT system in Japan as of 2019. The category “general wood, etc.” includes wood waste in sawing mills, imported lumber, and cut branches. Waste construction material power generation is JPY 13/kWh for all the scales and waste power generation for other general waste is JPY 17/kWh, power generation using general wood (<10 MW) (a bidding system is adopted for 10 MW or more of general wood power generation) is JPY 24/kWh, power generation of unused lumber (>2 MW) is JPY 32/kWh and that of unused lumber (<2 kW) is JPY 40/kWh, and methane fermentation biogas power generation is JPY 39/kWh [6]. From these figures, the average LCOE of Bio-REL in Japan would be somewhere in the range of JPY 13/kWh to JPY 40/kWh.

Table 1. Procurement price per 1 kWh of Bio-REL under the 2019 FIT system (JPY/kWh).

Unused Lumber (<2 MW)	Unused Lumber (>2 MW)	Construction Material Waste	General Wood, etc. (<10 MW)	General Waste and Other Biomass	Methane Fermentation Biogas
40	32	13	24	17	39

The fact that the procurement price of Bio-REL shown in Table 1 was close to its average LCOE can be evidenced from the capital cost, operation maintenance cost, and fuel cost data analysed by the METI [6] (all the following costs are the median values except for fuel costs; since the median value of fuel costs is not shown in the data of the committee, the average costs were utilised in the calculation of fuel costs.). Regarding the capital cost of power generation, 54 cases of unused materials (<2 MW) and general wood other than construction material waste were equivalent to JPY 450,000/kW, 19 cases of unused materials (<2 MW) to JPY 1,268,000/kW, 5 cases of lumber waste to JPY 509,000/kW, 69 cases of general waste and other biomass to JPY 894,000/kW, and 119 cases of methane fermentation biogas to JPY 2,164,000/kW. Regarding operation and maintenance costs, 61 cases other than unused materials (<2 MW) were worth JPY 44,000/kW/year, 13 cases of unused materials (<2 MW) JPY 71,000/kW/year, 207 cases of general waste and other biomass JPY 39,000/kW/year, and 103 cases of methane-fermented biogas were JPY 61,000/kW/year. The fuel costs of power generation for 15 cases of unused lumber (<2 MW) were JPY 860/GJ, 72 cases of unused lumber (>2 MW) were JPY 1085/GJ, 111 cases of general timber, etc. were JPY 723/GJ, and 44 cases of construction material waste were JPY 321/GJ [6]. Based on the costs and capacity factors in Table 2, LCOE per kWh was estimated at JPY 24.5–46.8/kWh when the equipment usage period were 20 years and the discount rate was 3% (Table 3).

Table 2. Bio-REL power generation registered in the FIT system.

	Unused Lumber (Less Than 2 MW)	Unused Lumber (2 MW or More)	Construction Material Waste	General Wood, etc. (Less Than 10 MW)	General Waste and Other Biomass	Methane Fermentation Biogas	Total
Number of facilities	30	40	5	56	98	182	411
Operating capacity (MW)	21	364	86	1291	289	63	2114
Actual capacity factor (%)	54.9	79.4	45.9	72.1	29.5	59.6	-
Percentage of total power generation (%)	0.83	20.76	2.82	66.78	6.13	2.68	100

Table 3. Estimated LCOE per 1 kW of Bio-REL equipment registered in the FIT system (JPY/kWh).

Unused Lumber (<2 MW)	Unused Lumber (>2 MW)	Construction Material Waste	General Wood, etc. (<10 MW)	General Waste and Other Biomass	Methane Fermentation Biogas
46.8	29.9	24.7	24.5	35.8	34.4

Notes: Assuming 20 years of equipment usage and a discount rate of 3% [3]. Estimated by the author from the METI [3].

Combining the results in Tables 1 and 3, the LCOE of Bio-REL falls within the range of JPY 13/kWh to JPY 46.8/kWh. To estimate the weighted average LCOE of retail Bio-REL, the share of Bio-REL production is examined. As shown in Table 2, as of December 2019, a total of 411 biomass power plants, with a capacity of 2.114 million kW, were in operation under the FIT system [17] (over 60% (1291 MW) of the operating capacity was general wood biomass, mainly fuelled by imports.). Assuming the lowest cost of each Bio-REL and scale in Tables 1 and 3, we estimated the weighted average LCOE of retail Bio-REL to be at least JPY 24.9/kWh (the FIT system also includes procurement by bidding, but the bid price is not included in the weighted average. Regarding the bid price of Bio-REL [6], four bids for general timber, etc. (>10 MW) were eligible to participate in the bid, but the actual bid was 35 MW (considering the biomass ratio). There was only one case (after output), and the winning bid was JPY 19.60/kWh. However, as the amount procured was less than

5% of the operating capacity (1291 MW) of general timber (less than 10 MW), it was not taken into consideration.).

3.1.2. LCOE of PV-REL

The system costs for PV-REL (<10 kW) and PV-REL (>10 kW) were 31.2 and 27.4 (JPY 10,000/kW), connection costs were 0 and 0.79 (JPY 10,000/kW), operation and maintenance costs were 0.288 and 0.460 (JPY 10,000/kW/year), and capacity factors were 13.5% and 14.4%, respectively. Table 4 shows the estimated costs based on the figures above, assuming 20 years of equipment usage and a discount rate of 3%. LCOE was estimated at JPY 17.7/kWh (PV-REL (>10 kW)) to JPY 19.1/kWh (PV-REL (own consumption) and PV-REL (<10 kW)). The weighted average LCOE of retail PV-REL was calculated from these figures, and the amount of power generated by PV-REL was as in the Bio-REL cases shown in Table 5. As of December 2019, the amount of PV-REL under the FIT system was 444 GWh for PV-REL (<10 kW) and 3033 GWh for PV-REL (>10 kW), whereas PV-REL (own consumption) was estimated to be 150 GWh. Therefore, the weighted average LCOE of PV-REL can be estimated as JPY 17.9/kWh.

Table 4. Estimated LCOE per 1 kW of PV-REL equipment (JPY/kWh).

	PV-REL (Own Consumption) *1	PV-REL Under FIT System	
		PV-REL (<10 kW)	PV-REL (>10 kW)
Power generation (10 MWh)	15,039	44,404.3	303,279
Estimated LCOE (JPY/kWh)	19.1	19.1	17.7

Notes: *1: Estimated by the authors by multiplying the amount of purchased electricity in the FIT system by the self-consumption rate [6]. As of December 2019.

Table 5. Benefits of reducing CO₂ emissions for Bio-REL and PV-REL in Japan.

	Bio-REL					PV-REL	
	Wood Chips (Domestic)	Wood Pellets (Domestic)	Wood Chips (Imported) *1	PKS (Imported)	Wood Pellets (Imported) *1	Residential PV	Industrial PV
CO ₂ emissions (g-CO ₂ /MJ)	3.3	14.1	25.7	13.4	23.3	-	-
CO ₂ emissions (g-CO ₂ /kWh) *2	11.9	50.8	92.5	48.2	83.9	-	-
CO ₂ emissions (power generation efficiency 20%) (g-CO ₂ /kWh) *3	59.4	253.8	462.6	241.2	419.4	38.0	58.5
CO ₂ emissions (power generation efficiency 30%) (g-CO ₂ /kWh) *3	39.6	169.2	308.4	160.8	279.6		
CO ₂ emission reduction (g-CO ₂ /kWh) *4	695.6	501.2	292.4	513.8	335.6	717.0	696.5
Benefits of reducing CO ₂ emissions (JPY/kWh) *5	1.15	0.83	0.48	0.85	0.55	1.19	1.15

Reference: [7,17]. Notes: *1: Since the lifecycle CO₂ for each import destination is calculated in the cited document, the average value from the minimum and maximum value was adopted. *2: The conversion of 1 kWh is 3.6 MJ. *3: In the calculation of CO₂ emission reduction amount, Bio-REL was calculated with a power generation efficiency of 20%. For PV-REL, the average value (58.5 g-CO₂/kWh) of the minimum and maximum values in the LCCO₂ range (58 to 59 g-CO₂/kWh) of 1 MW to 10 MW was adopted. The efficiency of the PV module of PV-REL was calculated at 13.9% for both residential and industrial PV in the references. *4: The amount of CO₂ emission reduction shows the amount of reduction compared with the average value (755 g-CO₂/kWh) of the minimum and maximum values of thermal power generation emissions (430 to 1080 g-CO₂/kWh). *5: Estimated from the CO₂ price as the average winning bid prices of JPY 1801/t-CO₂ (J-credit price for renewable energy projects) and JPY 1506/t-CO₂ (J-credit price for energy saving projects) in April 2019, the average of both prices, JPY 1653.5/t-CO₂, was utilised for calculation.

3.1.3. Comparison of LCOEs

From the above, it can be seen that the LCOE for retail Bio-REL and PV-REL ranged from JPY 13/kWh to JPY 46.8/kWh (weighted average cost JPY 24.9/kWh), and from JPY 17.7/kWh to JPY 19.1/kWh (weighted average cost was JPY 17.9/kWh), respectively (Figure 4). Thus, the LCOE of Bio-REL was, on average, 1.4 times that of PV-REL. Although small parts of Bio-REL are produced efficiently, the majority of Bio-REL is produced at

much higher costs than PV-REL. The above LCOE estimates do not include bid prices; however, in the 2018 bid for Bio-REL, four bids for general timber, etc. (>10 MW) were qualified to participate, but the actual bid was on only one case of 35 MW (output after considering the biomass ratio), and the winning bid was JPY 19.60/kWh. For PV-REL, there were 13 successful bids with a maximum price of JPY 15.5/kWh or less, even on a scale of 10 MW or less, and seven bids for all projects, including those up to about 90 MW. Therefore, even considering bid price, the conclusion that Bio-REL is, on average, more expensive than PV-REL remains unchanged. Indeed, small parts of Bio-REL facilities had even lower LCOE than PV-REL as of 2019; however, the average LCOE of PV-REL was expected to decrease further after 2019 [6].

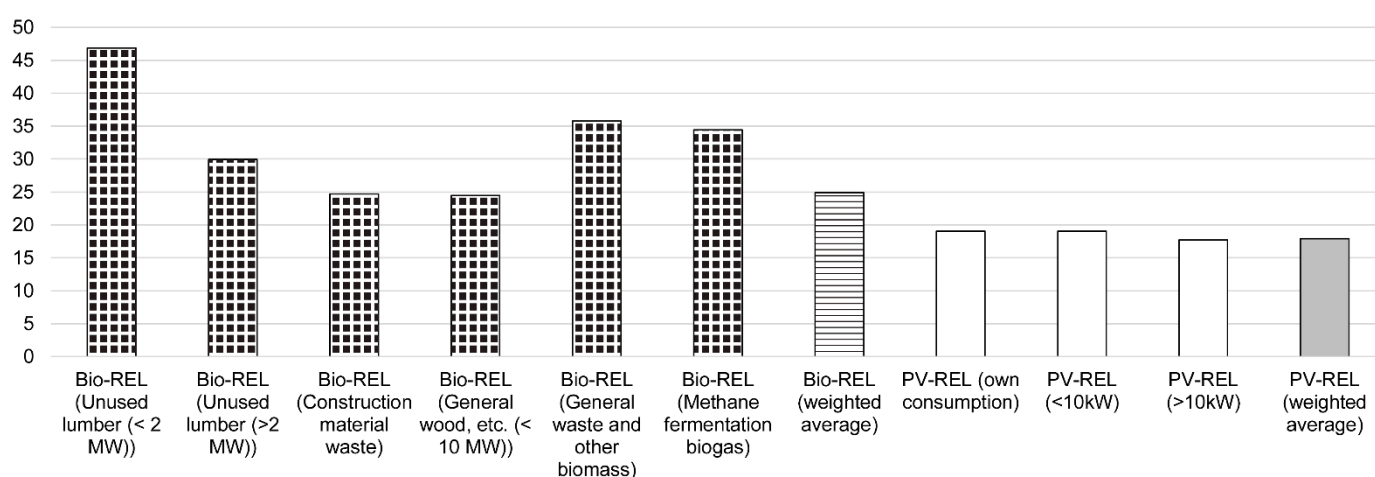


Figure 4. Estimation of the LCOEs of retail Bio-REL and PV-REL.

3.2. Benefits of Lifecycle CO₂ Emissions Reduction

Lifecycle CO₂ emissions of REL sources provide an important consideration for the efficiency of REL sources, especially when their major environmental benefit is to reduce CO₂ emissions, and therefore have direct implications for cost-saving. A part of the CO₂ emissions reduction benefits may be included in stated or revealed preferences, but these are not predicted to perfectly coincide with either. The reduction in CO₂ emissions significantly differs by REL source and conditions of resource usage, which seems especially relevant to Bio-REL, but also applies to other sources, including PV-REL, such as when solar panel frames are constructed differently and have different emissions implications. Therefore, this section focuses on Bio-REL's and PV-REL's CO₂ emissions in Japan, which again could become a reference for other countries with a similar procurement situation in power generation and bioresources.

The level of CO₂ emissions reduction was calculated from the reduction of CO₂ emissions compared to those of grey electricity. For example, lifecycle CO₂ emissions of thermal electricity generation ranged from 430 to 1080 g-CO₂/kWh. However, the lifecycle CO₂ emissions of nuclear electricity (pull thermal) was as low as 19 g-CO₂/kWh [7]. In Japan, Bio-REL based on imported biomass has been considered to have more lifecycle CO₂ emissions than PV-REL. As shown in Table 5, lifecycle CO₂ emission of PV-REL ranged from approximately 38 (residential PV) to 59 (industrial PV with a capacity of 10 MW) g-CO₂/kWh [7]. Here, lifecycle CO₂ emission volumes were examined for Bio-REL using wood-based biomass because the percentage of total power generation of Bio-REL for non-wood biomass (general waste and other biomass plus methane fermentation biogas) comprises only 8.8% of total Bio-REL (see Table 2) and its commercial costs are not available. When the power generation efficiency was 20%, all Bio-REL sources exceeded 59 g-CO₂/kWh, which is above the lifecycle CO₂ volume of residential and industrial PV-REL [18]. When the power generation efficiency was 30%, the lifecycle CO₂ volume of Bio-REL with wood chips (domestic) was 39.6 g-CO₂/kWh, almost the same as that of

residential PV. However, with a generation efficiency of 30%, other Bio-REL sources had higher lifecycle CO₂ emissions than PV-REL.

However, the weighted average benefits of reducing CO₂ emission for wood-based Bio-REL could not be as rigorously assessed, considering that Bio-REL based on construction material waste and general wood waste comprises as much as 76% of wood-based Bio-REL (see Table 2). However, its lifecycle CO₂ volumes included CO₂ emissions from transportation between waste generation sites and usage sites, which are unknown. Considering a wood sufficiency percentage of 37.8% [19], lifecycle CO₂ volumes for construction material waste and general wood waste would be closer to imported wood chips and pellets than domestic ones. Although this is not a rigorous assessment, the weighted average benefits of reducing CO₂ emissions may also be smaller, on average, for Bio-REL than PV-REL.

3.3. Benefit Evaluation by CE

The CE results show that all three attributes (PV, BIO, and COST) were significant at the 0.1% level, and their signs were as expected: COST had a negative sign, whereas PV and BIO had positive signs (Appendix B Table A6). The ML extension of this MNL model was estimated; the standard deviations of the random parameters were significant for all variables, namely, PV, BIO, and COST. Additionally, its AIC value was smaller than that of the MNL model (Appendix B Table A7). This suggests that the base model with PV, BIO, and COST fixed variables are not sufficient to address the variability of preferences. From the base model (Appendix B), it was revealed that consumers had positive WTP values for both PV and BIO, meaning that both REL sources had a positive impact on their preferences.

The best main-effect model was estimated by adding sets of variables, each of which improved the AIC value (Appendix C Tables A8–A10), to the base MNL model, and we determined whether the set of two or more variables also improved the base model using the criteria of the AIC values. The best MNL model was examined in terms of the lower AIC value and the statistical significance of the estimates. The ML model was also estimated based on the best MNL model but was rejected, as the random parameters (with regards to PV, BIO, and COST) were not statistically significant. This suggests that the best MNL model sufficiently addresses the preference variation by the addition of other explanatory variables to the base mode. Therefore, the maximum MNL model (Appendix D Table A11) was adopted. The result of the Bayesian version of the MNL model (Appendix D Table A12) was remarkably similar to that of the maximum MNL model.

Information provision in the adopted final model was insignificant. Local areas, including the Tohoku area where the Great East Japan Earthquake took place, were not a particularly significant factor in terms of the preference for REL. The participants of non-governmental or non-profit organisations (V10) accepted the cost burden of REL, whereas people who had frequent power cut problems (V30) did not. Older people preferred REL more than younger people, which is inconsistent with the global literature. However, this result is consistent with that of a previous study conducted by the authors. PV, BIO, and COST were all significant at the 0.1% level and had negative signs, with the negative signs for PV and BIO attributed to cross-variable effects.

A hypothetical respondent with average values for the explanatory variables had a positive WTP for both REL, JPY 1025 to 1026 for 100% PV, and JPY 508 for 100% BIO (Table 6). These amounts are in the lower range of the previous literature regarding WTP amounts for RELs in Japan. The WTP amounts of the Japanese population may be slightly lower than these amounts, considering that the respondents earned a slightly higher income than the average income in Japan. The WTP amount for Bio-REL was approximately half that for PV-REL. Table 6 shows that the preference for PV-REL was negative by less than 25%, whereas it was more than that for Bio-REL.

Table 6. Average respondents' WTP for 100% REL.

(a) Based on the maximum likelihood estimation						
	Estimate					
100% PV-REL	1026					
100% Bio-REL	508					
(b) Based on the Bayesian estimation						
	Mean	2.5%	25%	50%	75%	97.5%
100% PV-REL	1025	−1616	115	1019	1925	3673
100% Bio-REL	508	−1938	−307	494	1323	2968

Notes: Unit = JPY.

The common factors for preferring PV and BIO were values including V27 ("I oppose nuclear energy"), V17 ("Solving global environmental problems is important"), and marriage status. Age and sex were not relevant to the preferences for PV and BIO-REL sources. PV-REL was preferred by people who produced and used low-carbon electricity at home and who agreed with V18 ("Many renewable energy facilities should be installed in my current municipality"). Bio-REL was preferred by people who agreed with V26 ("Renewable energy will be disseminated even more in the future"). PV-REL was not preferred by people who wanted their municipalities to thrive (V20: "I want my current municipality to be more vitalised") and who thought that "There is a tendency to value local rules and social norms in my municipality" (V3). Bio-REL was not preferred by people who agreed with V11 ("I love the local community of my current municipality"), V8 ("There are facilities or offices related to electricity, such as power stations, in my municipality"), or by those who had children.

4. Discussion

The analysis of the efficiency of retail Bio-REL and PV-REL in Japan is summarised in Figure 5. The weighted average LCOE of retail REL for Bio-REL and PV-REL are JPY 24.9/kWh and JPY 17.9/kWh, respectively, for the latest estimation (as of 2019). Meanwhile, the CE result of this study estimated the average WTP amount, or the private benefits of retail Bio-REL and retail PV-REL, which were JPY 508 and JPY 1025, respectively, per household per month. As these WTP amounts were estimated for the same amounts of electricity usage both for Bio-REL and PV-REL, it means that WTP amounts per kWh of retail Bio-REL are about half per kWh of retail PV-REL. Therefore, private production costs of retail Bio-REL are about 1.4 times larger than for PV-REL, whereas the stated private benefits (WTPs) are about half of that PV-REL. This means that Bio-REL is costlier but has less value compared to PV-REL, suggesting that for retail, Bio-REL is less efficient than PV-REL.

Although the WTP values revealed in the market may be lower than the stated values, it is valid to assert that the comparative sizes of stated preferences among Bio-REL and PV-REL are also preserved in the market. This, in turn, suggests that the actual market values of Bio-REL may be lower than those of PV-REL, whereas its cost is higher if there are no subsidies, which has immense implications for Bio-REL and PV-REL retail marketing. Although the benefits of CO₂ reduction could not be examined rigorously, if the benefits of CO₂ emissions reduction are considered, the net benefit of Bio-REL could be even smaller than that of PV-REL. Therefore, the usage of relatively costly Bio-REL cannot be economically justified if it does not have other net-positive social impacts, which are not captured privately.

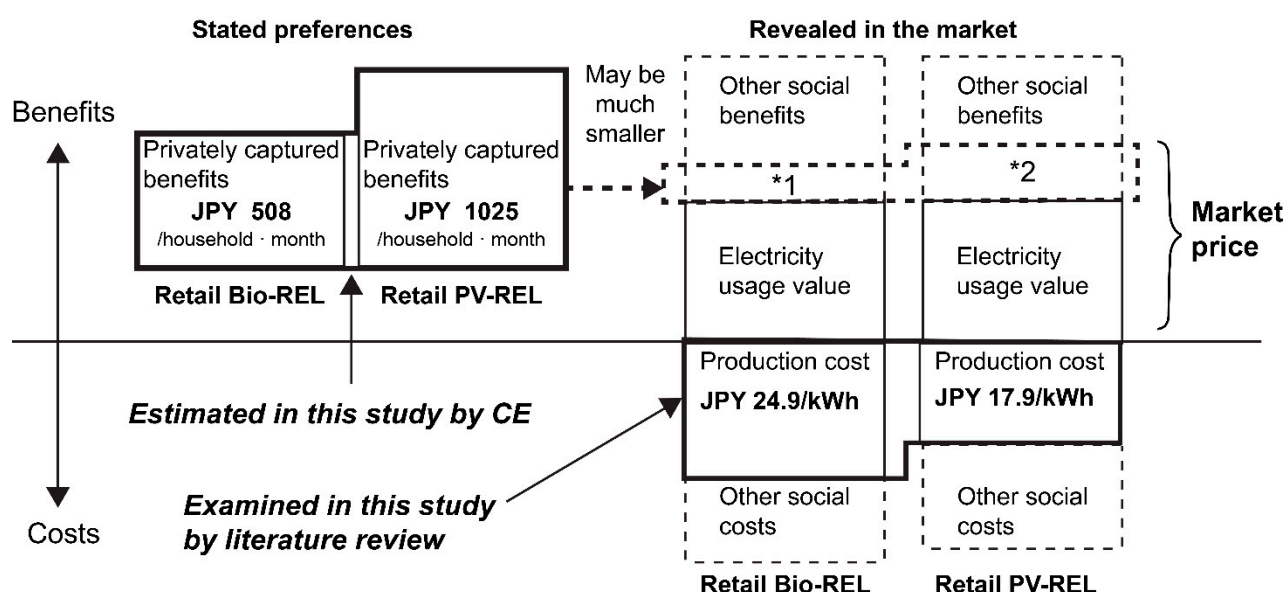


Figure 5. Analysis of the efficiency of Bio-REL and PV-REL for retail REL in Japan. Notes: *1 Privately evaluated benefits particular to retail Bio-REL. *2 Privately evaluated benefits particular to retail PV-REL.

The preference factors for PV-REL and Bio-REL are worth considering to generate future suggestions for the increase of social benefits and the decrease of social costs for both REL types. The results suggest that people understand that introducing PV-REL is more beneficial than Bio-REL, yet PV-REL was not considered to vitalise their communities or be suitable to install, as their communities valued local rules and social norms. This may mirror the fact that the installation of PV-REL is a private decision and community harmony may be sometimes impaired by private PV installation in Japan. The results also suggest that people expect Bio-REL to be disseminated further in the future than PV-REL to promote the usage of environment-friendly REL. People may be of the opinion that Bio-REL, with its current technology, may produce a similar NIMBY (Not In My Back Yard) problem for conventional power stations. Thus, it is suggested that an increase in net social benefits of Bio-REL can be attained if it can be produced by utilising more futuristic technologies and without impacting the environment. Information disclosure on successful Bio-REL production regarding non-existence of negative environmental impact and positive local social impact may lead to greater Bio-REL preference. PV-REL may elicit a wider preference if PV-REL facilities show more local vitalisation effects.

The study has considerable relevance for other countries outside Japan, where it is believed but not well understood that Bio-REL has higher production costs and lower WTP value than other REL sources. Uncaptured social benefits of Bio-REL with its current technology may include vitalisation of the local economy, such as an increase in local employment, or effective usage of bioresources, such as unutilised forest biomass or sewage waste, which may support forest biodiversity improvement or reduce sewage treatment costs compared to other REL sources. Many people may not know of such effective usage of biomass, and environmental education may be necessary to increase public knowledge. Bio-REL has been globally promoted not only due to its instant economic impact of GHG emissions reduction but also for other social impacts, including spillover effects to local vitalisation and utilising biomass resources. Other social benefits not privately evaluated are the government subsidies that enable electricity companies to sell Bio-REL profitably. Therefore, there is a need to examine the extent of the net social merits of Bio-REL. If Bio-REL (with larger LCOE) continues to be installed in the future, and the LCOE of PV-REL decreases further (a possible scenario), the social net benefits not privately captured ought to be considerably higher for Bio-REL than PV-REL. Future investigation into the extent of such social benefits is crucial to its increased adoption.

5. Conclusions

This study analysed the comparative efficiencies of retail Bio-REL and PV-REL in Japan to narrow the current research gap in the literature. It reviewed the relevant literature required to analyse the efficiency of REL introduction, including LCOE and lifecycle CO₂ emissions; conducted a CE to analyse the WTP of Bio-REL and PV-REL; and compared the efficiencies of Bio-REL and PV-REL.

The study found that production costs of retail REL were, on average, about 1.4 times larger for Bio-REL than for PV-REL. The WTP for Bio-REL was approximately half that of PV-REL. Retail Bio-REL was, on average, costlier but had less value compared to retail PV-REL, suggesting that for retail REL, Bio-REL was, on average, less efficient than PV-REL. Inefficiency of Bio-REL will be more prominent if the following technological risks discussed earlier are taken into consideration, namely, stable fuel procurement; fluctuations in prices and processing costs of fuel, by-products, and residues; and having longer instalment periods because of the necessity for local consensus. Using Bio-REL with a higher LCOE cannot be economically justified if it does not have other positive social impacts that are not privately captured, such as energizing local society and more effective usage of local bioresources compared to PV-REL. Although this study only assessed the Japanese case, the result of this analysis could apply to many other countries. When it becomes technically possible for overall electricity consumers to select their preferred REL sources, actual market values of Bio-REL may become lower than those of PV-REL even as its cost becomes higher, assuming no subsidy. This has far-reaching implications for electricity companies and their marketing, as well as for the application of governments' energy-mix strategies. It is by no means our intention to argue that Bio-REL should not be introduced; rather, we would like to highlight the need for a more rigorous economic assessment to include other social benefits and costs rather than only the financial costs and direct benefits of biomass usage.

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Abbreviations

AIC—Akaike information criterion; Bio-REL—renewable electricity using bioresources; CE—choice experiment; FIT—feed-in tariff; GHG—greenhouse gas; LCOE—levelised costs of energy; ML—mixed logit; MNL—multinomial logit; PPA—power purchase agreement; PV—photovoltaic; PV-REL—photovoltaic renewable energy; REL—renewable electricity; SDV—socio-demographic value; WTP—willingness to pay.

Appendix A. Choice Experiment

Table A1. Choice experiment attributes and levels.

Attribute	Level
PV-REL (PV)	0%, 25%, 50%
Bio-REL (BIO)	0%, 25%, 50%
Other electricity (fossil fuel-based, nuclear, large hydropower)	(Remaining %)
Cost of electricity (COST)	JPY 9800, JPY 10,300, JPY 10,800, JPY 11,300, JPY 11,800

Table A2. Summary of statistics regarding the survey population and the Japanese population.

	Variable	Sample	Population
Age (mean) ¹	Age	50.8	50.3
Male (mean)	Sex = 1	51.6	49.7
Female (mean)	Sex = 2	49.9	50.8
Sex ¹			
Male		50.0%	49.7%
Female		50.0%	50.3%
Area of residence ¹			
Hokkaido	HOKKAI	4.5%	4.2%
Tohoku	TOHO	5.1%	6.8%
Kanto	KAN	37.5%	35.0%
Hokuriku	HOKU	2.4%	4.1%
Chubu	CHUB	12.8%	12.7%
Kinki	KIN	20.9%	17.7%
Chugoku	CHUG	5.8%	5.6%
Shikoku	SHI	2.7%	2.9%
Kyushu ¹	KYU	8.3%	11.0%
Marital status ²	MAR	64.6%	60.3%
Number of household members (mean) ³	HM	2.7	2.4
Higher education ⁴ (bachelor's degree or higher)	ED	48.3%	23.1%
Offspring ⁵ (aged 20 years or less living at home)	CHI	26.3%	24.1%
Annual household income (mean thousand JPY) ⁶	HI	6048 ⁷	5523
Monthly electricity bill (mean JPY) ⁸	ELECON	10,109	9100

Notes: ¹: Age, sex, and residence composition of the general population are of people aged 20–79 as of 2019, obtained from the Residential Basic Book (“Jumin Kihon Daicho”) [20]. The Kyushu area includes Okinawa prefecture. ²: Marital status is the percentage of people aged 20 or over who are married. The data on marriage are from 2015 [21]. ³: Data as of 2019 [22]. ⁴: Data as of 2017 [23]. ⁵: Data as of 2019 [22]. ⁶: Average annual household income of the population is the average annual household income of Japanese population as of 2018 [22]. ⁷: The average annual household income of respondents was calculated by averaging all respondents’ annual household incomes. Each respondent’s annual household income was valued as the median value of the income range in the questionnaire of that respondent. ⁸: Data as of 2019 [24].

Table A3. Respondents’ views regarding the characteristics of their local area (explanatory variables V1–V8).

Variable	Mean Score ¹	Answer (%)				
		Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
V1 My local residents’ association is active and there is sufficient communication and ties to the community in my municipality.	2.9	8%	19%	49%	22%	3%
V2 The local government is sound in my municipality.	3.1	4%	13%	51%	27%	5%

Table A3. Cont.

Variable			Mean Score ¹	Answer (%)			
				Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree
V3	There is a tendency to value local rules and social norms in my municipality.	3.2	3%	11%	54%	28%	4%
V4	Use of natural energy and awareness of local environmental conservation issues are high in my municipality.	2.8	9%	22%	54%	13%	2%
V5	My municipality is either a big city or an urban area.	2.8	18%	20%	31%	19%	11%
V6	More than two features, including countryside, rich in nature, and environmentally good, apply in my municipality.	3.1	10%	16%	36%	28%	11%
V7	Declining population and birth rate and an aging population are apparent in my municipality.	3.0	10%	19%	41%	22%	8%
V8	There are facilities or offices related to electricity, such as power stations, in my municipality.	2.4	23%	28%	38%	9%	2%

Notes: ¹: Mean scores are calculated by the average scores of the respondents. The scores are as follows: Strongly Disagree = 1, Disagree = 2, Neither Agree nor Disagree = 3, Agree = 4, Strongly Agree = 5.

Table A4. Other explanatory variables except for variables regarding SDV and energy usage.

Variable		Mean Score ¹
Lifestyle and Attitudes		
V9	My household members or I actively participate in our local municipality (such as town activities, residents' associations and activities in public halls, communicating with other local people, or working as an officer of residents' associations).	2.78
V10	I or my household members actively participate in the activities of non-governmental or non-profit organisations.	2.17
V14	I have lived in my current municipality for a long time.	3.59
V15	I want to live in my current municipality in the future, too.	3.55
V16	My household members or I make a living in the current municipality.	3.63
Knowledge		
V23	I know global environmental problems well.	2.82
V24	I know energy problems well.	2.73
V25	I am familiar with renewable energy.	2.71
Value and Opinions		
V11	I love the local community of my current municipality (e.g., I like local community, or I consider the future of the local community of my current municipality).	3.22
V12	I trust in the people and companies in my current municipality.	3.16
V13	I want to abide by social norms or local rules.	3.73
V17	Solving global environmental problems is important.	3.81
V18	Many renewable energy facilities should be installed in my current municipality.	3.31
V19	It is important to conserve the environment or landscape in my current municipality.	3.67

Table A4. Cont.

Variable		Mean Score ¹
V20	I want my current municipality to be more vitalised.	3.47
V21	It is important to increase employment opportunities in my current municipality.	3.63
V22	It is necessary to vitalise industries in my current municipality.	3.36
V26	Renewable energy will be disseminated even more in the future.	3.55
V27	I oppose nuclear energy.	3.41
V28	Availability of electricity should be ensured.	4.06
V29	It is dangerous if energy facilities, such as power stations, are installed in my current municipality.	3.14
V30	It is a problem if power cuts happen, even if they last only 30 min.	3.63

Notes: ¹: Mean scores are calculated by the average scores of the respondents. The scores are as follows: Strongly Disagree = 1, Disagree = 2, Neither Agree nor Disagree = 3, Agree = 4, Strongly Agree = 5.

Table A5. Additional explanatory variables examined in the extended MNL model.

Variable	Definition	Assigned Values
SDV		
SEX	Sex	1: Male 2: Female
AGE	Age	(Year)
HM	Number of household members	1: One, 2: Two, 3: Three, 4: Four, 5: Five, 6: Six, 7: Seven or more
HI	Annual household income before tax	(JPY) ¹
II	Annual income before tax per household member	(JPY) ²
ED	Level of education	1: Studied at undergraduate or graduate level 0: Did not study at university
MAR	Marital status	1: Married 0: Not married
CHI	Number of children aged less than 20 living in respondent's household	
HOKKAI, TOHO, KAN, HOKU, CHUB, KIN, CHUG, SHI, KYU ³	Residence or otherwise in specific regions	1: Living in one of the regions 0: Not living in one of the regions
Energy usage		
RE	Installation of renewable energy device at home	1: Installed 0: Not installed
ELECON	Average monthly electricity payment	(JPY) ⁴
Features of local areas (see Appendix A Table A3) Lifestyle and attitudes (see Appendix A Table A4) Knowledge (see Appendix A Table A4) Values/opinions (see Appendix A Table A4)		1: Strongly Disagree 2: Disagree 3: Neither Agree nor Disagree 4: Agree 5: Strongly Agree

Notes: ¹: Unit = JPY 1000. The class value was used. JPY 14,000 or more were assigned JPY 15,000. ²: Calculated as HI divided by HM. ³: HOKKAI = Hokkaido, TOHO = Tohoku, KAN = Kanto, HOKU = Hokuriku, CHUB = Chubu, KIN = Kinki, CHUG = Chugoku, SHI = Shikoku, KYU = Kyushu, or Okinawa. ⁴: Unit = JPY. The class value (middle of the range of a class) was used. JPY 40,000 or more was assigned as JPY 45,000.

Appendix B. Base Model

Table A6. MNL model.

	Estimate	Std. Error	z-Value	Pr (> z)	
PV	0.979413	0.048718	20.104	$< 2.2 \times 10^{-16}$	***
BIO	0.495959	0.048766	10.170	$< 2.2 \times 10^{-16}$	***
COST	−10.607761	0.172331	−61.554	$< 2.2 \times 10^{-16}$	***
Log-Likelihood:		−11412			
AIC:		22829			

Significance: *** $p < 0.001$.

Table A7. ML model.

	Estimate	Std. Error	z-Value	Pr (> z)	
PV	1.170635	0.076826	15.2376	$< 2.2 \times 10^{-16}$	***
BIO	0.802796	0.072160	11.1252	$< 2.2 \times 10^{-16}$	***
COST	−15.408888	0.591250	−26.0615	$< 2.2 \times 10^{-16}$	***
sd.PV	2.205743	0.286825	7.6902	1.465×10^{-14}	***
sd.BIO	1.173461	0.452220	2.5949	0.009462	**
sd.COST	30.185358	2.103441	14.3505	$< 2.2 \times 10^{-16}$	***
Log-Likelihood:		−11333			
AIC:		22678			

Significance: *** $p < 0.001$, ** $p < 0.01$.

Appendix C. Variables with Effects in Terms of AIC Values

Table A8. Variables with effects on PV.

Variable Type	Variable	Coefficient	AIC
SDV	MAR	0.445	22812
	AGE	0.013	22820
	SEX	0.329	22820
	KIN	0.261	22827
	CHUB	−0.279	22828
	HI	0.000	22828
	HM	0.067	22829
SDV (cross term)	SEX × AGE	0.008	22807
Energy Usage	RE	1.287	22774
	ELECON	0.000013	22829
Features of Local Areas	V3	0.102	22828
	V6	0.078	22828
	V8	−0.111	22826
Lifestyle and Attitudes	V15	0.132	22823
	V16	0.264	22803
Knowledge	V23	0.197	22817
	V24	0.146	22823
	V25	0.173	22819
Values and Opinions	V11	0.207	22815
	V12	0.134	22826
	V13	0.385	22779
	V17	0.625	22679
	V18	0.665	22688
	V19	0.379	22780
	V20	0.177	22820
	V21	0.293	22801
	V22	0.244	22811
	V26	0.529	22737
	V27	0.643	22597
	V28	0.244	22806
	V29	0.113	22826
Information	INF	−0.310	22821

Table A9. Variables with effects on BIO.

Variable Type	Variable	Coefficient	AIC
SDV	AGE	0.027	22782
	SEX	0.583	22794
	MAR	0.436	22812
	CHI	−0.419	22817
	CHUB	−0.451	22822
	HOKU	−0.813	22824
	KAN	0.190	22828
	KIN	0.200	22828
	HM	−0.064	22829
SDV (cross term)	SEX × AGE	0.014	22744
	SEX × ELECON	0.000022	22808
Energy Usage	AGE × ELECON	0.000001	22815
	ELECON	0.000020	22825
	RE	−0.300	22828
Features of Local Areas	V2	0.127	22826
	V3	0.257	22812
	V8	−0.281	22797
Lifestyle and Attitudes	V10	−0.112	22825
	V14	0.137	22821
	V15	0.191	22814
	V16	0.319	22788
Knowledge	V23	0.088	22828
Value and Opinions	V11	0.090	22828
	V12	0.202	22818
	V13	0.490	22745
	V17	0.737	22617
	V18	0.530	22737
	V19	0.566	22716
	V20	0.328	22793
	V21	0.382	22779
	V22	0.257	22809
	V26	0.654	22684
	V27	0.691	22555
	V28	0.368	22772
	V29	0.166	22820
Information	INF	−0.631	22788

Table A10. Variables with effects on COST.

Variable Type	Variable	Coefficient	AIC
SDV	AGE	0.115	22759
	MAR	2.214	22793
	ED	−0.930	22824
	HI	0.001	22826
	SEX	0.778	22826
	SHIKOKU	−2.279	22827
	CHI	−0.705	22828
	CHUBU	−0.852	22829
SDV (cross term)	SEX × AGE	0.037	22785
	AGE × ELECON	0.000003	22792
	SEX × ELECON	0.000061	22815
Energy Usage	RE	4.431	22761
	ELECON	0.000106	22815

Table A10. Cont.

Variable Type	Variable	Coefficient	AIC
Features of Local Areas	V1	0.571	22822
	V2	0.460	22826
	V3	0.511	22825
	V4	0.291	22829
	V5	0.412	22822
	V6	0.300	22827
Lifestyle and Attitudes	V9	0.801	22804
	V10	0.902	22799
	V15	0.396	22825
Knowledge	V23	0.758	22814
	V24	0.585	22821
	V25	0.410	22826
Values and Opinions	V11	0.490	22824
	V12	0.706	22819
	V17	0.722	22815
	V18	0.718	22817
	V19	0.592	22821
	V22	0.365	22828
	V26	0.437	22826
	V27	1.280	22755
	V28	−0.372	22826
	V30	−0.664	22812
Information	INF	−2.312	22785

Appendix D. Adopted MNL Model

Table A11. Maximum likelihood estimation.

Variable	Estimate	Std. Error	z-Value	Pr (> z)	
PV	−2.80	0.30	−9.44	$< 2.2 \times 10^{-16}$	***
BIO	−2.80	0.30	−9.31	$< 2.2 \times 10^{-16}$	***
COST	−18.52	1.06	−17.43	$< 2.2 \times 10^{-16}$	***
V27 × PV	0.54	0.05	11.31	$< 2.2 \times 10^{-16}$	***
RE × PV	1.26	0.17	7.47	0.00	***
V3 × PV	−0.22	0.07	−3.35	0.00	***
V17 × PV	0.43	0.06	6.97	0.00	***
V18 × PV	0.42	0.07	6.33	0.00	***
V20 × PV	−0.19	0.06	−3.05	0.00	**
MAR × PV	0.28	0.11	2.58	0.01	**
V8 × BIO	−0.17	0.05	−3.40	0.00	***
V11 × BIO	−0.24	0.06	−4.22	0.00	***
V17 × BIO	0.44	0.06	6.91	0.00	***
V26 × BIO	0.29	0.07	4.32	0.00	***
V27 × BIO	0.51	0.05	10.89	$< 2.2 \times 10^{-16}$	***
CHI × BIO	−0.40	0.12	−3.26	0.00	**
MAR × BIO	0.34	0.11	3.05	0.00	**
RE × COST	4.83	0.53	9.09	$< 2.2 \times 10^{-16}$	***
AGE × COST	0.11	0.01	7.59	0.00	***
V10 × COST	0.92	0.16	5.65	0.00	***
V27 × COST	0.91	0.16	5.75	0.00	***
V30 × COST	−0.92	0.16	−5.81	0.00	***
ED × COST	−0.93	0.35	−2.66	0.01	**
Log-Likelihood:		−10857			
AIC:		21760			

Significance: *** $p < 0.001$; ** $p < 0.01$.

Table A12. Bayesian estimation of the adopted MNL model.

		Mean	Se_Mean	Sd	0.5%	2.5%	25%	50%	75%	97.5%	99.5%	n_Eff	Rhat
PV	*	−2.81	0.01	0.29	−3.50	−3.38	−3.00	−2.81	−2.62	−2.24	−2.09	1569	1.00
BIO	*	−2.79	0.01	0.29	−3.50	−3.36	−2.97	−2.79	−2.59	−2.23	−2.08	1322	1.00
COST	*	−18.56	0.03	1.09	−21.41	−20.68	−19.33	−18.51	−17.84	−16.35	−15.85	1028	1.00
RE × PV	*	1.26	0.00	0.16	0.85	0.96	1.14	1.27	1.38	1.59	1.66	1519	1.00
MAR × PV	*	0.27	0.00	0.10	0.00	0.08	0.21	0.28	0.34	0.47	0.55	1631	1.00
V3 × PV	*	−0.22	0.00	0.07	−0.38	−0.35	−0.27	−0.23	−0.18	−0.09	−0.04	1861	1.00
V17 × PV	*	0.43	0.00	0.06	0.28	0.31	0.39	0.43	0.47	0.56	0.58	1314	1.00
V18 × PV	*	0.42	0.00	0.07	0.26	0.28	0.37	0.42	0.46	0.55	0.60	1493	1.00
V20 × PV	*	−0.19	0.00	0.07	−0.35	−0.33	−0.24	−0.19	−0.15	−0.07	−0.03	1549	1.00
V27 × PV	*	0.54	0.00	0.05	0.42	0.44	0.51	0.54	0.58	0.64	0.66	1941	1.00
CHI × BIO	*	−0.40	0.00	0.12	−0.69	−0.65	−0.47	−0.40	−0.32	−0.18	−0.06	1538	1.00
MAR × BIO	*	0.34	0.00	0.11	0.04	0.11	0.26	0.34	0.42	0.56	0.66	1072	1.00
V8 × BIO	*	−0.17	0.00	0.05	−0.29	−0.28	−0.21	−0.18	−0.14	−0.07	−0.05	1529	1.00
V17 × BIO	*	0.44	0.00	0.06	0.27	0.31	0.39	0.44	0.48	0.56	0.61	1642	1.00
V11 × BIO	*	−0.24	0.00	0.06	−0.38	−0.35	−0.28	−0.24	−0.20	−0.12	−0.09	1964	1.00
V26 × BIO	*	0.29	0.00	0.07	0.13	0.15	0.24	0.29	0.33	0.42	0.46	1757	1.00
V27 × BIO	*	0.51	0.00	0.05	0.39	0.41	0.48	0.51	0.54	0.60	0.63	1928	1.00
RE × COST	*	4.84	0.01	0.53	3.47	3.85	4.51	4.82	5.18	5.91	6.22	2095	1.00
AGE × COST	*	0.11	0.00	0.01	0.07	0.08	0.10	0.11	0.12	0.14	0.15	1411	1.00
V10 × COST	*	0.93	0.00	0.17	0.50	0.59	0.82	0.93	1.05	1.24	1.36	1605	1.00
V27 × COST	*	0.91	0.00	0.15	0.54	0.63	0.81	0.91	1.02	1.23	1.29	950	1.00
V30 × COST	*	−0.93	0.00	0.16	−1.35	−1.25	−1.03	−0.93	−0.83	−0.60	−0.51	1258	1.00
ED × COST	*	−0.92	0.01	0.34	−1.77	−1.65	−1.15	−0.91	−0.68	−0.25	−0.05	1938	1.00
lp_	*	−10869	0.16	3.45	−10879	−10877	−10871	−10869	−10867	−10863	−10862	453	1.01

* 95% credible interval, which does not include a 0.

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