**Assessment of the impacts of willingness to pay on diffusion of renewable energy resources in Japan**

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**Abstract**

The aim of this study is to analyze and assess the impacts of the citizens’ willingness to pay on future diffusion of renewable energy resources in prefectures of Japan. Electricity production by renewable energy resources such as solar photovoltaic and wind power is an effective measure to mitigate climate change by reducing carbon dioxide emissions as well as to avoid depletion of fossil-fuel resources. Although its higher capital cost of renewable energy than those for conventional fossil fuel energy resources, there is a movement to defray the additional cost of electricity generated by renewable energy resources, further affecting the diffusion of renewable energy. For the purpose, we have developed series of models to estimate the willingness to pay and the corresponding acceptability for renewable energy resources. The model was designed to be incorporated into a multi-regional optimal generation planning model to determine the optimal energy roadmap.

1. **Introduction**

Global warming is already impact on many physical and biological systems. The special report on the global warming of 1.5 degree (SR 1.5) from the Intergovernmental Panel on Climate Change (IPCC) notes that continued warming increases the risks of flood, sea level, number of deaths because of heat waves and other extreme weather conditions. The potential dangers of global warming have led to policy reforms focusing on emission reductions to be proposed and the Paris Agreement calls global actions to keep global warming below 2˚C to reduce the risks of climate change

In order to reach goals by the Paris Agreement, numerous previous studies have suggested several pathways to promote the decarbonization of power sector (Howard et al., 2018; Sharifzadeh et al., 2017). Among these studies, one of key actions is diffusion of renewable resources such as solar and wind. For example, Howard et al. (2018) described a quantitative study with policy roadmaps to achieve 1.5 or 2.0 degree budget in Australian by 2050, and suggested that renewable energy have substantial effect on the reducing CO2 emission, in some cases by more than 90%.

On the other hand, some studies also pointed out that renewable energy resources need to overcome its higher generation cost than facilities and system those used conventional fossil-fuel resource. Fortunately, several recent studies revealed that the consumer would like to pay the additional cost of electricity (also known as Willingness To Pay, WTP) generated by renewable energy due to the increasing public concern for global environmental problems, especially climate change (Murakami et al., 2015; Nomura, 2009). Nomura (2009) employed stated preference surveys to elicit respondents’ willingness to pay (WTP) for increasing renewable energy resources in Japan. The results indicated the median WTP value per household in Japan for renewable energy was around USD 17 per month. Murakami et al. (2015) estimated the additional WTP of respondents for a 1% decrease in greenhouse gas emission was USD 0.26 per month. Yoo and Kwak (2009) evaluated the monthly mean willingness to pay for green electricity in Korea was 1.8 USD. Guo et al. (2014) pointed an average WTP for renewable electricity ranges from 2.7 to 3.3 US$ monthly in Beijing, China (Guo et al., 2014). Such consumer’s WTP may lead to remove cost barriers. However, most of these previous studies mainly focused on the survey of specific WTP values from the different regions. To our best knowledge, there is still no research about the impact of WTP on renewable energy diffusion, which can assist the policy makers to determine the subsidy policy for future sustainable energy development. As such, our study aims to assess the impacts of the citizens’ willingness to pay on diffusion of renewable energy resources in Japan.

We employed mixed methods to assess the impact of willingness to pay on diffusion of renewable energy resources, which included two parts. Firstly, we developed series of models to simulate the WTP for renewable energy resources in different regions. Then, we incorporated the developed WTP models into multi-regional optimal generation planning model which had been built by Ashina and Fujino (2007) to seek configuration for power plant outputs under the objective of minimizing generation cost with consumer’s WTP (section 2). In section 3, the WTP for renewable energy and potential optimal energy use pathways were simulated under two economic growth cases to 2030.

1. **Methods**
2. **Willingness to pay model by meta-regression analysis**

In this study, we applied meta-analysis involving a set of statistical methods for the collection of previous research studies in a given topic. An extensive search for the primary studies related to WTP for renewable energy was collected from Web of Science, Google Scholar and CiNii Articles. The search spanned from the 2000 to 2018 using the phrase “willingness to pay”, “Japan” and “Contingent Valuation Method” in combination with the following renewable energy related words: renewable energy, green, electricity, power, wind, solar, photovoltaic and hydro. These studies both included the English related studies and Japanese related studies. We collected 22 primary studies by using those research terms. Among the 22 studies, 14 studies which included the value of WTP for meta-regression analysis were selected. The median value of WTP for increasing the renewable energy in current electricity mix was used as dependent variable and the WTP for nuclear power is not included due to the negative preference for this kind of energy source (Murakami et al., 2015). For the purpose of comparison, WTP values was converted in Japanese Yen (JPY) per household per month. Our observed data are summarized in Table 1 and the average of WTP was 1,388 JPY/(household·month). The highest value of WTP (5,410 JPY/(household·month)) was found in Tokyo (Ise, 2006). The lowest value of WTP (238 JPY/(household·month)) was reported for using biomass in Kagoshima(Teraoka, 2002).

In this study, 2 variables (*Gender, Income*) were identified to calculate the WTP by meta-regression model and defined as follows:

(1)

Where Gender is the percentage of female share within total population (%), Income is the annual average household income (JPY)

In general, relationship between percentage of consumers willing to pay additional cost (or acceptability rates) and level of WTP follows Weibull distribution as follows:

(2)

Where, *F*base (X) is the base acceptability function which is estimated by previous studies. Y is acceptability rates, X is WTP in JPY/(household·month). The values of a and b are estimated through meta-analysis by several studies, and in this work, they are assumed to 6.505 and 1.065, respectively.

Theoretically, the WTP under the same acceptability rate of renewable energy is changing for consumers when median value of WTP is changed. This implies a shift in acceptability curve. Based on equation (1) and (2), the acceptability model can be defined as follows:

(3)

(4)

(5)

(6)

Where, *F*(*X*) is the acceptability function, Y50% is acceptability rates in 50%, t is the year.

1. **Incorporation of WTP into energy use model**
2. **Objective function for optimization**

Considering the results of the WTP, the energy using model which is bulid by Ashina and Fujino (2007) is modified to specify energy choice in future energy system coupling with consumers’ preferences. The supply quantity for each type of generators was calculated through total cost minimization during the analysis period, and estimated by following:

(7)

Where, *C*c, *C*o, *C*f, *C*t and *C*s are capital cost, opertation and maintenance cost, fuel cost, carbon cost and transport cost, respectively. *P*c is installed capacity, *O*g is the energy supply quantity, *T*i is the enenrgy supply quantity from other prefecture. RESBcost is the cost for addational renewable enegy capacity and second battery which are covered by consumer’ williness to pay. *g* is types of generators, *p* is the demand patterns, *l* is the location of power plant, *y* is the year.

1. **Other quation and constraints in energy use model**
2. Potential capacity for photovoltaics (PV) and wind power (WP)

(8)

Where are installed capacity and potentail capacity, respectively. F(x) is the acceptability function.

1. Total WTP for renewable energy

(9)

Where TWTP is the Total WTP in JPY/year, F(x) is the acceptability function, X is WTP in JPY/(household/month). Household is the numbers of household in target area.

1. Additional renewable energy

For renewable energy, we estimated the potential capacity for renewable energy based on both the natural and economic condition. Furtherly, we assumed all the WTP would be used for increasing the capacity of renewable energy and second battery. Those restriction conditions are defended as follows:

(10)

(11)

Where, are capital cost, and opertation and maintenance cost, respectively. is addational installed capacity. WTP is the williness to pay by consumer. RESB is types of renewable energy generators and second battery, *l* is the location of power plant, *y* is the year.

1. **Scenario setting in 2030**

As shown above, the WTP and Acceptability models was developed by history data. Next, these two models are used to project the future WTP and acceptability in different prefectures, assuming that the trends observed over the modeling period (2000-2014) will continue for the next several decades (2015-2030).

1. Socioeconomic condition

Income was forecast by Cabinet Office (2018) based on past performance and the current economic trend. The projection depicts two possible future condition.

* **Economic Growth Achieved Case**: This case offers a projection in which the policies of Abenomics overcome deflation and attain economic revitalization with solid results at a more feasible pace.
* **Baseline Case**: This Case offers a projection in which the economy will grow approximately at the rate of current potential growth

1. Scenario setting

To clarify the effect of WTP by consumer on renewable energy diffusion, three future scenarios were established.

* **Scenario Ref**: Estimation the feasible energy mix for achieving 26% GHG reduction in 2030 without consideration the impact of WTP.
* **Scenario 1**: Estimation the feasible energy mix for achieving 26% GHG reduction in 2030 with consideration the impact of WTP. Moreover, WTP is estimated under the baseline case.
* **Scenario 2**: Estimation the feasible energy mix for achieving 26% GHG reduction in 2030 with consideration the impact of WTP. While, WTP is estimated under the economic growth achieved case.

1. **Results**
2. Feasible energy mix for achieving 26% GHG reduction in 2030

In this study, we set a 26% Greenhouse gas (GHG) reduction from 2013 to 2030 based on nationally determined contributions (NDC) of Japan submitted to UNFCCC. Fig.1 show the trends in the makeup of power generation with years under scenario 1 and scenario 2. Overall, over 80% of electricity are generated from thermal and nuclear power plants which do have a lower production cost over the studied period. However, the electricity generation is predicted to shift gradually from thermal to nuclear power plants for achieving 26% GHG reduction in 2030. In detail, the proportion of electricity from thermal power plants that use fossil fuels are decreasing from 70% to 32%, against with the increase from 17% to 51% by nuclear power plants and from 4% to 7% by renewable plants over the period of 2015-2030.

To concern the renewable energy, the electricity generation under different scenario are shown in Figure 2. From 2015 to 2030, the electricity generation shows a remarkable increase, which can be reasonably explained because of increased WTP. The electricity generation over the period of 2015-2030 are expected to be whithin the ranges of 40-60 TWh and 40-70 TWh under the scenario 1 and scenario 2.



**Fig.1** Generation of Electricity by various types of power plant for achieving 26% GHG reduction under scenario 1 (a) and scenario 2 (b).



**Fig.2** Electricity generation from solar and wind power plants under economic scenario 1 and 2 from 2015 to 2030

1. The influence of WTP on diffusion of renewable energy



**Fig.3** Electricity generation by renewable energy power plants under scenario Ref, 1 and 2 to 2030.

The electricity generation from renewable energy power plants under different scenarios are shown in Fig. 3. In scenario 1 and 2, the electricity generation is expected to be 9 – 10-fold (60 and 69 GWh) than Ref scenario. To concern individual regions, the installed capacity in R3 is higher than that for other regions. This is mainly contributed by Tokyo which comprises the third of Japan’s major industrial region and in which the people living earn a relatively higher income. As the result, they have the ability to burden more cost of renewable energy by themselves.

1. Unit cost leading to the 26% GHG reduction

Moreover, Fig.4 show the energy generation cost and WTP under different socioeconomic scenarios in 2030. Totally, the results indicate the unit energy generation under scenario 1 and 2 which consider the WTP are lower than Ref scenario which ignoring the impact of WTP, even under the same carbon emission target. Furtherly, in the case of economic growth achieved, the energy generation cost is lower than that in baseline case and this is primarily attributable to higher income under a rapidly economic growth, as the latter leads to a higher WTP by consumer. To concern individual regions, in R6 and R8, the unit energy generation cost under the scenario 1 is higher than Ref scenario. This is mainly contributed by the increasing in fossil-fuel energy which can preserve electric power system stability.



**Fig.4** Projectedenergy generation cost and WTP under Ref, scenario 1 and 2 in 2030. Solid bars (Ref), Bars with hash pattern (scenario 1) and point pattern (scenario 2) show the energation cost with and without consideration of WTP, respectively. Point shows the WTP in each region.

1. **Conclusion**

This paper proposes a method for simulation impact of willingness to pay on diffusion of renewable energy resources in Japan during 2015-2030. We developed series of models to simulate the WTP for renewable energy resources in different regions. Then, we incorporate the developed WTP models into multi-regional optimal generation planning model to discuss the potential energy end use pathways.

In this study, several findings were obtained. First, the the renewable energy will increasing from 40 TWh to 70 TWh with considering the infulence of WTP over the period of 2015-2030. Morover, the electricity generation from renewable energy resources with considering the WTP is expected to be 10-fold than the Ref scenario which ignoring the impact of WTP. This resluts suggesting the WTP will improve the diffusion of renewable energy. Lastly, the unit energy generation under scenario 1 and 2 are lower than Ref scenario, due to its cover by user’ WTP.

Above all, in dealing with the increasing carbon emission, one of the most effective strategies is to use renewable energy. Although its higher capital cost than fossil-fuel resource, there is a movement to pay for it by consumer. This study evaluation of renewable energy diffusion in Japan could be improved by the user’ WTP in each region. In other words, the preference of user which is one of the local characteristics have a significant impact on the low carbon city development. For the future work, we would like to disscuss the impact by other local characteristics on the diffusion of renewable energy resources.

**Acknowledgment**

This research was supported by Environment Research and Technology Development Fund (2-1711) from Environmental Restoration and Conservation Agency and Ministry of the Environment, Japan.

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