ASSESSING THE IMPACTS OF WILLINGNESS TO PAY ON DIFFUSION OF RENEWABLE ENERGY RESOURCES IN JAPAN

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1.Overview

In order to reach goals in 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, suggesting renewable energy have substantial effect on the reducing CO_2 emmision, in some case by more than 90%.

Many studies also have pointed out that renewable energy resources need to overcome its higher generation cost than facilities and system those used conventional fossil-fuel resource. Several recent studies have revealed the consumer would like to pay the additional cost of electricity (also known as Willingness To Pay, WTP) generated by renewable egergy due to the increasing public concern for global environmental problems, especially climate change (Murakami et al., 2015; Nomura, 2009). Such comsumer's WTP may lead to remove cost barriers, however, most of these studies mainly focused on the survey of specific WTP value 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 aim to assess the impacts of the citizens' willingness to pay on diffusion of renewable energy resources in Japan.

2. Methods

This study employed mixed methods to assess the impact of willingness to pay on diffusion of renewable energy resources, which include two parts. Firstly, 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 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.

2.1. Willingness to pay model by meta-regression

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

$$WTP_{med} = f\,(Gender, Income) \tag{1}$$

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 (or acceptability rates) and level of WTP follows Weibull distribution as follows:

$$F_{base}(X) = Y = \exp(-\exp((\ln X - a) / b)) \tag{2}$$

In this specification, F_{base} (X) is the base acceptability function which is estimated by pervious studies. Y is acceptability rates, X is WTP in JPY/(household·month). The value of a and b have been estimated through meta-analysis by using 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:

$$F_{base}(X) = \exp(-\exp(((\ln X_t - a) - \alpha) / b)) \tag{3}$$

$$\alpha = X_{t,50\%} - X_{base}\ ,\ X_{t,50\%} = WTP_{med},\ X_{base} = \exp(a + b\ln(-\ln(Y_{50\%}))) \tag{4}$$

Where, $F(X)$ is the acceptability function, $Y_{50\%}$ is acceptability rates in 50%, t is the year.

2.2. Incorporation of WTP into energy model

The supply quantity for each type of generators was calculated through total cost minimization during the analysis period, and estimated by followed equation:

$$\text{MinTC}=\{[\Sigma\,(C_c(g)+C_o(g)\times P_c(l, g, y)]+[\Sigma\,(C_f(g)+C_t(g))\times O_g(p, t, l, g, y)]+[\Sigma\,C_s(l)\times T_l(p,t,l,y)]\,\}$$
$$\times\, i \times (1+i)^n/[(1+i)^n-1] + \text{Max}(RE_{cost}) \tag{5}$$

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. RE_{cost} is the cost for addational renewable enegy capacity which is 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.

For renewable energy, we estimated the potentiaial 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. Those restriction condition are definded as follows:

$$P(l, g_{pv,wp}) \leq P_{pot}(l, g_{pv,pw}) \times F(X) \tag{6}$$

$$RE_{cost}=[\Sigma\,(C_c(RE)+C_o(RE)\times P_c(l, RE, y))]\times i \times (1+i)^n/[(1+i)^n-1] \tag{7}$$

$$RE_{cost} \leq WTP,\ WTP = F(X_t) \times X_t \times Household \times 12 \quad (8)$$

Where P, P_{pot} and P_c are installed capacity, potentail capacity and addational installed capacity, respectively. *RE* is types of renewable energy generators, *WTP* is the total *WTP* in JPY/year, Household is the numbers of household.

2.3. Scenario Setting

Scenario Ref: Estimation of the feasible energy mix in 2030 without considering the impact of WTP.

Scenario 1 (S1): Estimation of the feasible energy mix in 2030 with considering the impact of WTP. WTP is estimated under the baseline economic case which assumes the econmy will grow as past patterns.

Scenario 2 (S2): Estimation of the feasible energy mix in 2030 with considering the impact of WTP. WTP is estimated under the economic growth achieved case which assumes the economic recovery.

3.Results

In this study, we set a 26% Greenhouse gas (GHG) reduction from 2013 in 2030 based on nationally determined contributions (NDC) of Japan submitted to UNFCCC. The renewable energy power installed capacity under different scenario are shown in Figure 1. Overall, the installed capacity shows a remarkable increase, which can be explained by the reason of increased WTP. In scenario 1 and 2, the installed capacity are expected to be 8 – 10 fold (34 and 42 GW) 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. In addition, the points in each figure show the energy generation cost, and the result indicate the unit energy generation with considering the WTP in this study is lower than pervious studies ignoring the impact of WTP.

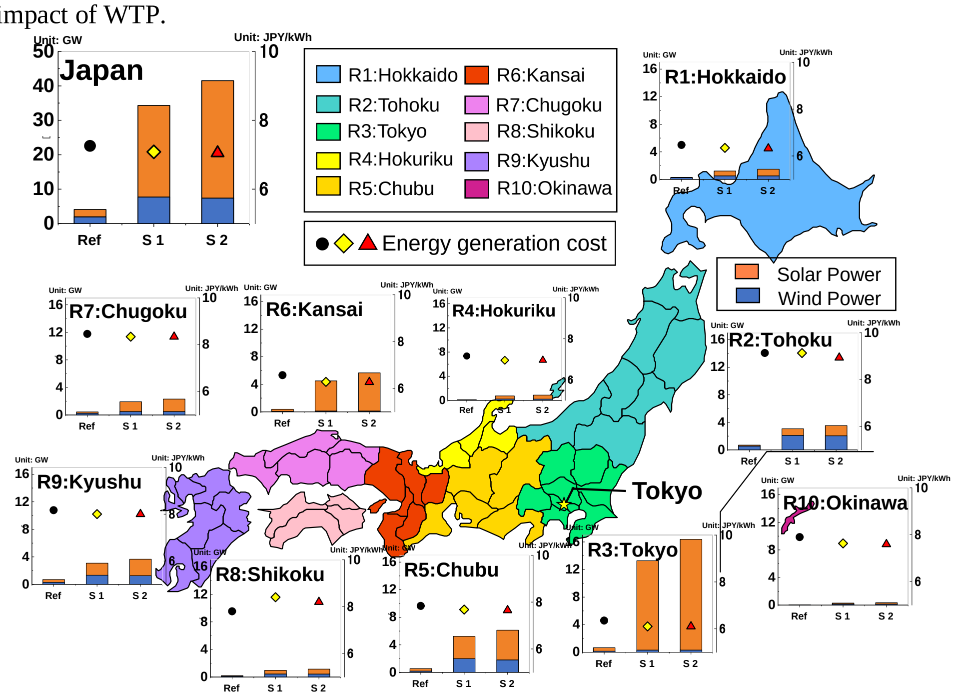

Figure 1. Installed capacity of renewable energy power generation and generation cost in 2030

4.Conclusions

This paper proposes a method for assessment of the impact of willingness to pay on the penetration of renewable energy resources in Japan. As show by our results, the install capacity of renewable energy are expected to be up to 42 GW in 2030, corresponding to 25% of the national target. The spread of renewable energy is mainly attributed to the WTP by consumers with higher levels of income, such as the ones in Tokyo. Furtherly, WTP will also cause the decrease of unit energy generation cost. The analysis of this study demonstrates that the incorporating WTP into mitigation policies has the significant effect on extensive diffusion of renewable energy and thus meeting the national CO_2 mitigation pathways.

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