IMPACT ASSESSMENT OF WILLINGNESS TO PAY ON THE INSTALLED AND TRANSMISSION CAPACITIES OF RENEWABLE ENERGY RESOURCES IN JAPAN

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1. Overview

To reach the goals of the Paris Agreement, numerous studies have suggested several ways to promote the decarbonization of power sectors, one of which is the diffusion of renewable resources such as solar and wind. For example, Howard et al. (2018) described a way to limit the temperature increase in Australia to 1.5° or 2.0° by 2050, suggesting that the use of renewable energy can have substantial effects on the reduction of CO_2 emissions, in some cases by more than 90%. Nevertheless, using renewable energy resources requires overcoming their high power generation costs and the challenge of transmitting electricity generated in remote areas. Wakiyama and Kuriyama (2018) highlighted that the Hokkaido and Tohoku regions of Japan have large potentials for renewable power, but those potentials are limited because of difficulties in transmitting the power to other regions owing to a lack of power grid capacity.

Recently, several studies have revealed that consumers are willing to pay a higher price for electricity generated by renewable energy sources because of their increasing concern for global environmental problems, especially climate change (Murakami et al., 2015; Nomura, 2009). An increased willingness to pay (WTP) may help to overcome the barriers of higher cost power generation and transmission for renewable energy sources. The impact of WTP on changing installed and transmission capacities of renewable energy, which could greatly assist policymakers in determining subsidy policies for sustainable energy development, has rarely been studied. Our aim was to systematically assess the impacts of the public's WTP on the generation and transmission of electricity from renewable energy resources in Japan, thus promoting their optimal configuration and output.

2. Methods

This study assessed the impact of WTP on the installed capacity of renewable energy resources and on transmission lines. We first developed a series of models to simulate WTP for renewable energy resources in different regions. Then we incorporated the WTP models into a multi-regional optimal generation planning model built by Ashina and Fujino (2007) to try to configure power plant outputs so as to minimize generation cost.

2.1. Modelling WTP by meta-regression

The meta-regression model used two variables (*Gender*, *Income*) to calculate median WTP as:

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

where *Gender* is the female share within the population (%) and *Income* is the annual average household income (JPY).

In general, the relationship between percentage of consumers (or acceptability rate) and WTP follows the Weibull distribution:

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

where $F_{\mathrm{base}}(X)$ is the base acceptability function estimated by previous studies, Y is the acceptability rate, and X is WTP in JPY per household per month. The values of a and b were estimated through a meta-analysis of data from several studies and were assumed to be a = 6.505 and b = 1.065.

Theoretically, the WTP for a given acceptability rate of renewable energy varies for consumers when $\mathrm{WTP_{med}}$ changes, which implies a shift in the acceptability curve. Based on equations (1) and (2), the acceptability model can be defined as:

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

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

where $F(X)$ is the acceptability function, the acceptability rate is 50%, and t is the year.

2.2. Incorporating WTP into the energy model

The supply for each type of power generator was calculated through total cost (TC) minimization during the analysis period as:

$$\mathrm{Min}TC = \{[\Sigma[C_{\mathrm{c}}(g)+C_{\mathrm{o}}(g)\times P(l,g,t)]+[\textstyle\sum(C_{\mathrm{f}}(g)+C_{\mathrm{t}}(g))\times O_{\mathrm{g}}(p,h,l,g,t)]\}\times i\times(1+i)^{\mathrm{n}}/[(1+i)^{\mathrm{n}}-1] + \mathrm{Max}(RE_{\mathrm{cost}} + TL_{\mathrm{cost}}) \tag{5}$$

where C_{c}, C_{o}, C_{f} and C_{t} are capital cost, operation and maintenance cost, fuel cost and carbon cost, respectively; P is installed capacity; O_{g} is the energy supply quantity; and RE_{cost} is the cost for additional renewable energy capacity covered by consumer WTP; TL is the cost for the transmission lines (also covered by WTP). In addition, g is type of generator, p is demand pattern, l is location of the power plant, h is the time, i is discount rate and n is payback period. The simulation period was through 2050 for 10 regions in Japan.

For renewable energy, we estimated the potential capacity for renewable energy on the basis of both natural and economic conditions. The restriction conditions were defined as follows:

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

$$RE_{\mathrm{cost}}=[\Sigma[C_{\mathrm{c}}(RE)+C_{\mathrm{o}}(RE)\times P_{\mathrm{c}}(l,\ RE,\ t))],i\times(1+i)^{\mathrm{n}}/[(1+i)^{\mathrm{n}}-1] \tag{7}$$

$$TL_{cost}=[\Sigma[C_s(l)\times T_l(p,h,l,t))]\times i\times(1+i)^n/[(1+i)^n-1] \quad (8)$$

$$RE_{cost}+TL_{cost}\leq WTP,\ WTP=F(X_t)\times X_t\times Household\times 12 \quad (9)$$

where P_{pot} and P_c are potential capacity and additional installed capacity, respectively. C_s is the transport cost, T_i is the energy supply quantity from other prefectures. In addition, *pv* and *wt* are the solar photovoltaic and wind power, respectively. *WTP* is total *WTP* (JPY/year), and *Household* is the number of households.

2.3. Scenario settings

Scenario Ref: Estimation of the feasible energy mix in 2050 without considering the impact of WTP.

Scenarios 1, 2, and 3 (S1, S2, and S3): Estimation of the feasible energy mix in 2050 considering the impact of WTP. WTP is estimated under SSP1 (a sustainability shared socioeconomic pathway) and is used for increasing only the installed capacity (S1), only the transmission capacity (S2), or both capacities (S3) of renewable energy.

3. Results and Conclusions

To concern the effects of WTP for renewable energy on decarbonization of power sectors, carbon emission reduction percentage was estimated in 2050 with applying WTP in different scenarios. Since that the Japanese Ministries had drafted climate change plan for 80% Greenhouse Gas (GHG) reduction from 2013 to 2050, the carbon emission in 2013 and 2050 are assumed as 100% and 20%, respectively. Emission reductions of 43% and 46% of the baseline 2013 emissions were estimated for 2050 under Scenarios 1 and 2, respectively. Moreover, the optimized configuration of WTP under Scenario 3 would further increase the carbon emission reduction to 48%, confirming the positive synergistic effect of using WTP to increase both installed and transmission renewable capacities on GHG reduction, even though the national reduction target of 80% was still not met. Figures 1 and 2 show variations of installed and transmission capacities, respectively, of renewable power plants in 10 regions of Japan in 2050 under the four WTP scenarios. The installed capacity of renewable energy would increase 14-fold (to 60 GW) in Scenario 2 relative to that of Scenario Ref. Much of this increase can be attributed to a high consumer WTP in the relatively higher-income regions, such Tokyo, Tohoku, Chubu and Kansai (Fig. 1; the regions are defined in Fig. 2). By contrast, the optimal WTP configuration in Scenario 3 shows an obvious increase of renewable transmission capacity between specific regions (e.g., from Tokyo to Chubu and from Chubu to Hokuriku; Fig. 2), suggesting the great potential of increasing renewable transmission capacity in these lines for future renewable energy expansion. All of these results demonstrate that incorporating WTP into flexible GHG mitigation policies would have significant effects on the diffusion of power from renewable energy sources to meet future national CO_2 reduction targets.

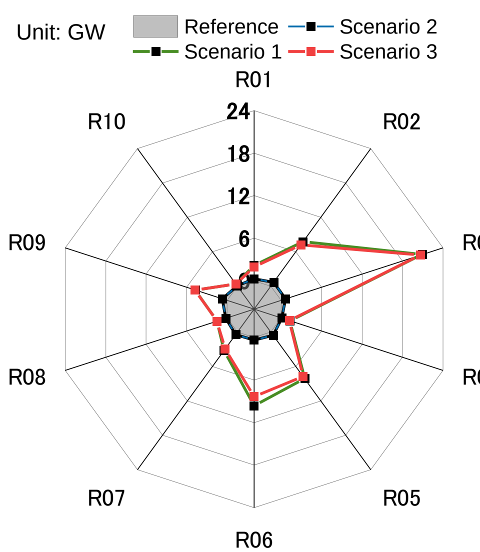

Fig 1. Installed capacity of renewable energy power plant in 2050

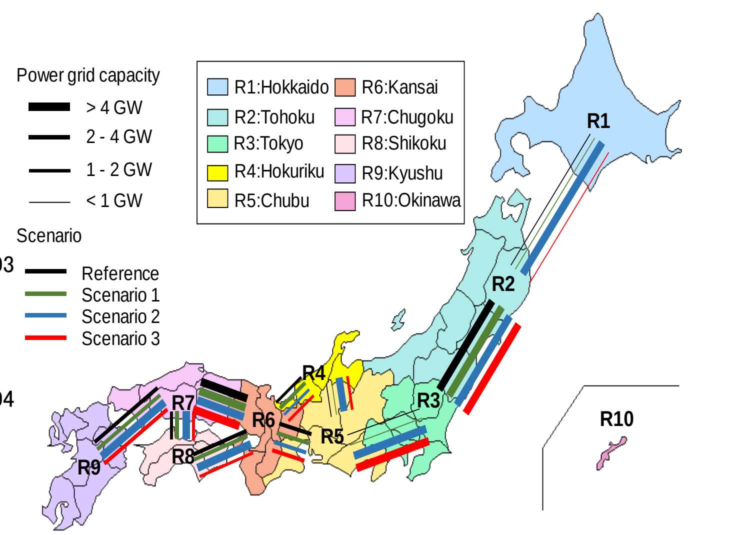

Fig 2. Power transmission capacity under scenario Ref, 1, 2 and 3 in 2050

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