ECONOMIC AND ENVIRONMENTAL EFFECTS OF PROMOTING RENEWABLE ENERGY ELECTRICITY IN REMOTE ISLANDS: A CASE OF TSUSHIMA, JAPAN

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Overview

Given the increasing concern about climate change, renewable energy (RE) is being steadily developed as an effective way to mitigate climate change. The Great East Japan earthquake and the Fukushima nuclear accident in March 2011 led Japanese public opinion to favor alternative, sustainable energy systems. Although RE capacity has rapidly increased especially after the introduction of feed-in tariff in 2012, the energy transition has been stagnant. The characteristics of RE as a distributed system still require to be disseminated nationwide in Japan.

There are approximately 400 remote islands in Japan and their development has important purposes such as territorial protection, local development, and the preservation of culture and environment. Since remote islands need to import fossil fuels, which is the main energy sources, from the mainland, RE development is vital for building a sustainable island society. However, social, economic, and local challenges have prevented RE penetration. Most border islands are too far from the mainland to construct economical electricity grid interconnections via submarines. Therefore, electricity is mainly supplied by small thermal power plants on such remote islands. However, the electricity cost of such system is three to five times higher than that on the mainland, although the cost does not directly reflect the electricity price because of the universal service price. Reducing power generation cost on remote islands is urgent not only for the islands but also for the entire country. Therefore, a transition to a sustainable energy system that harmonizes the economy with the environment is urgently required.

This study aims to provide RE policy suggestions to contribute to the further promotion of RE electricity and local economic development in remote islands without grid connections with mainland. To this end, we evaluated the potential direct and indirect economic and environmental effects of promoting RE electricity with energy storage system on a remote island in Japan, using Tsushima as an example.

Methods

This study employed an input-output (IO) modeling framework to quantitatively evaluate the system-wide economic and environmental impact of RE promotion. In this study, the IO table of Tsushima City for 2015 (38 sectors) developed by the Value Management Institute was used to expand the RE electricity-related sectors. The RE electricity-related sectors, including energy storage system, were then disaggregated from the existing sectors to develop the new Tsushima IO table with these sectors (49 sectors in total). Considering the current RE development of Tsushima, this study considered photovoltaics (PV) and wind power generation for RE.

Regarding the economic impact, the spillover effect can be calculated by sector using Eq. (1). Similar equations can be applied to evaluate other economic effects, including the employment effect.

$$\mathbf{X} = \left(\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{IM}}\right)\mathbf{A}\right)^{-1}\left(\left(\mathbf{I} - \widehat{\mathbf{IM}}\right)\mathbf{F} + \mathbf{EX}\right) \quad (1)$$

where $\mathbf{X}$ represents a spillover effect vector, $\mathbf{I}$ represents an identity matrix, $\widehat{\mathbf{IM}}$ represents a diagonal matrix of import coefficients, $\mathbf{A}$ represents a technical coefficient matrix, $\mathbf{F}$ represents a vector of the final demand change, and $\mathbf{EX}$ represents an export vector.

In addition, the environmental effect (carbon dioxide [CO_2] emissions in this study) by promoting RE electricity was evaluated using Eq. (2).

$$\mathbf{C} = \hat{\mathbf{c}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \quad (2)$$

where $\mathbf{C}$ represents a CO_2 emission effect vector and $\hat{\mathbf{c}}$ represents a diagonal matrix of CO_2 emission coefficients.

The CO_2 emission coefficients were taken basically from the Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID), but the coefficients provided by the Institute for Economic Analysis of Next-generation Science and Technology were also used for the RE-related sectors.

To evaluate the economic and environmental effects of promoting RE electricity, three scenarios for the potential future of RE electricity (annual increases in RE electricity) on the island were developed: (1) scenario based on the historical trend, (2) scenario based on the energy outlook of the Japanese government, and (3) scenario based on the World Energy Outlook 2021 of the International Energy Agency.

Results

Based on the data and assumptions presented in the previous section, changes in the final demand in RE-related sectors was first estimated for each scenario. The values for the construction of PV, wind power plants, and energy storage system, calculated based on the increases in the capacity and the construction cost, were JPY 355.84 million, JPY 14.85 million, and JPY 167.86 million (Scenario 1), JPY 84.71 million, JPY 8.95 million, and JPY 42.30 (Scenario 2), and JPY 383.44 million, JPY 132.08 million, and JPY 231.02 million (Scenario 3), respectively. In addition, the values of power generation (or electricity) allocated to the final demand for PV and wind power sectors were JPY 4.03 million and JPY 0.25 million (Scenario 1), JPY 0.96 million and JPY 0.15 million (Scenario 2), and JPY 4.34 million and JPY 2.19 million (Scenario 3), respectively. This suggests that, annually, the direct effect was much greater for construction than operation and management.

The spillover effects were estimated using the above direct effects for the three scenarios. The total spillover effects of increasing RE electricity in the island were JPY 578.61 million/year (Scenario 1), JPY 146.30 million/year (Scenario 2), and JPY 806.92 million/year (Scenario 3). Because the direct effect was the largest for Scenario 3, the spillover effect was also the largest. These effects were mainly brought about by the PV construction sector (Fig. 1a). In total, PV construction contributed JPY 408.37 million/year (Scenario 3; blue bars in the figure), which was about the half of the total spillover effect. This is primarily due to its larger direct effect compared with the other sectors. Observing the spillover effect in Tsushima by sector for Scenario 3 (Fig. 1a), the most significant effect was found in the PV construction sector, which was mainly induced by its direct effect. Similarly, the second and third largest effects (energy storage system and wind power construction) were due to its direct effect. The fourth and fifth largest effects were found in the transport & postal service sector and the wholesale sector, respectively. These were primarily generated by the indirect effects of the PV construction sector.

With regard to the environmental effect, because CO_2 is largely emitted from the construction of RE-electricity facilities but the emission reduction effect by replacing oil-fired power generation to RE electricity is limited, CO_2 emissions increased with a single-year analysis (333.34 t-CO_2 for Scenario 1, 85.90 t-CO_2 for Scenario 2, and 499.57 t-CO_2 for Scenario 3). However, the environmental benefit by introducing RE electricity will appear in the future by continuing power generation. Therefore, the cumulative effects for 10 years were calculated. Assuming construction of RE power generation facilities continues for 10 years with the even pace and RE power generation increases accordingly, although CO_2 is emitted every year from the construction of RE electricity facilities, negative effects by increases in RE electricity increased because the capacity of RE electricity increased every year (Fig. 1b for Scenario 3). As a result, the annual balance of CO_2 emissions became negative from the fourth year. Furthermore, the cumulative emissions became negative from the seventh year, and they became −3979.63 t-CO_2 in the tenth year. These results suggest that even though the construction of RE electricity facilities increases CO_2 emissions, power generation by those RE facilities contributes to reduction in the emissions in the future, and the negative cumulative emissions are eventually achievable.

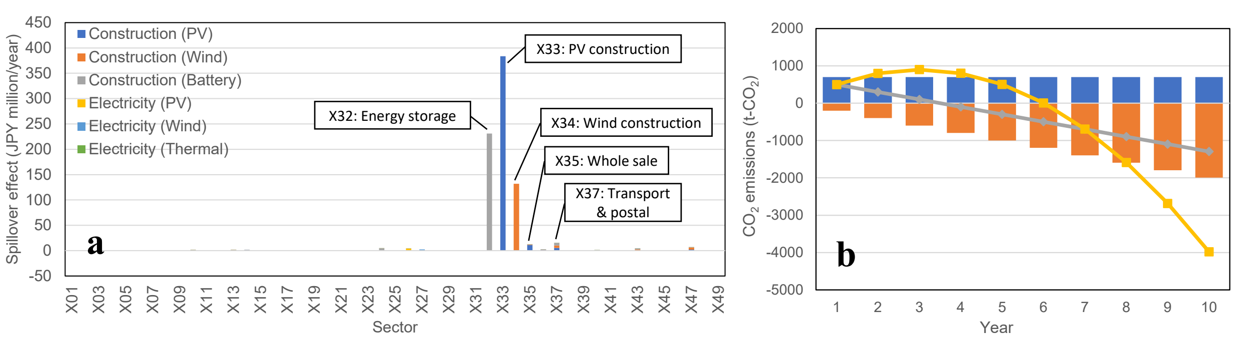

Fig. 1. Results of analysis (Scenario 3): (a) spillover effects by sector, and (b) CO_2 emission reduction effects.

Conclusions

From this study, it is elucidated that both economic and environmental effects were observed by increasing RE facilities together with energy storage system in a small remote island. However, to further promote RE electricity to achieve carbon neutral, further measurements are needed such as reinforcing grid capacity, fully utilizing the natural resources of islands, including biomass and hydropower, and developing distributed RE energy system in sparsely populated areas.