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Challenges and economic effects of introducing renewable energy in a remote island: A case study of Tsushima Island, Japan

Ken'ichi Matsumoto [a,b,*], Yuko Matsumura [c,**]

[a] Faculty of Economics, Toyo University, 5-28-20 Hakusan, Bunkyo-ku, Tokyo, 112-8606, Japan
[b] Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, 236-0001, Japan
[c] Graduate School of Human Sciences, Osaka University, 1-2 Yamadaoka, Suita, 565-0871, Japan

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ABSTRACT

Given the increasing climate change concerns and the importance of renewable energy in mitigating climate change and realizing sustainable development, it is essential to promote renewable energy electricity in remote islands where thermal power generation is the primary energy source. This study examines current renewable energy development, the barriers to its penetration, and the potential economic effects of promoting renewable energy electricity on the remote island of Tsushima, Japan. To this end, semi-structured interviews were conducted to clarify the renewable-energy development and barriers to penetration, and an input-output analysis was used to quantify the spillover effects of renewable energy promotion in Tsushima. It was found that the main barriers to renewable energy promotion were insufficient investment and a lack of technical personnel. The input-output analysis detected some economic spillover effects of introducing photovoltaics and wind power generation, including employment. Although the spillover effects inside Tsushima were not significant, there were also impacts outside the island. These results suggest that increasing renewable energy electricity in remote islands in Japan has economic merit. However, because of large spillover effects outside the island, it is necessary to reduce leakages, such as by attracting related industries/companies. Furthermore, considering that remote islands without grid connections with the mainland need to generate and control electricity inside the island, investments in energy storage systems are essential to strengthen variable renewable energy capacity.

Credit

Ken'ichi Matsumoto: Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Software; Visualization; Writing - original draft; Writing - review & editing. **Yuko Matsumura:** Conceptualization; Investigation; Methodology; Writing - original draft; Writing - review & editing.

1. Introduction

1.1. Background

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 increased rapidly, the energy transition in terms of policy aspects has been at a standstill compared to the European Union (EU), China, and South Korea. In light of the Fukushima nuclear accident, Prime Minister Suga pledged to make Japan carbon neutral by 2050 at his first address as the prime minister on October 26, 2020. The target is highly challenging, and nationwide RE development is required. The characteristics of RE as distributed systems still remain to be disseminated in various districts in Japan. In addition, there is a need to ensure local acceptance and concomitant socioeconomic development.

Japan has around 400 inhabited remote islands, the development of which has significant purposes, such as territorial protection, local development, and cultural and environmental preservation. Therefore, control of the remote islands is diplomatically and economically critical. In 1953, the Remote Islands Development Act was ratified to improve the islands' infrastructure, education, health systems, and industrialization. This Act was a 10-year long temporary legislation; however, it

* Corresponding author. 5-28-20 Hakusan, Bunkyo-ku, Tokyo, 112-8606, Japan.
** Corresponding author. 1-1 Yamadaoka, Suita, 565-0871, Japan.
E-mail addresses: matsumoto1005@toyo.jp (K. Matsumoto), ymatsumura@hus.osaka-u.ac.jp (Y. Matsumura).

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Nomenclature

Symbols

A	technical coefficient matrix
E	employment effect vector
$\hat{\mathbf{e}}$	diagonal matrix of employment coefficients
EX	export vector
F	final demand vector
I	identity matrix
$\widehat{\mathbf{IM}}$	diagonal matrix of import coefficients
V	value-added effect vector
$\hat{\mathbf{v}}$	diagonal matrix of value-added coefficients
X	spillover effect vector

Abbreviations

EU	European Union
EUR	Euro
GDP	gross domestic product
GRP	gross regional product
IO	input-output
JPY	Japanese yen
PV	photovoltaics
RE	renewable energy
SDGs	Sustainable Development Goals
US	United States
USD	United States dollar
WEO	World Energy Outlook

has been renewed six times because it is vital for the maintenance of remote islands. With the increased importance of border islands due to geopolitical issues in East Asia, such as territorial waters, several uninhabited islands, and marine resources, subsidies for these islands have increased. In addition, a new law (Act on Preservation of Areas of Remote, Inhabited Islands Establishing Territorial Seas and Maintenance of Local Societies on Areas of Specified Remote, Inhabited Islands Establishing Territorial Seas), issued in 2016, provides additional subsidies to designated remote islands where economic and social autonomy are crucial for sustainable and healthy community development, aiming at the development of the border islands. Since energy resources (i.e., fossil fuels) on remote islands are limited, RE has been 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 for economical electricity grid interconnections via submarines. On remote islands without such grid connections, electricity is mainly supplied by small local thermal power plants (internal combustion power generation). With this kind of system, the cost becomes three to five times higher than on the mainland. However, the cost does not directly reflect the electricity price because of the *universal service price* (i.e., citizens in the remote islands can use electricity at a similar price to the mainland by sharing of the difference between the electricity price and cost by all electricity consumers). Reducing the cost of electricity on remote islands is not only an issue for the islands but also a matter of national and regional concern; thus, a transition to an alternative energy system that harmonizes the economy with the environment is required.

Tsushima Island (Fig. 1), located 49.5 km south of the Korean Peninsula and 132 km from the mainland of Japan, is a remote border island designated under the two abovementioned acts. The island has an area of 695.74 km^2 with 13,350 households and 31,301 residents [1]. It relies heavily on small thermal power (heavy oil) stations for its power supply (approximately 93%). In addition, the island does not have a grid connection with the mainland, meaning that the electricity system is isolated. Although RE electricity generation has gradually been increasing, the share is still limited, and the types of RE electricity are also limited (only photovoltaics [PV] and wind). Therefore, the island must increase its RE electricity capacity to achieve a sustainable local

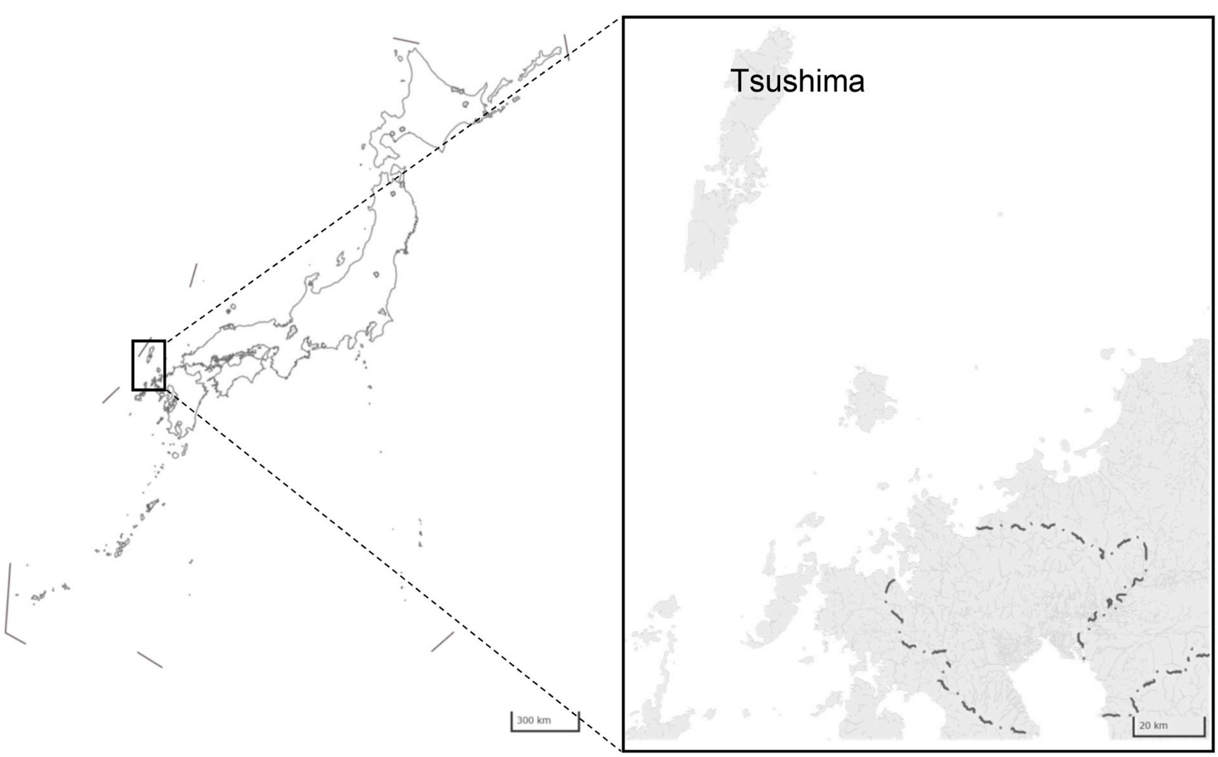

Fig. 1. Location of Tsushima. These maps were obtained from the Geospatial Information Authority of Japan (http://maps.gsi.go.jp/).

society.

This study aims to provide RE policy suggestions to contribute to the further promotion of RE electricity and local economic development in remote islands by considering the characteristics of the local society. To this end, this study clarifies 1) the current RE development and the barriers to RE penetration, and 2) the potential direct and indirect economic effects of promoting RE electricity on a remote island in Japan, using Tsushima as an example.

1.2. Literature review

1.2.1. Renewable energy impact on local development and barriers to renewable energy penetration in remote islands

As the United Nations proposed Sustainable Development Goals (SDGs), socially and economically harmonized development, as well as technological development, are required at the local and global levels. In other words, along with assessing sustainable energy development, it is important to evaluate the various values and impacts from economic, social, and cultural perspectives. The development of RE is of great social significance because it is linked to the revitalization of the local economy [2] and the improvement of infrastructure in remote areas [3]. Island regions are particularly vulnerable to climate change, as in small island developing states [4], and local interest in climate change action is high [5,6]. In recent years, RE development on remote islands has received increased attention in peer-reviewed articles due to the importance of the natural environment and the need for energy transition. For example, increasing energy self-sufficiency through RE can reduce power generation costs, protect the environment, and ensure a stable energy supply [7]. Furthermore, there are also various studies on techno-economic [8,9] and socioeconomic [10,11] aspects of RE in remote islands. With regard to the techno-economic aspect, for example, Ahmad and Zhang [8] conducted RE integration and techno-economic feasibility analysis of the islanded and grid-connected mode operations of utility to meet the demand for community and commercial loads. Furthermore, Bertheau [9] implemented geospatial and techno-economic (modeling) analysis to estimate the cost of supplying 100% RE electricity to non-electrified islands in the Philippines. In terms of socioeconomic aspects, Abu Saim and Khan [10], for example, conducted a questionnaire survey to evaluate the benefit and troubles of the solar home system in the rural areas of Hatiya Island, Bangladesh. Also, Fernández Prieto et al. [11] assessed the socioeconomic and environmental factors of wave energy in Gran Canaria Island, Spain. Previous research has often used the characteristics of remote islands to develop technologies and estimate and predict the next generation of technologies for energy transition. For example, some case studies on remote islands have been implemented, including evaluation of optimal energy systems combining traditional and RE power stations by applying a modeling approach [12], penetration of RE through interconnection of power systems [13], electrification and RE nexus by integrating hydrogen production and electric vehicles [14], and the cost reduction effect of power generation with a high share of RE by a simulation approach [15].

As for the social aspects, because RE is small-scale and locally distributed, development must consider the requirements of local communities [16]. To solve the issues related to RE in communities, the World Wind Energy Association [17] identified key principles of local ownership of RE as community power and provided guidelines to avoid community conflicts. Involving local stakeholders and residents of the surrounding areas in the ownership of wind turbines reduces opposition to turbine installation. Several case studies have dealt with effective policies, stakeholders of RE projects, and the characteristics of best practices on remote islands, such as Samsø Island (Denmark) [18], Hvaler (Norway), Orkney (Scotland), Madeira (Portugal), Rhodes (Greece), Unije (Croatia), and Bornholm (Denmark) [19]. Sperling [18], for example, analyzed the massive RE development on Samsø Island and the factors that contributed to its success by dividing contexts into external (EU and Danish energy plans and subsidies) and internal (local leadership, biking spirits, and other local cultural features). These case studies indicate that national policies, social structure, local leadership, and communication and cultures in the community are important factors influencing RE penetration in remote islands. Despite the immense potential of RE in remote islands, social, environmental, and economic barriers have limited its penetration [20]. Energy development through RE sources is considered to solve social problems, by improving quality of life through improved energy access in underdeveloped and marginalized areas, which may have gender implications through reduced household workloads and improved educational environments [21].

Regarding remote islands in Japan, Matsumura and Miyoshi [22] investigated 100% RE policies and leadership by local communities. For example, on Yakushima, a remote Japanese island registered as a World Natural Heritage site, a local company built a hydropower plant before the Kyusyu Electric Power Company, one of the largest electricity suppliers in Japan, started to provide electricity supply. The hydropower plants generate most of electricity on the island, which is noteworthy, with the highest rate of RE supply among the remote islands in Japan. Since this success was attributable to the unique geographical and natural environment, this model could not be applied to other remote islands. As a case study of community power, Matsumura and Miyoshi [23] conducted interviews with local RE enterprises (wind turbines, biofuels, and biomass boiler projects) in Tsushima. They indicated the importance of local ownership to the sustainability of RE projects, which may have contributed to job creation and reduced energy costs for the city, although they did not show the effect quantitatively.

Existing studies on RE development in remote islands have demonstrated many advantages and successes, although limitations and barriers exist from the islanders' viewpoints. However, case studies of RE in remote islands are still limited, especially in Japan, despite the rapid increase in installation and national interests in RE after 2011 [24].

1.2.2. Input-output analysis for renewable energy penetration

Input-output (IO) analysis has often been used to analyze the socioeconomic impacts of RE penetration in various countries, mainly at the national level, including technology-specific analysis, policy, investment, and climate change. Regarding solar power, Ciorba et al. [25] analyzed the potential economic impact (induced production and employment) of demand for PV devices in Morocco. They found that production of 5 MW PV modules induced production of EUR (Euro) 57.6 million and provided 2570 jobs if cells were locally produced and induced production of EUR 22.3 million and provided 489 jobs when the cells were imported. In China, Hongtao and Wenjia [26] evaluated the economic effects of clean power generation and found that replacing coal-fired power generation with PV generated positive gross domestic product (GDP) and employment effects. Zafrilla et al. [27], using a socially and environmentally extended multi-regional IO model, evaluated the impacts of the Spanish solar PV sector. They indicated that the solar PV sector accounted for 0.19% (direct) and 0.31% (induced) of GDP, and among indirect GDP effect, 60% was derived from domestic while 40% was generated abroad.

Regarding wind power, Nagashima et al. [28] conducted economic and environmental assessment of a wind power generation system in Japan considering actual data on wind turbine production processes. They found that the positive production and value-added effects outweigh the negative effects of installing the wind power system. Mikulić et al. [29] evaluated the gross value and employment effects of wind power deployment in Croatia. They showed positive indirect and induced effects, especially for the manufacturing, construction, transport, and other supporting sectors.

Other studies have evaluated various types of RE. Lee et al. [30], for example, evaluated the economic spillover effects from RE industries in Korea from 2010 to 2020. They found that the induced effects on production were 0.70–1.13 and those on value-added were 0.39–0.60.

Similarly, O'Sullivan and Edler [31] targeted the broad RE sectors (11 RE technologies) but focused on the gross employment effects from 2000 to 2018. Kamidelivand et al. [32] evaluated the effects of transition to low fossil-fuel electricity (or substitution of imported gas and coal with RE) in Ireland. Using a multi-regional IO model, Siala et al. [33] evaluated the environmental and socioeconomic effects of the EU's RE and greenhouse gas emissions goals in Germany. Similarly, applying a multi-regional IO model and structural decomposition analysis, Wang and Liu [34] identified India's RE consumption patterns and its transition drivers. Furthermore, Önder [35] evaluated energy consumption policy in Turkey using an energy-extended IO analysis.

There are also a few peer-reviewed articles focusing on Japan. Moriizumi et al. [36] developed an RE-focused IO table for Japan in 2013 to evaluate the environmental and socioeconomic impacts of various RE electricity technologies and policies. They found that the output multipliers of the RE sectors vary from 2.51 to 3.13 for the construction sector and from 1.05 to 2.62 for the operation sectors, depending on the type of technology. In addition, Hondo and Moriizumi [37] evaluated the employment characteristics of different RE electricity technologies using the same framework as Moriizumi et al. [36]. They found that the total employment creation potential over the life cycle was estimated to be in the range of 1.04–5.04 person-years/GWh, although the effects varied by technology type. Nakano et al. [38] developed an IO table with a next-generation energy system (i.e., RE and alternative fuel vehicle sectors) and estimated the effect of RE on Japan's economic structure. They showed that existing power generation options and the production of existing passenger vehicles would be reduced and replaced by alternative fuel vehicles and the RE sectors. Furthermore, Nakano et al. [39], using a similar framework as Nakano et al. [38] but extended to an interregional IO table, analyzed economic and environmental effects of RE penetration and RE-related policy in Japan using the framework. One of their findings showed that by abolishing feed-in tariff, significant cost-push effects were observed in regions where the composition ratio of solar power is high.

Compared to national-level studies, sub-national studies on RE electricity with IO models are still limited because it is often difficult to apply IO models to micro-level studies [37,40].[1] Heinbach et al. [43] estimated the local value-added and employment effects of introducing RE in Germany. However, the study applied the German national IO table with the assumption of a model municipality in Germany. In the United States (US), Carlson et al. [44] evaluated the economic impact of the wind energy turbine supply chain in Illinois. Faturay et al. [45] also focused on US wind farms, but they developed a multi-regional IO model for the US and applied it to estimate the multi-regional economic impacts of installing new wind farms in 10 US states. They found that the total economic impact was USD (US dollar) 26 billion, of which USD 3 billion was associated with the states where no new wind farms were installed. Similarly in Brazil, Vasconcellos and Caiado Couto [46] estimated the socioeconomic impacts of onshore wind power projects in the country's northeast region where the potential of wind power generation is large. They found that the direct employment effect was 10 jobs/MW, while the total effect was 31.9 jobs/MW. They also showed that more than 50% of the benefits occurred in just a few sectors. Jongdeepaisal and Nasu [47] evaluated the economic impacts of biomass energy (power plants) in Kochi Prefecture, Japan using a hybrid IO model. They found that introducing biomass power plants increased the total production of Kochi Prefecture's economy and this benefit overthrew the negative effect of the loss of resource demand in the existing economic sectors.

The above literature review on IO analyses of RE sectors indicates that the socioeconomic impacts of promoting RE have mainly been estimated at the national level. Only a few studies exist at the sub-national level and none focused on cities or remote islands, although some economic evaluations other than the IO approach exist. In addition, these studies have often used the inverse matrix of type $(\mathbf{I}-\mathbf{A})^{-1}$; however, considering that the components of RE facilities are traded, it is necessary to consider the trade effect, particularly imports to a non-industrial remote island, simultaneously.

[1] Sub-national studies on energy sectors not focusing on RE electricity exist [41,42], but such studies are also limited.

2. Methods

This study used qualitative and quantitative approaches to analyze the expansion of RE on a remote island, Tsushima. For the qualitative analysis, an interview survey was conducted with city officers and local RE business operators in Tsushima to investigate the island's energy transition and energy policies. For the quantitative analysis, an IO framework was applied to evaluate the socioeconomic impact of RE promotion.

2.1. Interview survey

A semi-structured interview was employed for the qualitative analysis to clarify the RE development and the barriers to RE development in Tsushima. This approach is effective for guiding topics to interviewees and collecting narratives and stories.

The interviews were conducted in Tsushima from 2011 to 2020 to investigate local energy policies and plans and whether these policies and plans were being implemented (Table 1). In this study, interviews were mainly conducted by the second author, who originates from Tsushima City, has a strong social background and sense of place in Tsushima, and has been exchanging policy opinions with stakeholders over ten years.

2.2. Input-output analysis

2.2.1. Input-output model and analytical framework

Input-output analysis is a useful tool for evaluating the system-wide economic impacts of the demand for commodities (goods and services) [37,48,49] and it is the standard method to evaluate the spillover effects, including RE, as mentioned in the literature review. Although it is not possible to treat the whole energy system unlike bottom-up energy system models, this top-down approach is the most appropriate method to realize the purpose of this study.

Since Tsushima City does not have its own IO table, the original IO table of Tsushima was developed by disaggregating the IO table of Nagasaki Prefecture in 2011 [50], where Tsushima is located. As with one of the IO tables for Nagasaki Prefecture (the IO table with the largest number of sectors), the basic Tsushima table consists of 108 sectors. The

Table 1
Schedule, interviewee, and interview topics of the semi-structured interviews.

Date	Interviewee	Interview topic
September 24–28 2011	City officers of Tsushima City	• Performance of the wind power plants • Local and non-local stakeholders related to the wind power plant projects • Social, environmental, and economic barriers
September 28, 2012	City officers of Tsushima City	• The amount and variations of RE technologies in Tsushima
January 3–6 2013	City officers of Tsushima City	• Performance of the wind power plants
February 9–11 2016	Local RE enterprises	• Performance of the wind power plants • Stakeholders of the wind power plants • Social, environmental, and economic barriers
March 8, 2018	City officers of Tsushima City	• New Energy Masterplan • Social, environmental, and economic barriers
November 7, 2020	Local RE enterprises	• Performance of the wind power plants • Stakeholders of the wind power plants

basic Tsushima table was developed following the method proposed by Doi et al. [51], described below.

- Total production: Each sector's total production was estimated using the ratio of the number of employees in Tsushima to that in Nagasaki Prefecture for each sector. However, different coefficients were used in some sectors. For the commerce sector, the ratio of annual sales in Tsushima to those in Nagasaki Prefecture was used. The ratio of populations was used for the gas and heat supply and water supply sectors. For the house rent (including imputed house rent) sectors, the ratio of the number of households was used. Finally, for the self-transport sector, the ratio of the number of offices was used.
- Intermediate input: The intermediate inputs were estimated by multiplying the total production estimated above by the coefficients of the intermediate inputs of Nagasaki Prefecture, assuming that the coefficients for Tsushima are identical to those for Nagasaki Prefecture.
- Gross value-added: The gross value-added was estimated by multiplying the total production by the coefficient of the gross value-added of Nagasaki Prefecture.
- Final demand: The final demand was estimated using the following methods per category.
  - Consumption expenditure outside households: The consumption expenditure outside households of each sector was estimated by multiplying the sum of those in the gross value-added by the share of the consumption expenditure outside households of the corresponding sector of Nagasaki Prefecture.
  - Private expenditure: The private expenditure of each sector was estimated by multiplying that of Nagasaki Prefecture by the ratio of the population of Tsushima to that of Nagasaki Prefecture and the ratio of per household expenditure.
  - Government expenditure: The government expenditure of each sector was estimated by multiplying that of Nagasaki Prefecture by the ratio of the population.
  - Fixed capital formation: The fixed capital formation of each sector was estimated by multiplying that of Nagasaki Prefecture by the ratio of gross regional product (GRP) of Tsushima to that of Nagasaki Prefecture.
  - Increase in stocks: The increase in stocks of each sector was estimated by multiplying that of Nagasaki Prefecture by the ratio of the number of employees in Tsushima to that of Nagasaki Prefecture.
- Trade: Trade (domestic and international) was estimated using the following methods:
  - Net export: The net export was estimated as the total production minus the total demand. However, commodities in some sectors (i.e., agricultural services, reuse and recycling, building construction, building repair, public construction, miscellaneous civil engineering and construction, imputed house rent, and self-transport) are not considered to be traded. For these sectors, the value zero was set for net exports by adjusting the total production of the corresponding sector.
  - Import: Import was estimated using the location quotient method [51,52].
  - Export: The export was estimated as net export plus import.

After developing the basic IO table for Tsushima using the above procedure, the RE electricity-related sectors were disaggregated from the existing sectors to develop the new Tsushima IO table with these sectors (Tsushima RE IO table). Although official IO tables published by governments, which did not disaggregate RE-related sectors, have often been used in the literature [53–57], such IO tables can lead to an aggregation error because of the homogeneity assumption [37]. Therefore, the following procedure was used to disaggregate the RE-electricity-related sectors. Considering the current situation of Tsushima, the model incorporated PV and wind power generation for RE electricity, but no other types. The RE-related sectors include wind turbine blades (disaggregated from the general-purpose machinery sector), other components of wind turbines (from the general-purpose machinery sector), PV modules (from the miscellaneous electrical machinery sector), PV construction (from the miscellaneous civil engineering and construction sector), wind power plant construction (from the miscellaneous civil engineering and construction sector), PV electricity (from the electricity sector), wind power electricity (from the electricity sector), PV repair services (from the motor vehicle maintenance and machine repair services sector), and wind power repair services (from the motor vehicle maintenance and machine repair services sector) [58].[2] The total production of these RE-related sectors was estimated based on the current situation of Tsushima. The input structure of these sectors was determined based on the technical coefficients obtained from the Institute for Economic Analysis of Next-generation Science and Technology [58]. Finally, the number of sectors in the Tsushima RE IO table was 117.

Based on the newly developed Tsushima RE IO table, a technical coefficient matrix ($\mathbf{A}$) and import coefficients were calculated.

To estimate the system-wide economic impacts of increasing the use of RE electricity in Tsushima, the inverse matrix of type $(\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{A})^{-1}$ was used. Given a final demand, the total production can be calculated by sector using Eq. (1).

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

where $\mathbf{X}$ represents a production vector, $\mathbf{I}$ represents an identity matrix, $\widehat{\mathbf{IM}}$ represents a diagonal matrix of import coefficients, $\mathbf{F}$ represents a final demand vector, and $\mathbf{EX}$ represents an export vector.

Furthermore, the impact on the value-added can be estimated using Eq. (2).

$$\mathbf{V}=\hat{\mathbf{v}}(\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{A})^{-1}((\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{F}+\mathbf{EX}) \tag{2}$$

where $\mathbf{V}$ represents a value-added effect vector and $\hat{\mathbf{v}}$ represents a diagonal matrix of value-added coefficients.

These equations for IO analysis can be employed to evaluate how changes in the final demand for commodities can affect the production (i.e., spillover effect) and the value-added of each industrial sector.

In addition to the effects on monetary value, the employment effects can be estimated using the IO framework (Eq. (3)).

$$\mathbf{E}=\hat{\mathbf{e}}(\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{A})^{-1}((\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{F}+\mathbf{EX}) \tag{3}$$

where $\mathbf{E}$ represents an employment effect vector and $\hat{\mathbf{e}}$ represents a diagonal matrix of employment coefficients.

In this study, the employment coefficients of Nagasaki Prefecture were applied to Tsushima because of data availability. Similar to the spillover effect, direct and indirect employment opportunities created by the given (changes in) final demands are evaluated using this framework.

Although the inverse matrix of type $(\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{IM}})\mathbf{A})^{-1}$ was mainly used as shown in Eqs. (1)–(3), the inverse matrix of type $(\mathbf{I}-\mathbf{A})^{-1}$ was also applied in these equations to estimate the total spillover and employment effects, including both Tsushima and outside the island. The difference between the effects calculated by the two inverse matrices can be interpreted as the effects obtained outside the island.

2.2.2. Scenarios

To evaluate the socioeconomic effects, including spillover and employment effects, of promoting RE electricity in Tsushima, three scenarios (Scenarios 1–3) for the potential future of RE electricity

[2] The original sectors that the RE-related sectors were disaggregated from are in parentheses.

(annual increases in RE electricity) on the island were developed. Because Tsushima City does not have numerical targets of the RE penetration, external scenarios were applied to develop the scenarios. Scenario 1 is based on the historical growth of capacity and power generation of PV and wind power in Tsushima. In Tsushima, the PV and wind power capacities were 539 kW and 1200 kW, respectively, in 2011, while they increased to 7770 kW and 1500 kW in 2016. Therefore, the annual increases in PV and wind power capacity were calculated based on these values. In addition, the annual increases in power generation were estimated assuming that the capacity factors are 0.13 for PV and 0.2 for wind power [37]. Scenario 2 is based on the Long-Term Energy Supply and Demand Outlook published by the Government of Japan [59]. The shares of PV and wind power generation in Tsushima are assumed to be identical to those of the outlook in 2030 (7.0% and 1.7%, respectively, of the total power generation), and the annual increases in power generation were estimated by linear interpolation of the power generation in 2016 and 2030. The increase in the capacity was estimated assuming the capacity factors described above. Scenario 3 was developed based on the Sustainability Scenario of the World Energy Outlook (WEO) 2019 [60]. Like Scenario 2, the shares of PV and wind power generation in Tsushima are assumed to be identical to those in Japan in 2030 obtained from the WEO 2019 (9.9% and 5.4%, respectively, of the total power generation), and the annual increases in power generation were estimated by linear interpolation of the power generation in 2016 and 2030. The increase in the capacity was estimated by the method used in Scenario 2.

Table 2 summarizes the annual increases in the capacity and power generation of PV and wind power. As shown in the table, Scenario 1 presents the highest increases in the total PV and wind power; in particular, the increase in PV is higher than that in the other scenarios. In terms of wind power generation, the increase in Scenario 3 was the greatest.

To convert these increases in physical values to monetary values to estimate the socioeconomic effects using the Tsushima RE IO table, the following assumptions were made. The unit price of electricity to calculate the final electricity demand was set as JPY (Japanese yen) 22/kWh (USD 1 ≈ JPY 110) based on the unit price of electricity in the Kyushu area where Tsushima is located. Further, the construction costs for PV and wind power plants were set as JPY 283,000/kW and JPY 297,000/kW, respectively [61]. With these data, the final demand in each RE-related sector is estimated for each scenario. First, the constructed PV and wind power facilities are allocated to fixed capital formation. Therefore, all constructed values are considered the final demand. By contrast, for power generation, not all electricity is consumed by the final demand sector; part of it is used as an intermediate input of production sectors. The increased PV and wind power generation corresponding to final demand was estimated based on the share of electricity used for final demand obtained from the Tsushima IO table because electricity is a homogenous commodity. In addition, it is assumed that the total demand for electricity does not change with an increase in RE electricity. Therefore, the demand increased by PV and wind power is offset by the decline in the electricity generated by traditional oil-fired power plants. The other RE-related sectors do not affect the final demand, as they are used only for intermediate inputs.

3. Results and discussion

The results of this study are shown and discussed in this section. First, the results of the interview survey explained in section 2.1 are presented in section 3.1. The results of the input-output analysis explained in section 2.2 are shown and discussed in section 3.2.

3.1. Current development and barriers of renewable energy promotion in Tsushima

3.1.1. Renewable energy development in Tsushima

Tsushima City has made several energy plans to date. In 1999, the former Kamiagata Town (merged to be Tsushima City in 2004) made a plan for a wind farm, operated by the third sector of the town (and Tsushima City) using the renewable portfolio standard in its energy vision. In 2007, Tsushima City formulated a new energy vision project subsidized by the New Energy and Industrial Technology Development Organization. The city planned to use waste cooking oil in biodiesel fuel, develop biomass and wind power generation, and build a microgrid system. However, at present, biomass power generation and a microgrid system have not been realized. In addition, the wind power capacity did not expand. The 2015 Energy Master Plan includes plans for offshore wind power and further RE expansion in Tsushima in the future.

Regarding wind power, the former Kamiagata Town invested around JPY 316 million to develop a town-owned wind power plant, which started operations in 2003. The New Energy and Industry Technology Development Organization provided approximately 44.7% of the investment as a subsidy, 54.7% by local government bonds, and 0.04% from the town's financial reserves. The wind power plant consisted of two wind turbines, the total output of which was 1200 kW (600 kW each). It operated well for four years. After that, however, first, one turbine failed and then the other, resulting in no wind power generation from 2012 to 2014. Because the repair cost was estimated at JPY 100 million, Tsushima City sold these two wind turbines to a local building contractor. The contractor then set up a joint venture for a wind power plant with a company in Tokyo. The joint venture finally scrapped the two turbines and developed a new wind power plant at the same location in 2015, the capacity of which was 1800 kW; 1500 kW of 1800 kW of wind power is permitted to be transmitted to the grid.

The joint venture also installed PV facilities, but these have not yet been in operation as of 2016. The main owners of PV facilities in Tsushima are local business entities (large-scale PV systems) and citizens (rooftop PV). The PV capacity gradually increased from 1844 kW in 2013 to 7770 kW in 2016 because of the feed-in tariff launched in 2012.

3.1.2. Main barriers to renewable energy electricity penetration

The interviews indicate that the principal barriers to RE penetration in Tsushima are (1) the lack of investment to meet local government plans and (2) the lack of planning and technical experts. The corresponding interview results are explained below.

As for the first point, the city officers mentioned that the greatest obstacle to RE penetration was the lack of investment to meet the local government's energy plan (interviews on September 28, 2012, January 4, 2013, and March 8, 2018). They also emphasized that a significant issue for Tsushima was that of grid capacity, which the Kyushu Electric Power Company controls. In 2013, this company stated that the RE capacity in Tsushima was already beyond 10% of the lowest nighttime demand. Therefore, the company needs to execute power output suppression control to maintain a safe and stable electricity supply when there is surplus power generation from RE sources. The grid capacity limitation has meant that the local government has not been able to design a radical energy policy, and local business entities cannot invest in developing additional RE facilities. Although the local government has also invested in RE, such as rooftop PV facilities at schools, it has not invested in other RE-related facilities because of the limited budget (an interview on March 8, 2018). The local government needs evidence of RE's economic and social effects to persuade citizens to further invest in RE development.

Another barrier to establishing a sustainable RE-based energy system in Tsushima is the lack of technical experts to plan and maintain RE facilities. Because Tsushima City has had few energy-planning specialists, it has outsourced energy planning to consulting companies outside the island (interviews on September 27, 2011, and March 8, 2018). In

Table 2
Annual increases in PV and wind power capacity (kW) and generation (MWh) in the three scenarios.

	Scenario 1		Scenario 2		Scenario 3	
	Capacity	Generation	Capacity	Generation	Capacity	Generation
PV	1446.20	1646.93	301.05	342.83	655.13	746.04
Wind	60.00	105.12	27.99	49.04	318.49	557.99

addition, there have been no local entities (local companies and governments) able to implement any new energy plans.

Regarding technical experts to maintain RE facilities or engineers, the owners of the wind power plant (Tsushima City in the past and the joint venture in the present) have not employed their own technical experts to maintain their wind turbines because they do not have enough turbines to justify having experts on the staff (an interview on November 7, 2020). Therefore, they rely on a company in Tokyo for maintenance and repair (an interview on November 7, 2020), which takes time to complete. On-site maintenance and quick repair by experts are significant factors that increase profits from RE in addition to the rapid procurement of components. Indeed, one of the main causes of the failure of the city-owned wind power plants in 2012 was the lack of technical experts in Tsushima and the dependence on mainland experts to repair the wind power plants.[3]

It is often said that a major barrier to RE development in local communities is social acceptance [17,62,63]. However, the interview results suggested that local governments, companies, and citizens had a strong interest in and positive attitudes toward RE in Tsushima.

These results show that the lack of local investment is an important barrier to the further development of RE electricity. Therefore, it is essential to understand the economic benefits of RE development on the island to encourage further investment. The following section presents the economic effects, mainly spillover effect, of RE promotion in Tsushima using IO analysis.

3.2. *Economic effects of renewable energy promotion in Tsushima*

Based on the data and assumptions presented in section 2.2.2, the final demand in each RE-related sector is first estimated for each scenario to assess the spillover effect of promoting RE electricity in Tsushima. The values for the construction of PV and wind power plants, calculated based on the increases in the capacity and the construction cost, are JPY 408.91 million and JPY 17.82 million (Scenario 1), JPY 85.12 million and JPY 8.31 million (Scenario 2), and JPY 185.24 million and JPY 94.59 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 4.75 million and JPY 0.30 million (Scenario 1), JPY 0.99 million and JPY 0.14 million (Scenario 2), and JPY 2.15 million and JPY 1.61 million (Scenario 3), respectively. This suggests that, annually, the direct effect is much greater for construction than operation and management.

Table 3
Spillover effect inside and outside Tsushima (unit: JPY million/year).

	Inside Tsushima	Outside Tsushima	Total
Scenario 1	461.45	977.32	1438.77
Scenario 2	101.14	212.60	313.73
Scenario 3	304.49	614.77	919.26

Based on the above direct effect, the spillover effect was estimated for the three scenarios using Eq. (1) (Table 3). The total spillover effects of increasing RE electricity in Tsushima were JPY 461.45 million/year (Scenario 1), JPY 101.14 million/year (Scenario 2), and JPY 304.49 million/year (Scenario 3). Because the direct effect is the largest for Scenario 1, the spillover effect is also the largest. This spillover effect was mainly brought about by the PV construction sector (Fig. 2). In total, PV construction contributed JPY 441.61 million/year (Scenario 1; blue bars in the figure), which is about 96% of the total spillover effect. This is primarily due to its larger direct effect compared with the other sectors in the scenario.

Comparing the spillover effects inside and outside Tsushima, that inside Tsushima is much smaller (around one-third of the total effect).[4] This is because most of the intermediate inputs for RE sectors come from outside the island. In addition, the spillover effect in Tsushima was mainly due to direct effects.

Observing the spillover effect in Tsushima by sector for Scenario 1 (Fig. 2),[5] the most significant effect was found in the PV construction sector, which is mainly induced by its direct effect. Similarly, the second largest effect (the wind power construction sector) was due to its direct effect. The third and fourth largest effects were found in the commerce and road transport sectors, respectively. These are primarily generated by the indirect effects of the PV construction sector.

Focusing on the indirect effect (i.e., spillover effect minus direct effect) in Tsushima, the effect induced by the PV construction sector is the greatest (JPY 32.70 million/year) because of its sizeable direct effect, followed by the PV electricity sector (JPY 1.98 million/year), the wind power construction sector (JPY 1.80 million/year), and the wind electricity sector (JPY 0.15 million/year) for Scenario 1.[6] However, the indirect effect of the unit direct effect indicates the highest value for the

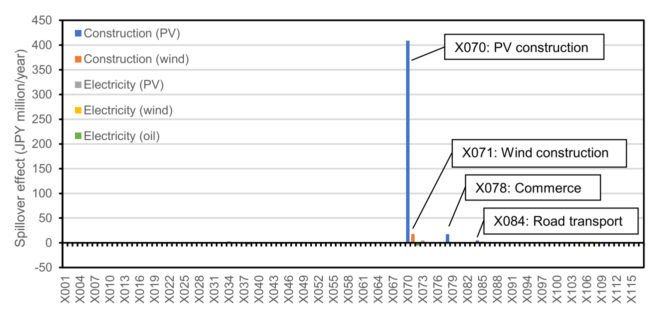

Fig. 2. Spillover effect observed in Tsushima by sector (Scenario 1). Sector numbers (X-axis) and the corresponding sector names are shown in Table S1 of Supplementary Material. The corresponding figures for the other scenarios are presented in Figs. S1 and S2 of Supplementary Material.

[3] The wind turbines often fail because of the island's environmental conditions, including high wind speeds, typhoons, and salt damage. Without indigenous technical experts and the components, it usually takes a few weeks to repair them, increasing the operating costs.

[4] For the spillover effects outside Tsushima, it is not possible to distinguish the effects in other parts of Japan and abroad because of the lack of data.

[5] The following section focuses on the results of Scenario 1, but similar trends were seen for the other scenarios. See Figs. S1 and S2 of Supplementary Material for the results from the other scenarios.

[6] The reduction in oil-fired power generation results in negative spillover and indirect effects.

wind electricity sector (0.50), followed by the PV electricity sector (0.42), the wind power construction sector (0.10), and the PV construction sector (0.080). This means that if the final demand increases by the same amount (value), the electricity sectors will generate more indirect and spillover effects than the RE construction sectors, and the wind power sector will have a higher effect than the PV sector.

The indirect effects in Tsushima by sector were then investigated (Fig. 3). The figure shows that the commerce sector exhibits the most significant effect, followed by road transport (excluding self-transport), self-transport, and cement and cement products sectors. In contrast, the steel product sector has the greatest negative effect. As with the above results, the PV construction sector largely contributed to the indirect effect in these sectors.

Regarding the effects on value-added, the total effects inside Tsushima were JPY 59.08 million/year (Scenario 1), JPY 13.59 million/year (Scenario 2), and JPY 51.13 million/year (Scenario 3) (Table 4). Because the direct effect is the largest for Scenario 1, the effect on value-added was also the largest. In this scenario, the effect on value-added was mainly due to the PV construction sector. In total, the PV construction sector contributed JPY 51.86 million/year (Scenario 1; blue bars in Fig. 4), which is approximately 88% of the total effect. However, this percentage is smaller, and the contributions of the wind construction and PV electricity sectors are larger than those of the spillover effect because the value-added produced per unit of direct effect is smaller for the PV construction sector than for the other RE-related sectors (PV construction: 0.13, wind power construction: 0.27, PV electricity: 0.80, and wind electricity: 0.73).

Observing the sector-wise effects for Scenario 1 (Fig. 4), the PV construction sector showed the most prominent effect (JPY 27.95 million/year), primarily due to its direct effect. The commerce sector also exhibits a relatively large effect (JPY 14.48 million/year), brought about by the indirect effect (mainly of the PV construction sector), followed by the effects of the wind power construction sector (JPY 3.69 million/year), the road transport sector (JPY 3.38 million/year), and the PV electricity sector (JPY 3.21 million/year). Compared to the spillover effect and the employment effect (see below), the impact on power generation sectors is greater because their value-added coefficients are relatively large.

Concerning the employment effects of RE electricity promotion, those inside Tsushima were 19.30 person/year (Scenario 1), 4.21 person/year (Scenario 2), and 12.39 person/year (Scenario 3) (Table 5). In Scenario 1, for example, the employment effect was mainly due to the PV construction sector as its large direct effect and the unit employment effect (PV construction: 0.045, wind power construction: 0.042, PV electricity: 0.026, and wind electricity: 0.036 [person/JPY million]). Observing the sector-wise effect for Scenario 1 (Fig. 5), the employment effect was largest in the PV construction sector (13.90 person/year), primarily caused by its direct effect. The commerce sector also has a relatively significant effect (3.34 person/year), brought about by the indirect effect (mainly of the PV construction sector). The wind power construction sector exhibits an employment effect of 0.55 person/year, caused by its direct effect. The employment effect of the road transport sector (0.63 person/year), the third-largest, is a mixture of the indirect effect induced by the PV and wind power construction sectors, although the contribution of the PV construction sector is more.

Comparing the employment effects inside and outside Tsushima, the effect for Tsushima is much smaller (less than 30% of the total effect). This trend is because most of the intermediate inputs for RE sectors come from outside the island, and employment is created there. In addition, the employment effects for Tsushima are mainly due to direct effects (Fig. 5 and Figs. S1 and S2 in Supplementary Material).

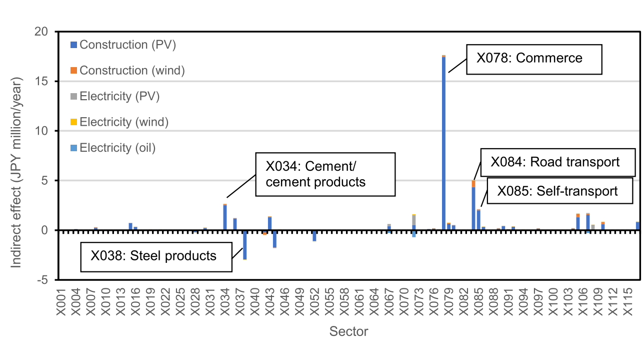

Fig. 3. Indirect effect observed in Tsushima by sector (Scenario 1). Sector numbers (X-axis) and the corresponding sector names are shown in Table S1 of Supplementary Material. The corresponding figures for the other scenarios are presented in Figs. S1 and S2 of Supplementary Material.

Table 4
Effect on value-added inside and outside Tsushima (unit: JPY million/year).

	Inside Tsushima	Outside Tsushima	Total
Scenario 1	59.08	147.01	206.08
Scenario 2	13.59	32.78	46.37
Scenario 3	51.13	107.54	158.67

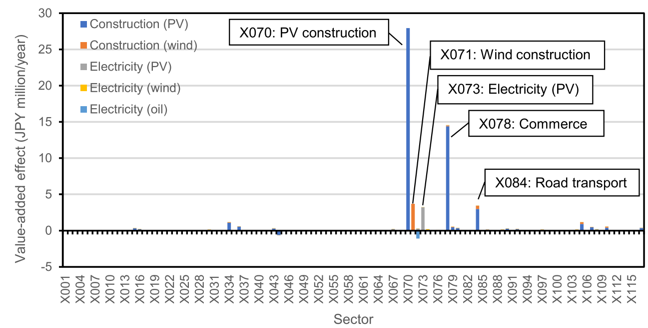

Fig. 4. Effect on value-added observed in Tsushima by sector (Scenario 1). Sector numbers (X-axis) and the corresponding sector names are shown in Table S1 of Supplementary Material. The corresponding figures for the other scenarios are presented in Figs. S1 and S2 of Supplementary Material.

Table 5
Employment effect inside and outside Tsushima (unit: person/year).

	Inside Tsushima	Outside Tsushima	Total
Scenario 1	19.30	49.62	68.92
Scenario 2	4.21	10.89	15.10
Scenario 3	12.39	33.03	45.42

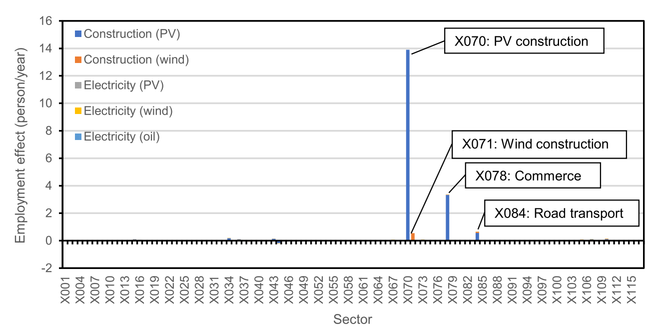

Fig. 5. Employment effect observed in Tsushima by sector (Scenario 1). Sector numbers (X-axis) and the corresponding sector names are shown in Table S1 of Supplementary Material. The corresponding figures for the other scenarios are presented in Figs. S1 and S2 of Supplementary Material.

The GRP in Tsushima was JPY 92.9 billion in 2011, and the total employment was 15,547 people in 2010.[7] Therefore, the spillover and employment effects of promoting RE power generation were 0.11–0.50% and 0.027–0.12%, respectively, depending on the scenario. This trend indicates that the spillover effects under the scenarios were not large but not negligible. In addition, RE promotion in Tsushima will generate spillover and employment effects outside the island (more than twice the effect in Tsushima) because most PV and wind power plant components are imported from the mainland and abroad.

Finally, as the RE power generation lasts for the lifetime of the power plants, and the spillover, value-added, and employment effects were generated for that period, these effects were evaluated assuming the lifetime of power plants as 20 years [37]. With 3% of the discount rate, the discounted present values of spillover effect inside Tsushima were JPY 464.53 million (Scenario 1), JPY 101.91 million (Scenario 2), and JPY 308.35 million (Scenario 3), and of effect on value-added were JPY 92.06 million (Scenario 1), JPY 20.90 million (Scenario 2), and JPY 12.89 million (Scenario 3). This study evaluated RE construction in a single year, but RE construction is expected to continue to increase the amount of RE. Therefore, more economic effects are expected in the future with further development of RE electricity in the island.

The results suggest that increasing RE electricity in remote islands in Japan has economic merit. However, for additional economic effects from the expansion of RE in remote islands, it is essential to attract and grow an RE-related industry, enabling the islands to procure the necessary components and services by themselves and reduce the leakages of economic effects outside the islands. This would also contribute to an increase in the number of indigenous technical RE experts, the lack of whom is an important barrier to the island having more RE. However, it is not an easy solution, as the scale of RE in the islands is still limited. The Government of Japan is now making a new basic energy plan, which is expected to increase the percentage of RE in 2030 relative to the current plan. In addition, the development of a considerable amount of RE is urgent to realize a net-zero emission (carbon-neutral society). Remote islands like Tsushima have a large potential for RE, and considering examples of remote islands in Europe, further increasing RE and aiming, for example, at 100% RE islands would contribute to the policy. This would be an opportunity for industrial development on remote islands and eventually for local development. Fostering the industry through public-private partnerships would be an important approach considering the current situation of the remote islands.

4. Conclusion

Given the increasing concerns about climate change and the importance of RE in mitigating the impacts, it is essential to promote RE electricity in remote islands where thermal power generation is the primary energy source. In this study, semi-structured interviews were conducted to clarify the current RE development and the barriers to RE electricity penetration, and an IO analysis was conducted to quantify the economic effects of RE promotion on a remote island, Tsushima. The interviews indicated that the main barriers to RE promotion were insufficient investment and the lack of technical experts. Therefore, promoting investments, such as reinforcing grid capacity, and developing indigenous technical experts to maintain RE facilities are urgent to incorporate additional RE and ensure stable operation. In addition, the IO analysis indicated that some economic spillover effects of introducing PV and wind power were observed (JPY 101.14–461.45 million/year inside the island), including employment effects (4.21–19.30 person/year inside the island). Although the spillover effects within the island were not large, they were also generated outside the island (JPY 212.60–977.32 million/year). Although there have not been any opposition from the local residents against RE facilities in Tsushima so far, conflicts between the residents and RE developers can happen as with other cases when installation of RE facilities is accelerated due to potential environmental problems, such as impacts on landscape and degradation of the natural environment. Therefore, dialogue with the residents to reach a local consensus and precautionary measures to avoid possible environmental problems are required. In addition, the local economic effects brought about by increasing RE facilities in the present and future shown in this study contribute to local development and may facilitate the local acceptance of RE facilities.

Because remote islands without grid connections with the mainland need to generate and control electricity inside the island, investments in energy storage systems, including batteries, are essential to strengthen and stabilize variable RE capacities such as PV and wind power generation. In addition, because the cost of small thermal power plants in remote islands is high and a certain proportion of the cost of electricity in remote islands is borne by citizens outside the islands as a universal service, as described in the introduction, RE penetration in remote islands is more profitable than the existing energy system for both local and other citizens. Therefore, understanding the socioeconomic effects of further promotion of RE with energy storage systems will be an important future research topic.

[7] Because of data unavailability, the employment data used here is for the year 2010.

Role of the funding sources

None.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2022.112456.

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