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Development and application of an inter-regional input-output table for analysis of a next generation energy system

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ABSTRACT

Inter-regional and inter-sectoral considerations are important for more effective use of renewable energies. We have developed an input-output table for a next generation energy system (IONGES) that includes new sectors related to renewable energies. In this study, we expand the national IONGES to include the inter-regional table. The inter-regional IONGES has two sets of extended tables: extended renewable energy sectors for 2005 (Ex2005, actual data of 2005) and extended renewable energy sectors for 2030 (Ex2030, hypothetical data for 2030). More than half of renewable energy potential is located in eastern Japan. The potential of residential solar power is large in regions that have metropolitan areas. Some renewable energies induce more output and create more jobs than conventional electricity, but at the same time such renewable energies are more expensive than conventional electricity. When we evaluate the effects of introducing renewable energies in each region, we must consider both types of effects. We calculated the induced production in every sector of every region based on one million JPY of consumption in each region. Comparing the induced electricity (which is interpreted as the electricity fee embodied in consumption) of Ex2030 and that of Ex2005, the inducements are largely decreased in those regions where the composition ratio of wind power is high. We calculated the supposed CO_2 reductions attributed to a decline in conventional electricity induced by consumption. It seems that the effective use of residential solar power in metropolitan areas and the effective use of locality-specific renewable energies in rural areas are important for CO_2 reductions. We calculated cost-push effects following the abolition of FIT. There are significant effects on regions where the composition ratio of solar power is high.

Analyses using inter-regional input-output tables will be a useful analytical tool for effective use of renewable energy facilities that have already been installed, as well as for future designs of smart energy systems.

1. Introduction

This study presents analytical results a using Japanese inter-regional input-output table that we have developed for incorporation of the renewable energy sectors. Moreover, using the table, we estimated effects that the introduction of feed-in tariff (FIT) brought to each region of Japan.

FIT were implemented five years ago in Japan, and the challenges that must be overcome – if renewable energies are to be used more effectively – are becoming clearer. Table 1 shows that such challenges differ depending on the energy source.

Because photovoltaic (PV) and wind power are variable energies, variation-mitigating measures are indispensable. One such measure is extending a local grid to a wider area and constructing inter-regional systems, which can lead to smoothing of the variation in both PV and wind. Furthermore, because excellent areas for large-scale PV and wind power generation are usually located far from urban areas, a new transmission network will have to be constructed. With the spread of PV systems for residential use, it is predicted that local voltage management in residential areas will become more difficult and that construction of regional energy systems within residential community units will be required in the near future.

As for large-scale geothermal generation, the resources for this energy source usually exist in national parks near major hot-spring areas. Thus, the construction and operation of geothermal power plants are both likely to cause conflicts between power producers and local residents. Producers will have to carefully examine common regional interests and concerns.

Small-scale geothermal, water, biogas, and woody biomass are dispersive energies and have geographical characteristics. Here, well-

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Table 1
Challenges to utilizing renewable energies.

Renewable energy	Challenges	Countermeasures
Large-scale PV, Wind power	Variable, Far from area of power demand	Widening the power grid, Construction of multi-regional transmission systems
PV for residential use	Variable, Located in residential areas (areas of terminal distribution system)	Construction of regional energy systems within residential community units
Large-scale geothermal power	Located in national parks near tourist hot-spring areas	Share common regional interests and concerns
Small-scale geothermal power, Small-scale water power, Biogas power, Woody biomass power	Small-scale and distributed	Construction of regional energy management systems of local production for local consumption

planned regional energy management systems – of local production for local consumption – are indispensable for efficient use of these energies.

Clearly, regional and inter-regional considerations are important for effective utilization of renewable energies. We have already developed an input-output table for a next generation energy system (IONGES) [1,2], which was compiled from the Ministry of Internal Affairs and Communications (MIC)'s input-output table [3] so as to include new sectors related to renewable energies. In this study, we expand the national IONGES to the inter-regional table, with which we will be able to analyze the inter-regional and inter-sectoral dependence of the economy when renewable energies are used. Using the new database, we reviewed our policy research on FIT that was performed using a national IONGES.

2. Literature review

2.1. Input-output analysis and renewable energies

Input-Output (IO) analysis has often been used to assess the effects of introducing renewable energies. In its early years, it was used to calculate induced employment from the introduction of renewable energies [4–6]. However, recent articles have used IO analysis to assess how the use of renewable energies affects nearby regions. Martínez et al. [7] assessed the impacts of sugarcane-derived bioethanol production in northeast Brazil. Nakano et al. [8] calculated the economic and environmental effects of a woody biomass power plant on the region where it is located. Ejdemo and Söderholm [9] addressed the impacts of promoting wind power energy in the region where power generation is located (northern Sweden). Okkonen and Lehtonen [10] did the same for northern Scotland, as did Kumar et al. [11] for the state of Indiana in the United States. In some of the most recent studies, effects of the introduction of promising renewable energies, which have not yet been realized, on regional economies are considered. Varela-Vázquez and Sánchez-Carreira [12] pointed out that offshore wind power has considerable influence on the Spanish economy through its value chain; they claimed that an industrial policy with a long-term perspective is necessary. Okkonen and Lehtonen [13] have claimed that bio-oil production based on forest biomass has positive effects on the economy of the depopulated region of Finland and will lead to the elimination of regional disparities. All of these studies focus on the introduction effect of individual forms of renewable energy and do not consider alterations in the overall energy system.

2.2. Input-output (IO) analysis and energy systems

Recent research studies regarding renewable energies have been conducted from the viewpoint of the energy system as a whole. These studies take into consideration the relationship between energy production and consumption, or the energy strategy of a country. In such research studies, IO analysis is often used as an analytical method.

Wang et al. [14] measured the rebound effect in Beijing household electricity consumption by linking the demand theory to IO analyses; accordingly, they considered that an effective energy policy mix is necessary. Su et al. [15] conducted a structural decomposition analysis of CO_2 emissions associated with energy consumption in Singapore through an IO analysis and discussed energy policies in cities. Kaltenegger et al. [16] have focused on "real unit energy costs" based on an IO analysis recommended by the German government and EU. They point out that the current energy policy debate is not achieving its designated objectives when considering the indirect energy costs revealed by real unit energy costs. Hondo and Moriizumi [17] created detailed input coefficient vectors of renewable energy sectors for the Japanese IO table and compared employment characteristics of the various renewable energies in detail. Further, they provided information useful for constructing renewable energy policies in Japan. Nakano and Washizu [18] developed an IO table for Japan incorporating renewable energy sectors; they also created input coefficient vectors of sectors related to hydrogen energy (i.e., future technologies). In addition, they evaluated the roadmap presented by the Japanese government regarding future hydrogen energy system construction and offered necessary policy recommendations.

Thus, the most recent IO analyses are used politically to evaluate current energy systems or plan for future energy system construction.

2.3. Inter-regional input-output analysis and renewable energies

Recent articles regarding renewable energies have also demonstrated the effects of introducing renewable energies in one region on other regions. Okadera et al. [19] evaluated the water footprint of the energy supply of China's Liaoning Province and showed that it could depend on water resources in a neighboring province. Li et al. [20] showed that Beijing's total embodied energy is composed of local, domestic and foreign components and noted that multi-scale governance is recommended for overall energy abatement. Li et al. [21] showed that fuel-related mercury emissions in Beijing are embodied in imported goods through an IO analysis considering regional and international transactions. They argue that regional measures are insufficient in combatting mercury pollution. Using an inter-regional IO table, Fu et al. [22] considered optimal inter-regional industrial shifts that will reduce carbon intensity in China. Hong et al. [23], using China's multi-regional IO table, investigated the sectoral and regional CO_2 emissions of China's construction industry.

Other recent articles have considered international relationships associated with energy use. Zeng et al. [24] used structural decomposition analysis and showed that changes in the commodity composition of foreign trade caused China's energy intensity to increase. Sievers and Schaffer [25] analyzed the impacts of the German biofuel quota and showed that this policy affects the import ratio of agricultural products. Wiebe and Lutz [26] used a large-scale macro-econometric IO model and showed that domestic installations of renewable energy modules were affected by global capacity. Chen and Wu [27] developed a new database (an energy IO table for the global economy) that adds energy usage data to the multi-regional IO table; it reflects a consideration for global energy chains. Such a database would be indispensable for building sustainable energy policies at the international, national, and regional levels, as the authors have asserted.