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Socioeconomic Life Cycle Analysis of Geothermal Power Generation Considering Regional Industrial Structures

Shunichi Hienuki[1)], Hiromi Kubota[2)]

1) Yokohama National University 79-5 Tokiwadai, Hodogaya, Yokohama, 240-8501, JAPAN

hienuki-shunichi-sh@ynu.ac.jp

2) Central Research Institute of Electric Power Industry, 1646 Abiko, Abiko-shi, Chiba 270-1194, Japan

hiromi-n@criepi.denken.or.jp

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ABSTRACT

The introduction of geothermal energy is expected to have socioeconomic effects. Our previous studies showed that these effects were greater in the operation and maintenance (O&M) stages than in the manufacturing and construction stages. However, additional research and complex economic models are required to identify quantitatively the regions where these effects occur. Additionally, when the introduction of a technology is being considered, study time and information resources are limited. Therefore, it is necessary to construct a highly versatile method that can be applied to answer questions quickly. The purpose of this study is to construct a method that analyzes the effects of the introduction of geothermal energy generation technologies both within and outside regions by combining input–output (IO) models that reflect the industrial structure and relevant information about the energy technology. The target technology is geothermal energy generation with a capacity of 50,000 kW. The study considers equipment manufacturing, including turbines and generators, well drilling (including surveying and additional drilling), transportation-pipe construction, and O&M (including the Japanese feed-in tariff) of 40 years. The information used for this study, on costs and social situations, covered the period 2011–2015. Analysis of the results showed that there was a difference in the indirect effect on the manufacturing sector related to electronic devices and related parts, depending on regional industrial structures. However, there was also an indirect effect on service sectors, including maintenance, freight transportation, and commerce (wholesale and retail) in all regions. Our method could be applied to any region for which a regional IO table was prepared and could be used for other renewable and hydrogen-based energy systems.

1. INTRODUCTION

Geothermal resources can be used for power generation and thermal energy. It has the advantages of being able to provide stable supply and energy security. Thus, its contribution to energy utilization is expected to increase significantly in some countries (Bertani 2012) (Huttrer 2020). Japan is a tectonically active country, with nearly 200 volcanoes and some potentially geothermal resource-rich places (Yasukawa et al. 2018). In response to the Great East Japan Earthquake of March 11, 2011, the gird mix and energy policy of Japan was changed drastically (Ministry of Economy, 2018, with the goal of increasing geothermal energy use so that it accounts for approximately 1% of all power generated by 2030. To achieve this, the installed capacity of geothermal power plants must be increased to three times of the current capacity. Thus, the Ministry of Economy, Trade and Industry and Ministry of the Environment have resumed the provision of economic assistance and support to developers of geothermal power generation, in terms of relaxation of regulations such as issuing of permits for development in national parks (Ministry of Economy, 2012) (Ministry of the Environment, 2014). This kind of policy-based support can have an impact on the economic and financial viability of developers. Some subsidies, deregulations, and incentives due to political changes have been implemented. The number of development plans and surveys for new geothermal power plants has been increasing. However, some barriers have been reported to the introduction of geothermal power generation, such as development risk, business feasibility, and consensus building within the region (Kubota et al. 2013). In particular, to obtain a social license, it is important to recognize the regional benefits of introducing geothermal energy (Thomson and Boutilier 2011), and quantitative visualization is required.

The economic effects of geothermal energy generation in Japan can be broadly divided into two perspectives: business and society. Research regarding the business aspect has been conducted to evaluate the characteristics of energy generation based on construction costs and capacity factors (Iikura 1996). Additionally, research has examined business profitability by considering the natural conditions around a power plant (Adachi 2011). However, as an example of the latter, employment and economic effects have been analyzed using national input–output (IO) tables (Hienuki, Kudoh, and Hondo 2015) (Hondo and Moriizumi 2017) (Nakano and Washizu 2017). Analyses using such tables have also been conducted in countries such as Spain and Germany (Tourkolias and Mirasgedis 2011) (Lehr et al. 2008). Moreover, another analysis of regional IO tables targeted the state of Asturias in Spain (Moreno and López 2008) and Washington State in the USA (Lesser 1994).

The IO analysis of the introduction of a new technology mainly takes two prominent factors into account. The first is the transaction of goods and services between regions. IO models typically reflect the industrial structure of a single region. A multi-regional IO (MRIO) table spans multiple regions. The former model is used by approximately 400 sectors in Japan. From these, it is possible to understand in detail the direct and indirect environmental, economic, and social impacts caused by the introduction of a technology. However, the impact of imports and transactions between regions is not reflected. MRIOs, however, reflect the transactions of goods and services between regions, but the analysis results are quite coarse. Recently, MRIOs have used approximate calculations (Lenzen et al., 2013; Timmer et al., 2015), reflecting both direct and indirect effects, considering the characteristics of individual technologies. The second is the sector resolution of the input-output table. Single national or regional IO tables comprise approximately 400 sectors, even in the detailed tables. Therefore, to calculate the direct and indirect effects of a technology in more detail, two main methods are used. One is the integrated hybrid method, which estimates and complements high-impact activities using process-based analyses. The other is the IO-based hybrid (extended) method, which establishes transactions of goods and services of individual technologies (Wiedmann et al. 2011). However, it is extremely difficult for local governments, businesses, and investors to use because they require a substantial amount of time, excessive costs, and specialized knowledge.

The objective of this study is to construct a more versatile and simple method compared to conventional IO analysis of introducing geothermal energy generation technologies both within and outside a region by combining published IO tables and technology information.

2. METHODS AND MATERIALS

2.1 IO model for regional socioeconomic effects

In previous studies, we developed versatile and simple methods to estimate effectively the socioeconomic effects that can be applied to any region. Figure 1(a) shows the difference-IO model (DIO) and Figure 1(b) shows the two-relational IO models (TRIO), which require relatively few work steps based on the published IO table. The difference between DIO and TRIO is that, whereas DIO estimates the impact inside and outside a region by combining the estimation results of each, TRIO adds the step of creating a two-region IO table. Therefore, although DIO can easily estimate the impact inside and outside a region, TRIO reflects the transactions of goods and services. Moreover, the rebound effect is considered. The rebound effect implies that the increase in demand within the region increases demand outside the region (including other countries) through an increase in imports and production outside. The production in this study shows the direct and indirect economic effects of the activity of construction and geothermal power generation, and it generally uses units of money such as dollars, euros, yen, etc..

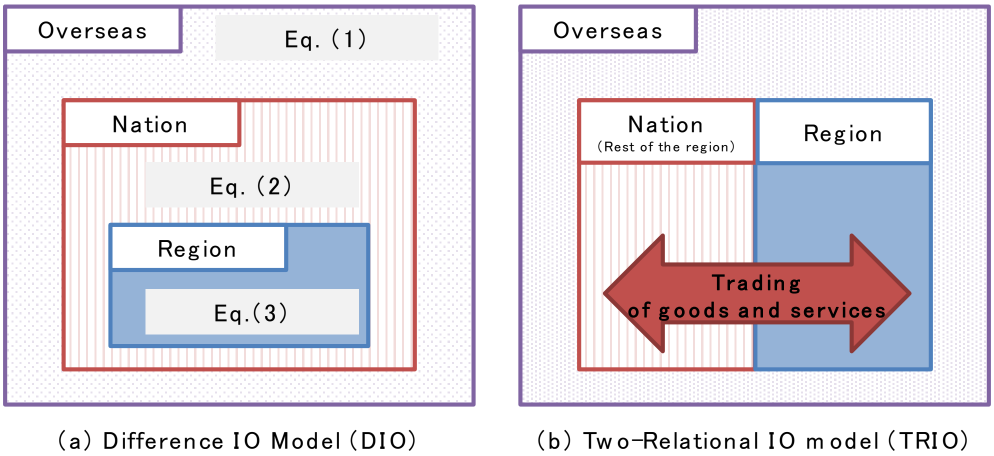

Figure 1: Overview of DIO and TRIO models and corresponding equation references (Hienuki and Hondo 2017)

Table 1 summarizes the calculation results of national IO, regional IO, DIO, and TRIO when analyzing the spillover effect of the introduction of technology. The publicly available use of national and regional IO can be effectively estimated by obtaining appropriate monetary information, such as estimates prepared for regional industrial information. However, it is difficult to distinguish clearly the socioeconomic impacts inside and outside the region for every use. Moreover, although the DIO and TRIO models are restricted by the number of sectors in the regional table, it is possible to analyze the impact on the region from outside the region using the existing IO table. Additionally, DIOs estimate the impact both inside and outside the region based on the difference in the estimation results using national and regional tables. Thus, it requires fewer steps than the TRIO model, which, in turn, requires the creation of a multi-regional table.

The main conclusions of our previous study show that the DIO model has advantages in terms of versatility and simplicity as applied to the lifecycle analysis of energy technology and its impact inside and outside the region. Additionally, it shows that the TRIO model is effective for analyzing the impact of the manufacturing and construction (M&C) industry in more detail (Hienuki and Hondo 2017). Because this research focused on versatility and simplicity, we chose the DIO model for further research.

Table 1 Advantages and disadvantages of four IO models (Hienuki and Hondo 2017)

	Lifecycle stage	Original national IO	Original regional IO	DIO	TRIO
Estimation of nation-level impact (outside prefecture)	Manufacturing	S	I	M	S
	Construction	S	I	S	S
	Operation and maintenance	S	I	S	S
Estimation of region-level impact (inside prefecture)	Manufacturing	I	S	M	S
	Construction	I	S	S	S
	Operation and maintenance	I	S	S	S
Sector disaggregation	-	S	M	M	M
Required labor	-	S	S	S	I

S: Superior, M: Moderate, I: Inferior.

When the national or regional table is used independently for the analysis, the total production value, $\boldsymbol{X_t}$, the domestic production, $\boldsymbol{X_{nr}}$, the regional production, $\boldsymbol{X_r}$, the external production, $\boldsymbol{X_n}$, and the overseas production value $\boldsymbol{X_o}$, are based on equations (1)–(5) below. $\boldsymbol{I}$ is the unit matrix, $\boldsymbol{A_{nr}}$ is the national IO input coefficient matrix; $\boldsymbol{X_o}$ is the prefecture IO input coefficient matrix; $\boldsymbol{\widehat{M}_{nr}}$ is the diagonal matrix of the national table import coefficient; $\boldsymbol{\widehat{M}_r}$ is the diagonal matrix of the regional table import coefficient; $\boldsymbol{\widehat{N}_r}$ is the diagonal matrix of the import coefficients in the regional table; and $\boldsymbol{F}$ is the final demand vector. The DIO model estimates the total production value, $\boldsymbol{X_t}$, the regional production value, $\boldsymbol{X_r}$, and the external production value, $\boldsymbol{X_n}$, by giving the final input, $\boldsymbol{F}$, to the existing IO table, and by taking the difference between them, the production amounts of the three regions can be estimated separately.

$$\boldsymbol{X_t = (I - A_{nr})^{-1}F}, \quad (1)$$

$$\boldsymbol{X_{nr} = \left\{I - \left(I - \widehat{M}_{nr}\right)A_{nr}\right\}^{-1}F}, \quad (2)$$

$$\boldsymbol{X_r = \left\{I - \left(I - \widehat{M}_r - \widehat{N}_r\right)A_r\right\}^{-1}F}, \quad (3)$$

$$\boldsymbol{X_n = X_{nr} - X_r}, \textbf{ and} \quad (4)$$

$$\boldsymbol{X_o = X_t - X_{nr}}. \quad (5)$$

2.2 IO model for lifecycle analysis of renewable energy

Japan's national IO table contains approximately 400 sectors and is the most detailed of the world's publicly available IO tables. However, there are two sectors related to energy generation (i.e., commercial and private), and there is one sector dedicated to energy-plant construction. However, individual energy-generation technologies cannot be distinguished. Therefore, if the existing IO table were to be used, it would be strongly affected by large-scale technologies, such as nuclear and thermal energy. Thus, it is difficult to analyze accurately the production of individual renewable energy sources. Hondo and Moriizumi (2017) created a renewable energy-focused IO model (REFIO) that accommodated the national IO via large-scale interviews with businesses and literature reviews. This model has 12 energy generation types (i.e., residential, small-scale, large-scale (roof-mounted), large-scale (ground-mounted), wind, large-scale geothermal, small-scale geothermal, small-scale hydro, wood biomass, sewage-sludge biogas, animal-waste biogas, and food-waste biogas), and 17 related sectors of input and output information are provided. The latest version of the published information related to 2011, and it reflected the IO information related to revenue from the Feed in Tariff (FIT) from selling electricity to the grid.

Table 2 shows the relationship between the sectors related to large-scale geothermal energy generation from the REFIO and related lifecycle stages. Sectors related to geothermal energy generation include five survey sectors (Nos. 1–5), five construction sectors (Nos. 6–10), and one operation and maintenance (O&M) sector (No. 11). Of these, geothermal energy generation requires additional drilling. Thus, production and reduction well drilling is considered a production activity for both the M&C and O&M stages.

Table 2 Sectors related to large-scale geothermal energy generation in REFIO

No.	REFIO sector	M&C	O&M
1	Gravity exploration	✓	
2	Electromagnetic exploration	✓	
3	Environmental impact assessment	✓	
4	Eruption test	✓	
5	Survey well drilling	✓	
6	Production well drilling	✓	✓
7	Reduction well drilling	✓	✓
8	Vapor-transport pipe laying	✓	
9	Laying hot-water transport pipe	✓	
10	Construction of large-scale geothermal energy generation facility	✓	
11	Geothermal energy generation		✓

2.3 Prerequisites for geothermal energy generation

The targets for geothermal energy generation are: a capacity of 50,000 kW, which provides a capacity factor of 74%, a lifetime of 40 years, manufacturing and construction costs of 32,000 million yen, and annual O&M costs of 7,900 million yen per year (Table 3). The largest capacity among those of all the currently functioning geothermal power plants in Japan is 50,000 kW, and previous studies have assumed a similar scale. M&C costs include research, planning, design, mechanical equipment, electrical equipment (including grid connection costs), civil engineering construction, and building construction. O&M costs include wages, consumables, overhead costs, insurance premiums, depreciation costs, taxes, FIT-related costs, regular maintenance, and repair costs.

Table 3 Main prerequisites for geothermal energy generation

Capacity [kW]	50,000
Capacity factor [%]	74
Lifetime [year]	40
M&C [Million yen]	32,000
Annual O&M [Million yen]	7,900

The target area for introduction was the Kumamoto prefecture in the Kyushu region, which has one of the highest potential for the introduction of geothermal energy in Japan (Renewable Energy Industrialization Promotion Committee, 2017). Kumamoto Prefecture has an area of 7,409 km^2 and has a population of approximately 1.7 million (Government, 2020).

3. RESULTS AND DISCUSSION

3.1 Production inside and outside region (Case of Kumamoto prefecture)

Production was estimated to be worth 488,000 million yen over the 40 y generation lifecycle of geothermal energy (Figure 2). Because the total final demand for geothermal energy generation is 348,200 million yen, the induced production is approximately 1.3× that of the final demand. From this, 18% occurs during the M&C stage, which includes the effect of the introduction plan on the start of operations. However, 82% occurs during the O&M stage, which has a continuous economic effect over a 40-year period. According to previous research, wind and solar energy generation have a large effect on equipment manufacturing and parts (Hienuki, Kudoh, and Hondo 2015), such that the effect of the M&C stage tends to be large. However, geothermal energy generation induces the effect of the O&M stages, which provides a major advantage of geothermal energy generation.

Focusing on the ratio of inside and outside regions, 80% of the total (11% M&C, 70% O&M) is an economic effect within the Kumamoto Prefecture. However, of the 80%, 65% includes the geothermal energy generation sector (No. 11), 11% are on-site surveys, well drilling, and construction (Table 1 and Nos. 1–10), and 4% are in the other indirect sectors within the prefecture. It should be noted that the production generated in the geothermal energy generation sector is related to the activities of the electricity company and includes the revenue from selling electricity, including FIT. Additionally, the economic effects of research, drilling, and construction are determined by distinguishing whether or not the business operator exists within the region. In particular, the effects of production and reduction well drilling (including additional drilling) accounts for 10% of the total, a relatively large proportion.

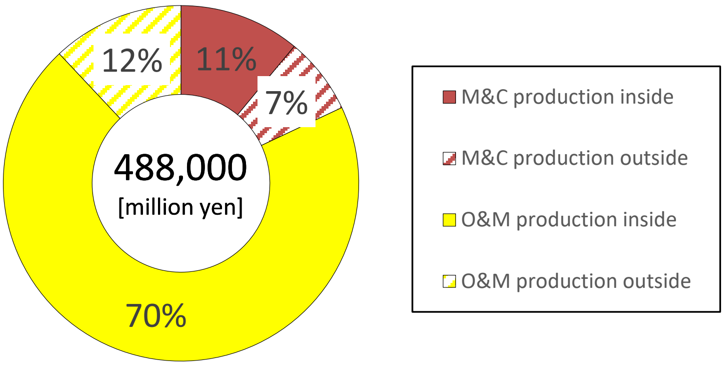

Figure 2: Production by lifecycle stage (Case of Kumamoto prefecture)

3.2 Production value by sector in the region

Figure 3 shows the economic effects that occurred in the top 15 sectors of other industries in the prefecture. As seen in the figure, 10 sectors have an economic effect of 1,000 million yen or more. Notably, the effects of service sectors, such as commercial, car maintenance, machine repair, finance, and insurance, are ranked high. Moreover, the effects on manufacturing industries, such as industrial electronic equipment, machines for general use, and non-metal minerals, are also confirmed. Car maintenance, machine repair, other business services, and goods-rental service sectors are the production activities required for plant engineering and O&M. Additionally, commercial and road transportation sectors are affected by commerce and transportation variables, which underlie the above production activities.

3.3 Comparison with other regions

By comparing the economic effects of introducing similar geothermal power plants, in the Akita Prefecture, we can clarify the difference in economic effects, depending on the industrial structure of the region. Akita Prefecture has the largest geothermal power plant in Japan and has high potential for geothermal energy production, similar to Kyushu. For this purpose, we compared the economic effects of introducing the same geothermal power plant inside and outside the Akita Prefecture. The production generated in the Akita Prefecture was approximately 81% (M&C 11%, O&M 70%) out of a total of 488,000 million yen. In addition, the ratios of the geothermal energy generation sector (Table 1 and No. 11), on-site surveys, excavation, construction (Table 1 and No. 1–10), and other industries in the prefecture were 65%, 11%, and 5%, respectively. Therefore, there is no significant difference between the production values of the two regions and that of the ratio inside and outside the region.

However, the effects of other industries on production differ between the two prefectures. Figure 3 and 4 show the production during the M&C and O&M stages excluding direct activities (Table 1 and Nos. 1–11). First, we focused on the M&C stage. The inside effects are characterized by relatively large impacts on the “Commercial,” “Car maintenance/machine repair,” “Other business services,” and “Road transportation” segments, which together come to over 1,000 million yen. The "Commercial" sector is the effect of the trading materials and parts required for construction. "Car maintenance/machine repair" and "Other business services" sectors include maintenance and plant engineering of machines used at construction sites. “Road transportation” is an essential industry to support these activities. The difference between the two prefectures is that the effects of the three sectors in Kumamoto “Pig iron, crude steel, steel products,” “Fabricated constructional and architectural metal products” and “Miscellaneous metal products” are less than 200 million yen compared to Akita. On the other hand, the effects of “Industrial electrical equipment” are 200 million greater in Kumamoto Prefecture than in Akita Prefecture. Additionally, service sectors such as “Commercial,” “Car maintenance/machine repair,” and “Other business services” have a large economic effect, but the difference between the two prefectures is small. At the O&M stage, the four sectors of “Finance/insurance,” “Car maintenance / machine repair,” “Other business services,” and “Commercial” have a greater effect than 1,000 million yen. In particular, the effect of finance and insurance has the biggest impact on other sectors in the prefecture due to the impact of insurance required for operations. However, Akita Prefecture is approximately 400 million yen larger. This is because of the difference in the scale of the industry. Additionally, although this study assumed a lifetime of 40 years, this difference will increase if the product is operated for a longer period. In addition, the effects of the “Non-metal minerals” and “Pig iron, crude steel, steel products” sectors were shown as the effects of the resources required for the additional drilling of geothermal power production wells and reduction wells.

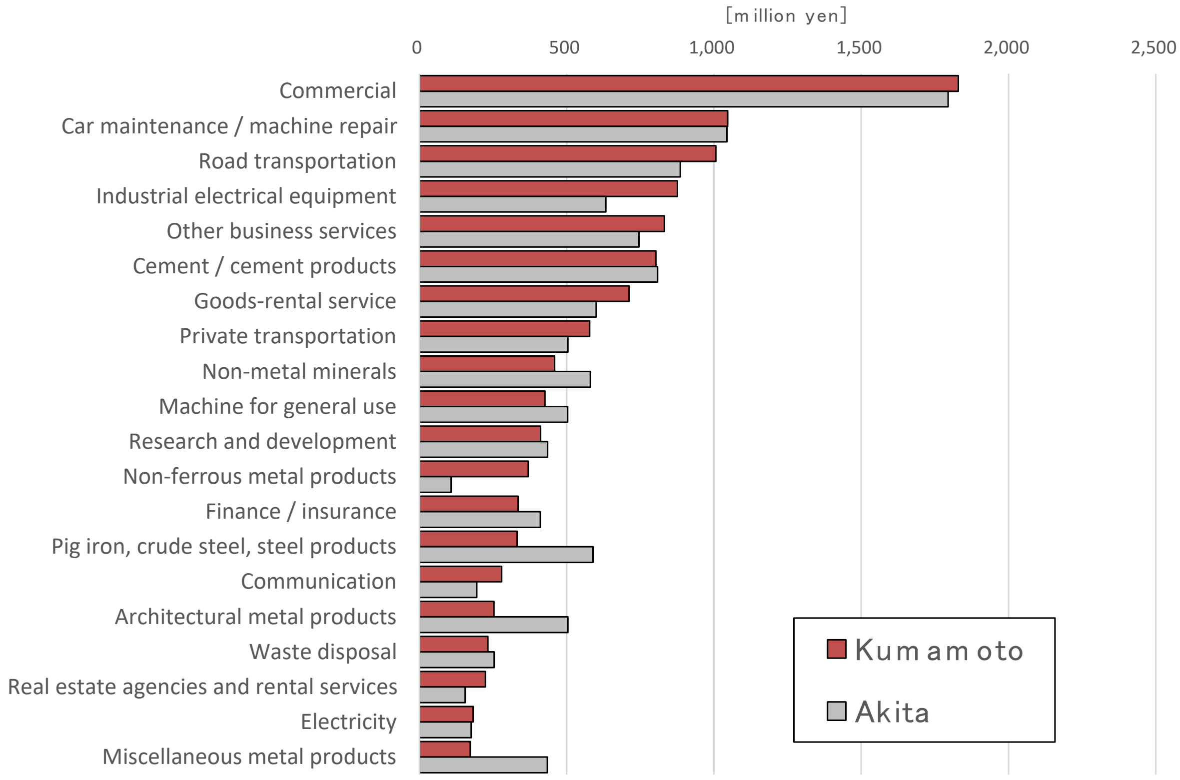

Figure 3: M &C production inside, except for direct activities (Table 1 and Nos. 1–10)

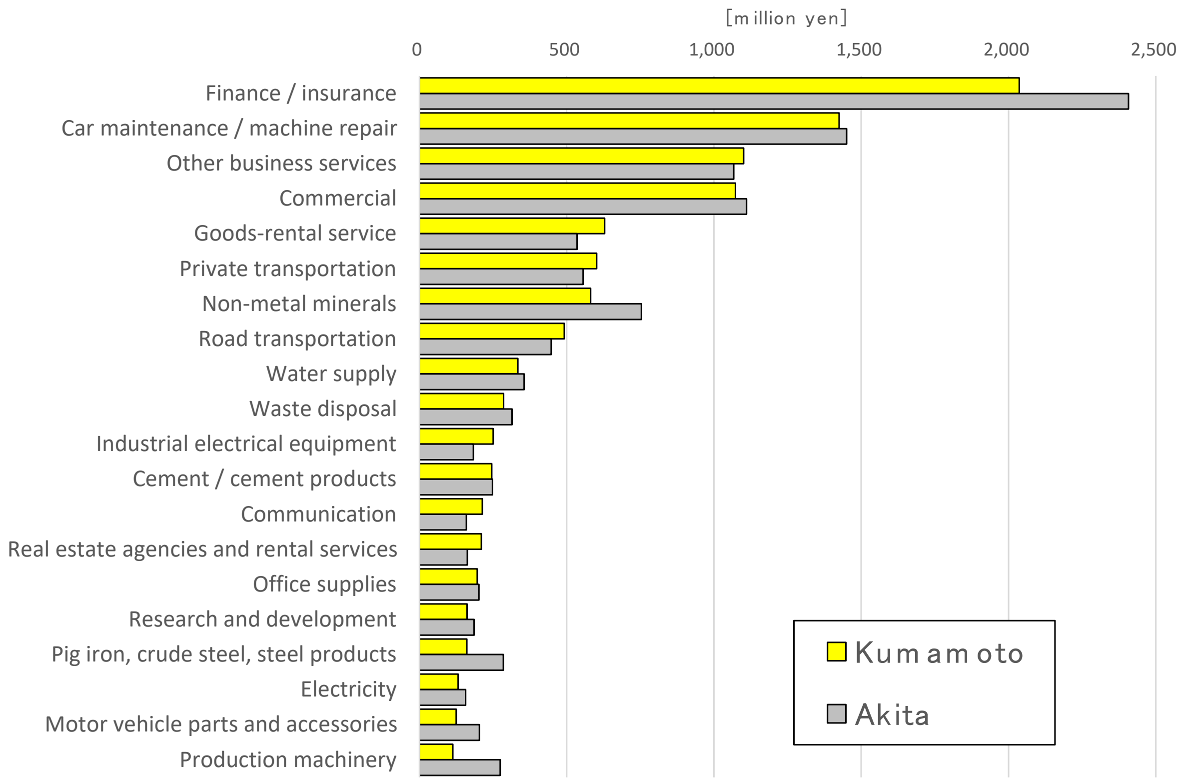

Figure 4: O&M production inside, except for direct activities (Table 1 and No. 11)

4. CONCLUSION

This study analyzed the impact of the introduction of renewable energy inside and outside regions in Japan in pursuit of a versatile and simple reporting and prediction for geothermal energy generation. As a result, the following issues were identified.

- By adopting an estimation method based on the publicly available IO table and information on renewable energy, it was shown that the method of analysis could reflect the characteristics of the regional industrial structure and individual technologies had become possible. The method adopted in this study was a versatile method that could be applied to any region of the world if there are two or more input–output tables, a national version and a regional version. Additionally, by comparing the results of the Akita and Kumamoto Prefectures, it is clearly necessary to reflect the characteristics of the industrial structure of the region. This makes it possible to contribute to the decision-making of regional energy systems, even in situations where social and technical information is extremely limited. The analysis and results make it possible to visualize quantitatively which part of the industrial structure of the region will bring benefits, which is useful when explaining (promoting understanding) to local stakeholders.

- As an impact on the local industry of geothermal energy generation, indirect effects are expected in the sectors related to plant engineering for equipment maintenance, commercial, and transportation that make intermediate transactions. This is an expected effect when introduced in any region of the country. In particular, geothermal energy generation is expected to have continuous economic effects at the O&M stage because it has indirect effects not only for equipment maintenance and repair, but also for additional excavations. However, the effects of machinery, equipment, and raw materials are temporary during the M&C stage; they are strongly dependent on the industrial structure of the region when new technologies are introduced.

- This study estimated only the economic effects of geothermal energy generation. However, it is still necessary to compare it with the results of wind and solar energy generation to provide information that contributes to technology selection. In addition, the method of this research can be applied to value-added and employment analyses. Hence, we plan to address these issues in the future.

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