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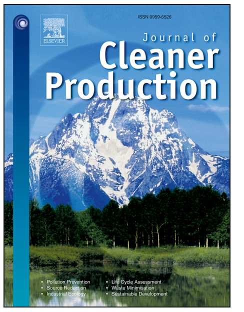

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Life Cycle Employment Effect of Geothermal Power Generation Using an Extended Input-Output Model: The Case of Japan

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Abstract

The present paper evaluates the employment impact of introducing geothermal power generation on Japanese society. An extended input-output table is created for estimating not only direct employment but also the indirect effect associated with geothermal power generation. Our originality lies in the use of published financial statements data for estimating goods and services required for the newly formed sector of geothermal power generation. This assures reliability and transparency of the geothermal power generation input structure estimation. The estimated embodied employment intensity shows that the electricity demand for geothermal energy can generate employment of 0.89 person-years per GWh through the five life-cycle stages of resource survey, manufacturing, construction, operation and maintenance, and disposal. The employment created in the operation and maintenance stage accounts for 66% of the total, indicating that geothermal power generation can generate long-term employment opportunities in service sectors. On the other hand, a large portion of the total employment for both wind and PV power generation is temporary and created in industrial sectors at the manufacturing and construction stages. The present study reveals

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that there is a distinctive difference in terms of employment effect of geothermal in comparison with wind and PV power generation. It is further observed that 86% of the total employment is domestic to Japan, higher than the domestic ratios of wind and PV power generation.

Keywords: Disaggregation; Embodied employment intensity; Geothermal power generation; Input-output table; Renewable energy

1. Introduction

In the aftermath of the Great East Japan Earthquake that occurred in March 2011, the shape of the entire energy demand and supply systems, in both the short- and long-term, has become an urgent issue for Japanese society. Of the various energy technologies available, renewable energy technologies are considered promising and are expected to play an important role in improving energy self-sufficiency and mitigating carbon dioxide (CO_2) emissions. Since July 2012, the Japanese government has implemented a feed-in-tariff (FIT) scheme (METI, 2012) for renewable energy sources such as geothermal, wind, photovoltaic (PV), small hydro and biomass power generation. The main purposes of FITs are to improve energy self-sufficiency, to reduce CO_2 emissions and to stimulate Japanese industries and local economies by the implementation of renewable energy sources.

There is a growing interest in geothermal energy as a renewable energy source because of the current FIT scheme. Currently, Japan operates 20 geothermal power generation plants with total capacity of 540 MW, which only accounts for 2.3% of its total power plant capacity in 2012 (IEA, 2012). However, Japan is reported to have the third-largest global geothermal resource potential (IEA, 2012). Geothermal energy can provide a stable power supply in comparison with other renewable energy sources such as solar and wind power; hence, it has attracted recent attention as an important renewable energy option in Japan.

The environmental impacts of geothermal power generation have been extensively analyzed in Japan. Studies have examined geothermal reservoirs affected by the operation of power plants (Muraoka et al., 1998; Yahara and Tokita, 2010), and conducted landscape assessments of power plants (Osawa, 1986; Kumagai and Yanase, 1985). Other studies undertook a life cycle analysis from the viewpoints of greenhouse gas emissions (Hondo, 2005) and other environmental stressors (Takahashi et al., 2013). Further studies investigated the social acceptance and economic characteristics of geothermal power generation. Kubota et al. (2013) analyzed dominant barriers to developing geothermal power generation based on data from interview surveys. Iikura (1996) estimated the cost of generating geothermal power based on assumed capacity factors and the expected construction costs. Adachi (2011) assessed its business profitability using internal rate of return (IRR) from the power generating cost, considering both equipment scale and natural conditions. To the best of the authors' knowledge, however, such socio-economic studies all focus on a plant or site level and there is no published peer-reviewed paper dealing with the impacts of investments in geothermal power generation on a national or local scale in Japan.

The present study aims at analyzing socio-economic impacts associated with the introduction of geothermal power generation on the Japanese economy. Specifically, the employment effect over the life cycle of geothermal power generation was analyzed based on an input-output (IO) table that was extended by the authors.

Section 2 of the paper provides an overview of the previous studies that investigated the employment effects of renewable energy technologies using IO methods. Section 3 explains how our extended IO table was created from the original IO table for Japan. The methods used to analyze the employment effect over the life cycle are described in Section 4, and the employment impact of geothermal power generation is presented in Section 5. The main findings are concluded in the final section, together with way forward of this research.

2. Quantification of employment effects

The employment effect can be classified to direct and indirect measures. Direct employment is the employment directly related to the production of products or services and there are some studies that assessed the direct employment effect associated with renewable energy technologies (Blanco and Rodrigues 2009; Valente et al. 2011). Indirect employment refers to the employment created in up-stream provision of inputs of products or services. IO methods are useful to estimate the macro-economic effects of products or services because they take both direct and indirect effects into consideration. IO methods provide an effective framework for quantifying jobs created by the introduction of renewable energy technologies. Balance of the IO table is represented by the following equation (1) and by deforming the equation (1), production $\boldsymbol{X}$ can be computed by equation (2). As shown in equation (3), employment ($\boldsymbol{L}$) can be estimated by using the employment coefficient ($\widehat{\boldsymbol{\ell}}$).

$$\boldsymbol{AX} + \boldsymbol{f} = \boldsymbol{X} \tag{1}$$

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\ \boldsymbol{f} \tag{2}$$

$$\boldsymbol{L} = \widehat{\boldsymbol{\ell}}\ (\boldsymbol{I} - \boldsymbol{A})^{-1}\ \boldsymbol{f} \tag{3}$$

Where $\boldsymbol{L}$ is the direct and indirect employment vector, $\widehat{\boldsymbol{\ell}}$ is the diagonal matrix of employment coefficient by employment table, $\boldsymbol{I}$ is the unit matrix, $\boldsymbol{A}$ is the input coefficient matrix by IO, and $\boldsymbol{f}$ is the final demand vector representing the detailed cost of power generation technologies.

Several studies have evaluated the employment impacts of introducing renewable energy technologies using the conventional IO method. Tourkolias and Mirasgedis (2011) estimated the benefits of job creation in Greece associated with construction and operation of renewable energy technologies such as wind, PV, hydro, geothermal and biomass. Markaki et al. (2013) calculated the employment created by green investments in renewable energy technologies in the Greek economy. Delivand et al. (2012) and Silalertruksa et al. (2012) used IO table to assess the employment effect attributed to biomass feedstocks for energy use in Thailand. Caldés et al. (2009) estimated the employment attributable to the construction of solar thermal power plants in Spain. Ziegelmann et al. (2000) estimated the employment effect in Germany by the introduction of solar thermal and photovoltaic energy systems. These studies focused on national employment impacts; others have analyzed employment impacts at a local level. For example, Lesser (1994) focused on geothermal power plants in Washington State, in the United States. He analyzed the employment, wage and income effect using a regional IO table for Washington State based on detailed technical and employment information extracted from a company survey and previous domestic cases.

Although IO methods are useful because of their broad economic approach, they can only be undertaken under specific assumptions (Hondo et al., 2002). One such assumption is the homogeneity assumption that postulates that each IO sector produces a single product and has a single input structure. The use of the conventional IO method leads to an aggregation error because of this homogeneity assumption. For example, the electricity sector generally includes a mix of several power generation technologies; hence, the average of these is included in the input structure for this sector. But an input structure of a renewable power technology differs from that for the electricity sector. Thus, the electricity sector needs to be disaggregated to more appropriately estimate the jobs created by the operation of renewable energy technologies.

To accurately analyze renewable energy technologies an extended IO table can be created by adding new sectors related to renewable energy technologies based on detailed technical and employment data. It is both difficult and time-consuming to gather such information by survey; hence, there are few examples of extended IO tables for assessing renewable energy technologies. Ciorba et al. (2004) evaluated the macro-economic impact of producing PV modules by adding an ad-hoc PV sector to the existing Moroccan IO table. Lehr et al. (2008, 2012) analyzed the impact on the German labor market using their extended IO table that was created from the results of a domestic company questionnaire survey on renewable energy.

While the employment effects of such examples are representative of the situation in the originating countries, the results cannot be directly transferred to the Japanese economy. Job ratios (in terms of jobs per GWh or jobs per MW installed) should not be used as evidence of job creation unless using a study specific to the region and technology under discussion (Lambert and Silva, 2012). The appropriate estimation of job creation requires detailed data reflecting the actual conditions of the regions or countries where the renewable energy technologies are deployed. Therefore, to analyze the employment effects in Japan, it is essential to use data and information on

Japanese renewable energy technologies.

Two studies investigated the employment effects of renewable energy technologies on the Japanese economy using the IO table. The Ministry of the Environment (MoE) (2009) estimated the employment effects for geothermal, wind, PV, small hydro and biomass power generation technologies using the 2000 Japanese IO table. However, the technical characteristics of renewable energy technologies were not sufficiently reflected in this study because an IO table comprising only 104 sectors was used in the analysis. In addition, it only estimated job creation in the manufacture and construction of power plants, and did not account for jobs created during the operation and maintenance (O&M) and disposal stages. Last but not least, it should be noted that there is no distinction between the power generation technologies in the construction of electric power facilities and electricity sectors of the conventional IO table; all the properties inherent to each power generation technology are aggregated to one so that we can only analyze the macro-economic effects of averaged power generation technology regardless of thermal power or renewables. To comprehensively deal with these shortcomings, Matsumoto and Hondo (2011) created an extended IO table with 413 sectors, based on the 2005 Japanese IO table (MIC, 2011)[1], by disaggregating several sectors related to wind and PV power generation from the original IO table. Using the extended IO table, Matsumoto and Hondo analyzed the employment effects of wind and PV power generation over the life cycle, and demonstrated that an extended IO table had benefits over the original IO table. Nevertheless, their employment effect analyses were limited to wind and PV power generation. To estimate the socio-economic impacts of geothermal power to the Japanese economy, detailed geothermal power technological information should be precisely reflected to conduct an analysis using IO tables.

[1] The latest 2005 Japanese Ministry of International Affairs and Communications IO table comprises 520 rows and 417 columns in rectangular matrix from for the basic sector classification and some of these sectors are usually aggregated to an n-dimensional square matrix for analyses. It also offers nine supplementary tables including the import table and employment table to provide detailed pieces of information to specific economic subjects.

3. Creating an extended input-output table

In the present study, an extended IO table was created based on the Japanese IO table of 2005 (MIC, 2011) to analyze the employment effects of geothermal power generation technologies. As shown in Table 1, the extended IO table includes five new sectors related specifically to geothermal power generation (in addition to the 401 sectors in the original IO table in square-matrix form): “geothermal resource survey”, “production well construction”, “injection well construction”, “steam transport pipe construction”, and “geothermal power”. These sectors were selected because the specifications of a geothermal power plant (e.g. the number of and the depth of wells) are significantly dependent on the natural conditions of the target site (Bertani, 2005), and their investment costs significantly affect to the total cost of a geothermal power plant.

3.1. Input structure of new sectors

The five sectors related to geothermal power generation have been disaggregated from the “construction of electric power facilities” and the “electricity” sectors of the original IO table.

3.1.1. Plant construction related sectors

The input structure of the four sectors related to construction of a geothermal power plant (geothermal resource survey, production well construction, injection well construction, and steam transport pipe construction) was determined based on the 50 MW model plant assumed in the MoE Study of Potential for the Introduction of Renewable Energy FY2010 (MoE, 2011) and detailed data on existing plants obtained by interviewing several related companies. Annual production figures for 2005 were estimated for the resource survey using annual investment data (NEDO, 2006), and for the other three sectors using the MoE report (MoE, 2011), the PREC report (PREC, 2011), and interview data.

3.1.2. Geothermal power sector

The input structure for the final new sector, electricity generated by geothermal power, was determined from data extracted from the published financial statements (statements of income and detailed schedule of electricity business cost) included in the securities reports of the four electricity power companies that operate geothermal power plants in Japan (Hokkaido, 2011; Tohoku, 2011; Tokyo, 2011; Kyushu, 2011). Making use of open data such as securities reports can reduce uncertainty and improve reliability of the input structure estimates compared with previous studies (Ciorba et al., 2004; Lehr et al, 2008; Matsumoto and Hondo, 2011) that used data obtained by interviews.

Published financial statements include cost data for power plant operation. For example, breakdowns of about 40 expense items for each of its five power generation categories (hydro, thermal, nuclear, internal combustion and geothermal powers) are provided in the published financial statement of Tokyo Electric Power Company (2011). The Japanese IO table assumes that the sector classifications are based on activities relating to the types of goods and services, hence, inputs relating to the geothermal power sector were determined by allocating these cost data to their correspondent sectors of IO table. The gross domestic product deflator (CAO, 2012) was used to adjust costs to 2005 rates.

3.2. Output structure of new sectors

The capital items produced in the four construction related sectors (resource survey, production well construction, injection well construction and steam transport pipe construction) have a lifespan of many years. Thus, it is assumed that all the outputs from these sectors are allocated to the “fixed capital formation of final demand” sector in accordance to the Japanese IO table rule. The output for the disaggregated electricity sectors shown in Table 1 (i.e. nuclear, thermal, hydro, and geothermal), is assumed to have the same price and calculated by multiplying the ratio of each power generation (JEA, 2009) by the original output of electricity sector.

3.3. Input and output structure of the disaggregated sectors

The input and output amounts for the disaggregated sectors (construction of electric power facilities and electricity) can be calculated by subtracting the estimated input and output amount of the newly formed sectors from those of the original sectors (before disaggregation), as described by equations (4) and (5).

$$S'_{j,k} = S_{j,k} - S_{j,k+1} \tag{4}$$

$$T'_{j,k} = T_{j,k} - T_{j,k+1} \tag{5}$$

Where $S_{j,k}$ and $T_{j,k}$ are the input and output amount from sector j to sector k before disaggregation, $S_{j,k+1}$ and $T_{j,k+1}$ are the input and amount from sector j to newly formed sector $k+1$ (disaggregated from sector k), and $S'_{j,k}$ and $T'_{j,k}$ are the input and output amount of sector j to sector k after disaggregation.

3.4. Estimating the import and employment coefficients

The import coefficients represent the amount of imports per domestic demand. By using this factor, it is possible to analyze the domestic production and job creation. The import coefficients for existing sectors are estimated based the 2005 IO table (MIC, 2011). All the production activities of the five newly formed sectors in the present study are done domestically; hence, the import coefficients of these sectors are set to zero.

The employment coefficients that represent the number of employees per production can be calculated by equation (6). In the present study, the estimation method differs for the original sectors and newly formed sectors. The employment coefficients for existing sectors are estimated using the 2005 employment table (MIC, 2011) published as a supplement to the IO table. This estimation is a general method that reflects the average goods and services transactions of the entire individual industry sector. In contrast, the employment coefficients for the five newly formed sectors are estimated from the amount of employment and production assumed for a geothermal power plant with a 50 MW capacity (MoE, 2011).

Equation (7) estimates the employment amount associated with the four new sectors related to plant construction (i.e. geothermal resource survey, production well construction, injection well construction and steam transport pipe construction). The employment amount for sector of electricity by geothermal power generation can be calculated by equation (8), originally defined by (MoE, 2011).

Table 2 shows the import coefficients and the employment coefficients of the newly formed sectors. It should be noted here that the form of employment created (e.g. temporary or secure jobs) are not taken into account in the present estimation.

$$Ec = Ev / Pv \tag{6}$$

$$Ev = Md / Wd \tag{7}$$

$$Ev = 0.0002 \bullet C + 4.5327 \tag{8}$$

Where Ec is the employment coefficient (man-years/million yen), Ev is the employment amount (man-years), Pv is the production (million yen), Md is the number of man-days required (man-days), Wd is the annual working days (days/year) in Japan (JILPT, 2012) and C is the installed capacity of a geothermal power plant (MW).

4. Analysis of life cycle employment effects

This section describes how the life cycle employment effects are evaluated using the extended IO table created.

4.1. Estimating domestic and overseas employment effect

The direct and indirect employment that is induced domestically and abroad by the introduction of geothermal power generation can be estimated using equations (9) – (11).

$$\boldsymbol{L} = \widehat{\boldsymbol{\ell}'} \, (\boldsymbol{I} - \boldsymbol{A}')^{-1} \; \boldsymbol{f}' \tag{9}$$

$$\boldsymbol{L_d} = \widehat{\boldsymbol{\ell}'} \, \left[\boldsymbol{I} - \left(\boldsymbol{I} - \widehat{\boldsymbol{M}'}\right)\boldsymbol{A}'\right]^{-1} \left(\boldsymbol{I} - \widehat{\boldsymbol{M}'}\right) \boldsymbol{f}' \tag{10}$$

$$\boldsymbol{L_o} = \boldsymbol{L} - \boldsymbol{L_d} \tag{11}$$

Where $\boldsymbol{L}$ is the direct and indirect employment vector, $\boldsymbol{L_d}$ is the domestic employment vector, $\boldsymbol{L_o}$ is the overseas employment vector, $\widehat{\boldsymbol{\ell}}'$ is the diagonal matrix of employment coefficient by extended IO, $\boldsymbol{I}$ is the unit matrix, $\boldsymbol{A'}$ is the input coefficient matrix by extended IO, $\boldsymbol{f'}$ is the final demand by detailed cost data and $\widehat{\boldsymbol{M}}$ is the diagonal matrix of import coefficient by extended IO.

4.2. Estimating embodied employment intensity

The present study estimates the embodied employment intensities by resource survey, manufacturing, construction, O&M and disposal stages. It should be noted here that the employment created for these stages is not concurrent. The resource survey stage, specific to geothermal power generation, can last up to ten years. This is because a longer time is required for conducting environmental impact assessments in Japan before proceeding with construction than in other countries. Following that initial stage, temporary employment is generated during the manufacture and construction of the plant (creating physical capital). The O&M stage offers ongoing, regular employment. Finally, by considering the effect of disposal stage, the employment effect over the life cycle of a geothermal power plant can be estimated.

The amount of employment at each life cycle stage is calculated by giving the final demand ($\boldsymbol{f'}$), such as price of goods and services required, to equations (9) and (10). For example, the employment generated at resource survey stage ($\boldsymbol{L_s}$) can be computed by equation (12).

$$\boldsymbol{L_s} = \widehat{\boldsymbol{\ell}}' (\boldsymbol{I} - \boldsymbol{A}')^{-1} \ \boldsymbol{f'_s} \tag{12}$$

Where $\boldsymbol{f'_s}$ is the final demand of this stage. In the same manner, the employment at manufacturing, construction, O&M, and disposal stages ($\boldsymbol{L_m}, \boldsymbol{L_c}, \boldsymbol{L_o}, \boldsymbol{L_d}$) can be calculated by equations (13) – (16) and final demands of each stage ($\boldsymbol{f'_m}, \boldsymbol{f'_c}, \boldsymbol{f'_o}, \boldsymbol{f'_d}$) that are given in Table 3.

$$\boldsymbol{L_m} = \widehat{\boldsymbol{\ell}}' \, (\boldsymbol{I} - \boldsymbol{A}')^{-1} \; \boldsymbol{f'_m} \tag{13}$$

$$\boldsymbol{L_c} = \widehat{\boldsymbol{\ell}}' \, (\boldsymbol{I} - \boldsymbol{A}')^{-1} \; \boldsymbol{f'_c} \tag{14}$$

$$\boldsymbol{L_o} = \widehat{\boldsymbol{\ell}}' \, (\boldsymbol{I} - \boldsymbol{A}')^{-1} \; \boldsymbol{f'_o} \tag{15}$$

$$\boldsymbol{L_d} = \widehat{\boldsymbol{\ell}}' \, (\boldsymbol{I} - \boldsymbol{A}')^{-1} \; \boldsymbol{f'_d} \tag{16}$$

Then the embodied employment intensity is estimated by dividing the total amount of employment by the total amount of electricity produced during in the lifetime of the plant (Q kWh per year). The former term is calculated as the sum of equations (12)-(16) and the latter is computed by equation (17).

$$Q = C \bullet 365 \bullet 24 \bullet f_l \bullet (1 - \eta) \bullet T \tag{17}$$

Where C is the generation capacity (kW), f_l is the capacity factor, η is the internal consumption rate and T is the lifetime of the power plant (years). Table 4 gives the parameters used to calculate Q in the present study.

5. Results and discussion

Fig.1 depicts the embodied employment intensity of geothermal power generation. The employment effects by resource survey, manufacturing, construction, O&M, and disposal stages were calculated as 0.0038, 0.084, 0.16, 0.59 and 0.017 person-years per GWh, respectively. In relation to the employment amount, the resource survey, manufacturing, construction and disposal stages provide temporary employment, whereas the O&M stage requires continuous work during the plant’s lifetime. Fig. 1 shows that the O&M stage can generate 66% of the total employment; hence, geothermal power generation creates long-term employment through its O&M stage.

5.1. Employment by sectors

Fig.2 shows the direct and indirect employment effect by each sector related to geothermal power generation. Service sectors (repair of machine, wholesale trade and other business services) and construction sectors (construction of electric power facilities, steam transport pipes, production wells and injection wells) have a greater employment effect than sectors producing the basic components (transformers and reactors, turbines and rotating electrical). Employment created in the "repair of machine" and "other business services" sectors amounts to 0.11 and 0.057 person-years per GWh, respectively, most of which are provided by maintenance and repairs of geothermal power plants in the O&M stage. Besides, in some construction sectors (i.e. production well and injection well construction), employment is created not only in the construction stage but also in the O&M stage due to stable power generation. In sum, the results reveal that frequent equipment maintenance, repairs and additional construction of wells (needed for stable power generation) have large impacts on the total amount of employment created by geothermal power generation. It is further observed that geothermal power generation indirectly induces large employment in the service sectors (such as wholesale trade, worker dispatching services and road freight transport service) that seem to have a weak relationship with electricity.

5.2. Domestic and overseas employment

Fig.3 shows the amount of domestic and overseas employment created, with domestic employment accounting for 86% of the total employment. For each life cycle stage, the domestic ratios are resource survey (91%), manufacturing (72%), construction (90%), O&M (86%) and disposal (92%). The manufacturing stage has a low domestic employment ratio in comparison with the other stages because most of the materials and parts required are imported.

5.3. Uncertainties relating to embodied employment intensity

The activity of four sectors (geothermal resource survey, production well construction, injection well construction and steam transport pipe construction) is specific to geothermal power generation. The specifications required for these sectors vary according to the site conditions. For example, for geothermal power plants around the world, the number and depth of both production and injection wells differ, given the same power plant capacities (MoE, 2011; Bertani, 2005; Bertani, 2012). Moreover, slant drillings are required for the wells in some geothermal power plants (METI, 2009), the construction of which is more costly than vertical drillings. Therefore, to take into account the uncertainties inherent to geothermal power generation in terms of costs and eventually inventories, the uncertainties of the embodied employment intensity were examined by assuming the fluctuations in final demand of the four sectors (Fig. 4.).

Plus or minus 50% in the final demand of the four sectors mentioned above will lead to embodied employment intensity changes from 0.78 to 1.00 person-years per GWh. The employment required for daily O&M is large (0.51 person-years per GWh); however, the embodied employment intensity fluctuates by only approximately 10% with the uncertainties attributed to site conditions of geothermal power plants.

As described in Section 3, the input structures of the four sectors (geothermal resource survey, production well construction, injection well construction and steam transport pipe construction) were determined by interviews with several companies related to geothermal power generation. Although uncertainties are attached with the use of data obtained by interviews, the employment created directly and indirectly by these four sectors only accounts for 25% of the embodied employment intensity. Data from securities reports are used for the determination of input structure of the O&M stage of Fig. 4 (or geothermal power sector) and a better input structure reliability is assured for this stage than for the above four sectors. The O&M employment accounts for the greatest fraction of the embodied employment intensity; thus, the use of securities reports for estimating the input structure in this study contributes to the reliability of the employment effect of geothermal power generation.

5.4. Comparison with wind and PV power generation

To understand the employment creation characteristics of geothermal power generation among the renewable energy sources, it is necessary to compare the embodied employment intensity of geothermal power generation with those of wind and PV power generation as estimated by Matsumoto and Hondo (2011). It must be noted here that their estimations for wind and PV power generation do not include the disposal stage in the system boundary due to data restrictions. As assumed in Table 3 that IEA (2010) estimates the disposal costs of wind and PV be 5% of the total construction cost, however, it is deemed that the employment effects of wind and PV associated with their disposal stage be relatively small in comparison with the other stages. Moreover, the assumed capacities of wind and PV power were 2,000 and 3.5 kW respectively, lower than that of the model geothermal power plant of 50 MW in this study. Therefore, we presumed that the employment created at the disposal stage of wind and PV is small, and that the embodied employment intensities can be approximated by their estimations.

(1) As shown in Figs. 5 and 7, wind and PV power generation create 42% and 30% of the total employment at the O&M stage, while Fig. 1 shows that geothermal power generation offers 66% of the total at this stage (58% from daily O&M and 8% from additional construction of production wells, injection wells and steam transport pipes). Even if considering the uncertainties arising from site conditions as analyzed in Section 5.3, it can be said that geothermal power generation relatively generate long-term employment opportunities in the O&M stage. On the other hand, wind and PV power generation can create a lot of short-term employment in the manufacturing and construction stages.

(2) As can be confirmed from Fig. 2, all the top three sectors (machine repair, wholesale trade and other business services) that create employment from geothermal power belong to service industry. The top two sectors creating employment for wind power (Fig. 6) are electricity generated by wind and construction of wind turbines, followed by service sectors (non-life insurance and road freight transport). Employment generated by sectors related to manufacturing and construction (such as relay switches and switch boards, other electrical devices and parts, and PV installation) rank high for PV power (Fig.8). These figures demonstrate that the employment effect of the related sectors differs by renewable energy.

(3) Section 5.2 confirmed that 86% of Japanese geothermal power employment is domestic to Japan, higher than the domestic ratios of wind and PV power generation of 65%, 70%, respectively. This can be explained because the O&M stage accounts for a large percentage of embodied employment intensity for geothermal power and hence high domestic employment. Additionally, most of the components required for wind turbines are imported, thus lowering the domestic employment intensity for wind power technologies. It should be noted that the domestic employment effect by PV power might decrease if the imports of the PV panels expand.

(4) Figs. 1, 5 and 7 show that the embodied employment intensity of geothermal, wind and PV power generation is 0.89, 0.69 and 2.8 person-years per GWh respectively; however, it is important to notice that the employment effect should not be determined solely from the magnitude of these amounts. For example, the reason for the large embodied employment intensity of PV power can be explained because of the high cost of PV in 2005. In general, the lower the proficiency and dissemination rate of the technology, the higher the cost and the more employment is induced. The results of the present study provide an important indication that the employment generation structure should differ by the selection of renewable energy sources.

6. Conclusion and the way forward

To evaluate the employment impact of introducing geothermal power generation in detail, an extended IO table was created by disaggregating sectors related to geothermal power from the original 2005 Japanese IO table. The study originality lies in the use of published financial statements data. These data are freely available and are used to estimate the goods and services required in the new “geothermal power” sector for electricity generation. This assures a greater reliability and transparency of the input structure estimate compared with the use of interview data.

Geothermal power generation can create employment of 0.89 person-years per GWh throughout its life cycle. The O&M stage accounts for 66% of its total employment, indicating that geothermal power generation can provide long-term employment opportunities in service sectors. On the other hand, a large portion of the total employment for both wind and PV power generation is temporary and created in industrial sectors at the manufacturing and construction stages. The present study reveals that there are distinctive differences between employment effects of geothermal, and wind and PV power generation. It is further observed that 86% of the total employment is domestic to Japan, higher than the domestic ratios of wind and PV power generation.

The findings in the present study can be further expanded. The analyses presented here can estimate the amount of employment created by each life cycle stage. However, the quality of employment is another important aspect to evaluate. The United Nations Economic Commission for Europe Task Force on the Measurement of Quality of Employment includes security of employment, skills development and life-long learning in measuring quality of employment (UNECE, 2009). For example, the amount of employment is limited if a job requires a specific qualification or skill. The construction of additional steam transport pipes and drilling wells that are required for a stable power generation in a geothermal power plant only induces irregular and temporary jobs. Since the employment generated through the life cycle of a certain sector with skilled jobs can offer a positive socio-economic impact on society, it is preferable that the employment associated with potential renewable energy resources be evaluated in terms of security of employment (stable or temporary jobs) and skilled or unskilled jobs.

The framework of the extended IO table proposed in the present study provides a snapshot of the embodied employment generation from renewable power sources. In the future, the employment created by conventional sources of power generation will be reduced as the proportion of renewable sources increases in the total supply-mix of electricity. A drastic change to the current structure of electricity power supply will not occur in the short term. Hence, the employment impact by the selection of renewable power sources towards the entire society should be assessed considering the lead time for a good dissemination of renewable energy sources.

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Fig.1. Embodied employment intensity of geothermal power generation by life cycle stages

Fig.2. Employment by sectors for geothermal power generation

Fig.3. Domestic and overseas employment created through geothermal power generation

Fig.4. Uncertainty of the embodied employment intensity by geothermal power generation

Fig.5. Embodied employment intensity of wind power generation by life cycle stages (Matsumoto and Hondo, 2011)

Fig.6. Employment by sectors for wind power generation (Matsumoto and Hondo, 2011)

Fig.7. Embodied employment intensity of PV power generation (Matsumoto and Hondo, 2011)

Fig.8. Employment by sectors for PV power generation (Matsumoto and Hondo, 2011)

Table 1 Newly formed sectors disaggregated from the original IO table

Original sectors	Newly-formed sectors
Construction of electric power facilities	Construction of electric power facilities
	Geothermal resource survey
	Production well construction
	Injection well construction
	Steam transport pipe construction
Electricity	Nuclear power
	Thermal power
	Hydro power
	Geothermal power

Table 2 Import and employment coefficients of newly formed sectors

Newly-formed sectors	Import coefficients		Employment coefficients	
	Coefficient	Source	Coefficient	Source
Geothermal resource survey	0	PREC (2011)	0.0676	Interview
Production well construction	0	PREC (2011)	0.0350	Interview
Injection well construction	0	PREC (2011)	0.0243	Interview
Steam transport pipe construction	0	PREC (2011)	0.0233	Interview
Geothermal power	0	JEA (2009)	0.0031	MoE (2011)

Table 3 Final demands by geothermal plant life cycle stages over 30 years

2005 prices: million JPY[a]	Resource survey	Manufacturing[c]	Construction	Operation and maintenance	Disposal[d]
Turbines	0	1,328	0	0	0
Refrigerators and air conditioning apparatus	0	1,936	0	0	0
Other general industrial machinery and equipment	0	1,133	0	0	0
Rotating electrical equipment	0	965	0	0	0
Transformers and reactors	0	1,634	0	0	0
Other industrial electrical equipment	0	1,516	0	0	0
Construction of electric power facilities	0	0	3,503	0	1,458
Geothermal resource survey[b]	1,699	0	0	0	0
Production well construction	1,529	0	3,439	4,204	0
Injection well construction	510	0	3,057	3,312	0
Steam transport pipe construction	0	0	5,844	631	0
Geothermal power	0	0	0	137,598	0
Real estate agencies and managers	0	0	1,062	0	0
Total	3,737	8,512	16,906	145,743	1,458

[a] USD equivalent can be calculated using the currency rate of 110.22 JPY per USD in 2005 (World Bank, 2014).

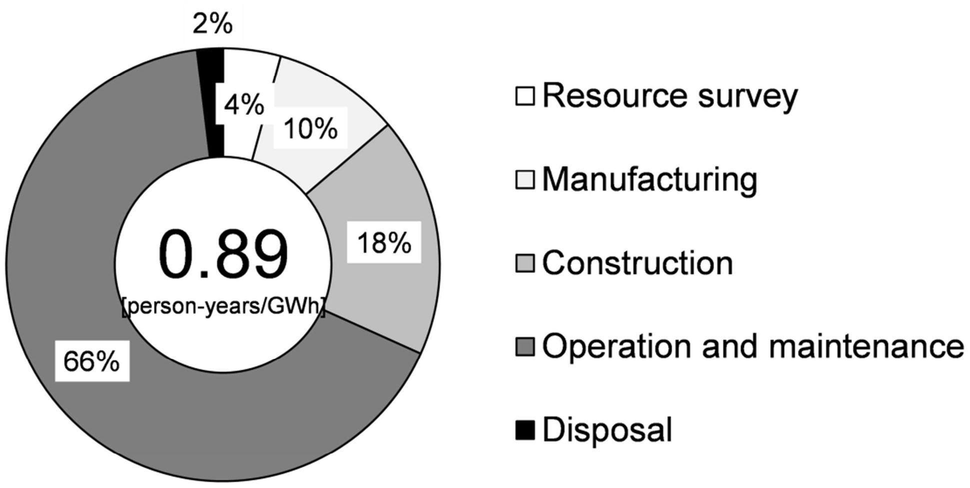
[b] Small diameter well (2,000m) comprises 7 test drilling wells, gravity survey, electromagnetic exploration, environmental research and jet test.

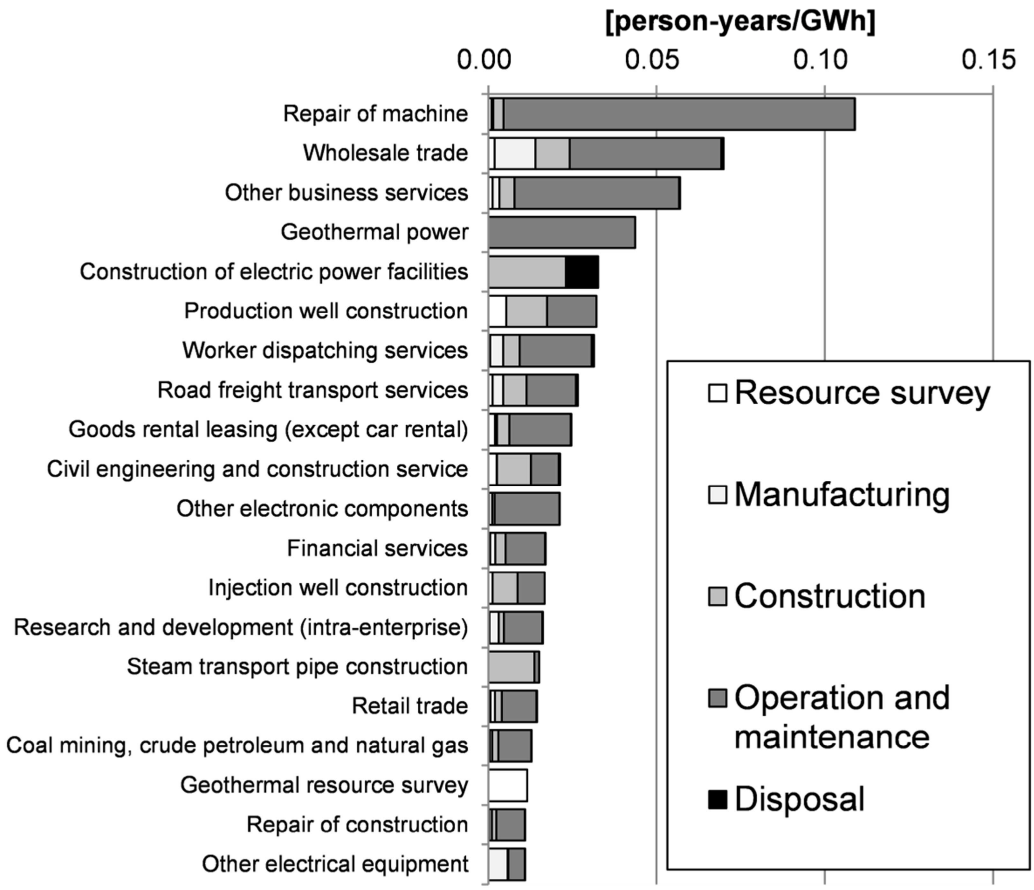
[c] Total cost of manufacturing is allocated to each sector in accordance with NEDO (2002).

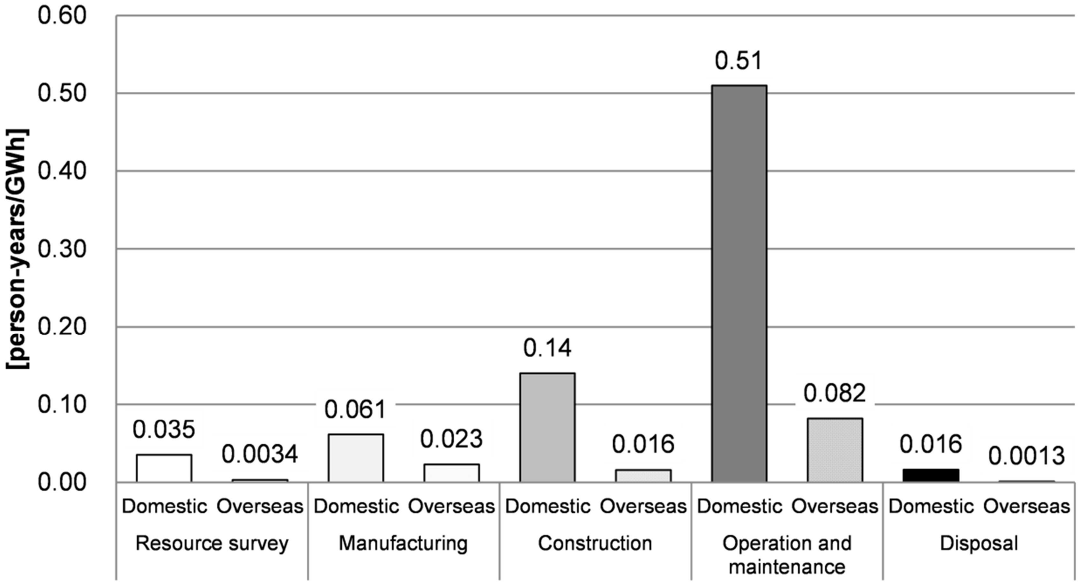
[d] Following IEA (2010), disposal cost is calculated to be 5% of the total construction cost.

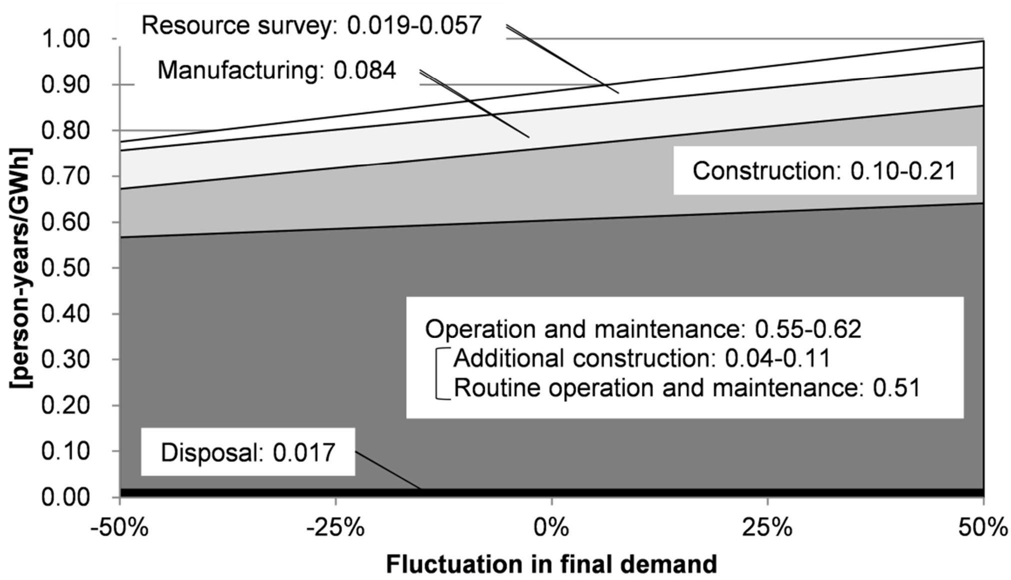
Table 4 Assumed geothermal power plant factors used in this study

Generation capacity [MW]	50
Capacity factor [%]	80
Internal consumption rate [%]	5
Lifetime [years]	30

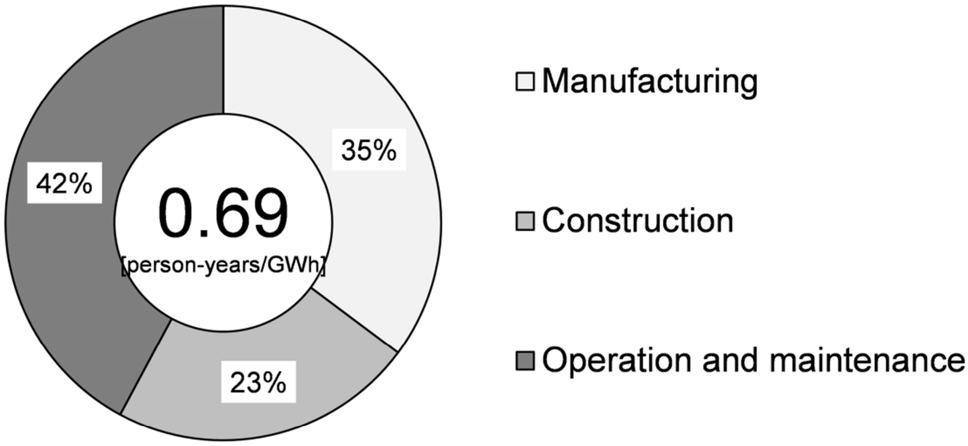

2%
4%
10%
18%
66%
0.89
[person-years/GWh]
Resource survey
Manufacturing
Construction
Operation and maintenance
Disposal


[person-years/GWh]
0.00
0.05
0.10
0.15
Repair of machine
Wholesale trade
Other business services
Geothermal power
Construction of electric power facilities
Production well construction
Worker dispatching services
Road freight transport services
Goods rental leasing (except car rental)
Civil engineering and construction service
Other electronic components
Financial services
Injection well construction
Research and development (intra-enterprise)
Steam transport pipe construction
Retail trade
Coal mining, crude petroleum and natural gas
Geothermal resource survey
Repair of construction
Other electrical equipment
Resource survey
Manufacturing
Construction
Operation and maintenance
Disposal

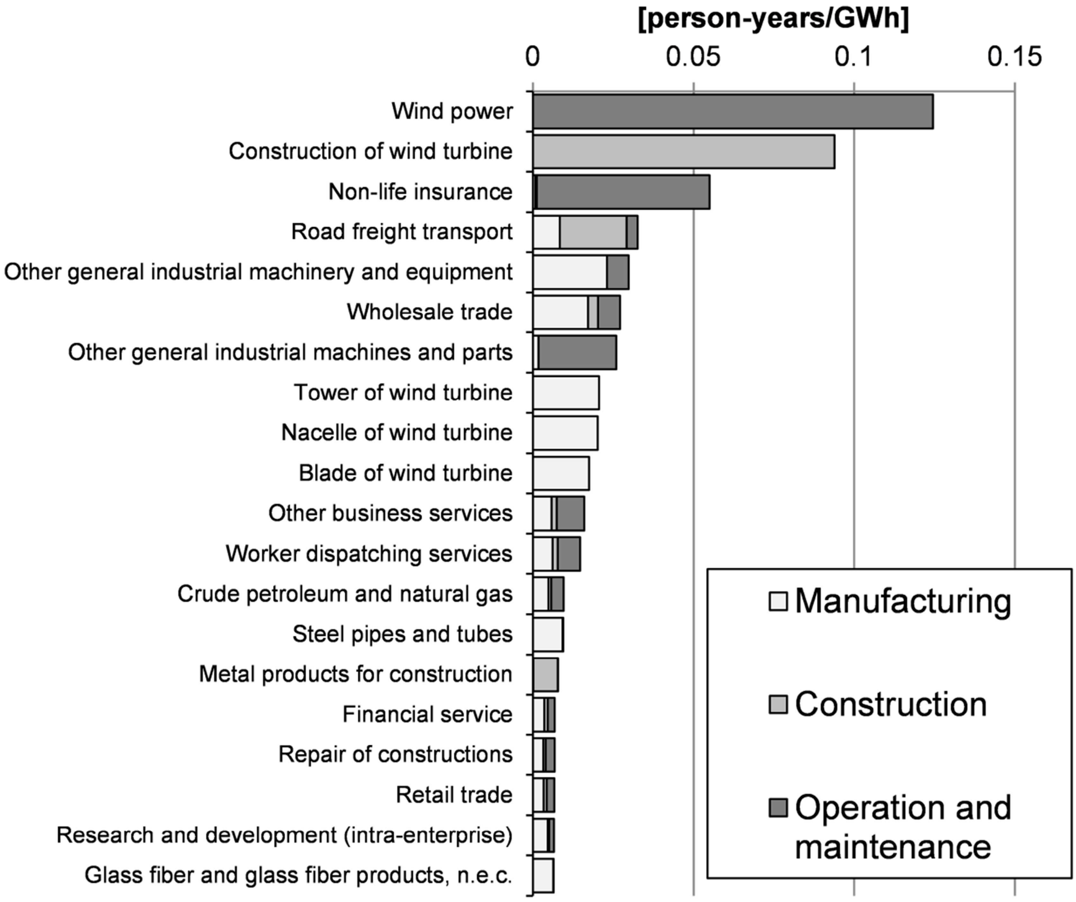

0.60
0.50
0.40
0.30
0.20
0.10
0.00
[person-years/GWh]
0.035
0.0034
0.061
0.023
0.14
0.016
0.51
0.082
0.016
0.0013
Domestic
Overseas
Resource survey
Manufacturing
Construction
Operation and maintenance
Disposal

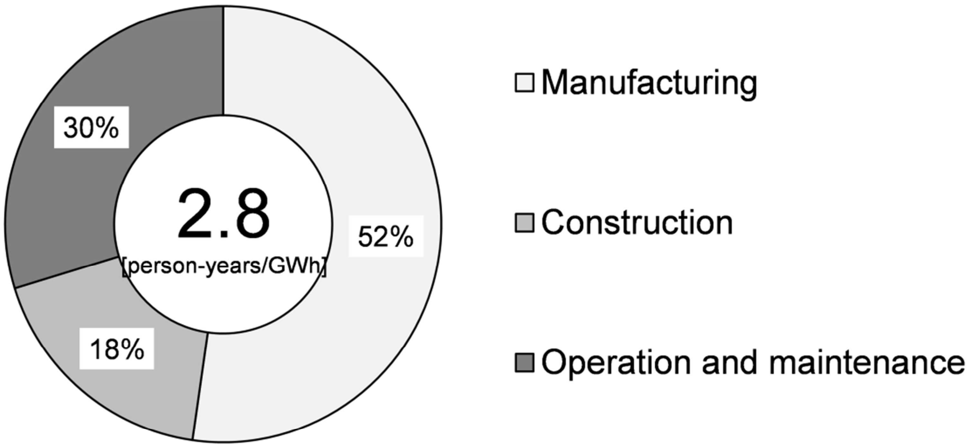


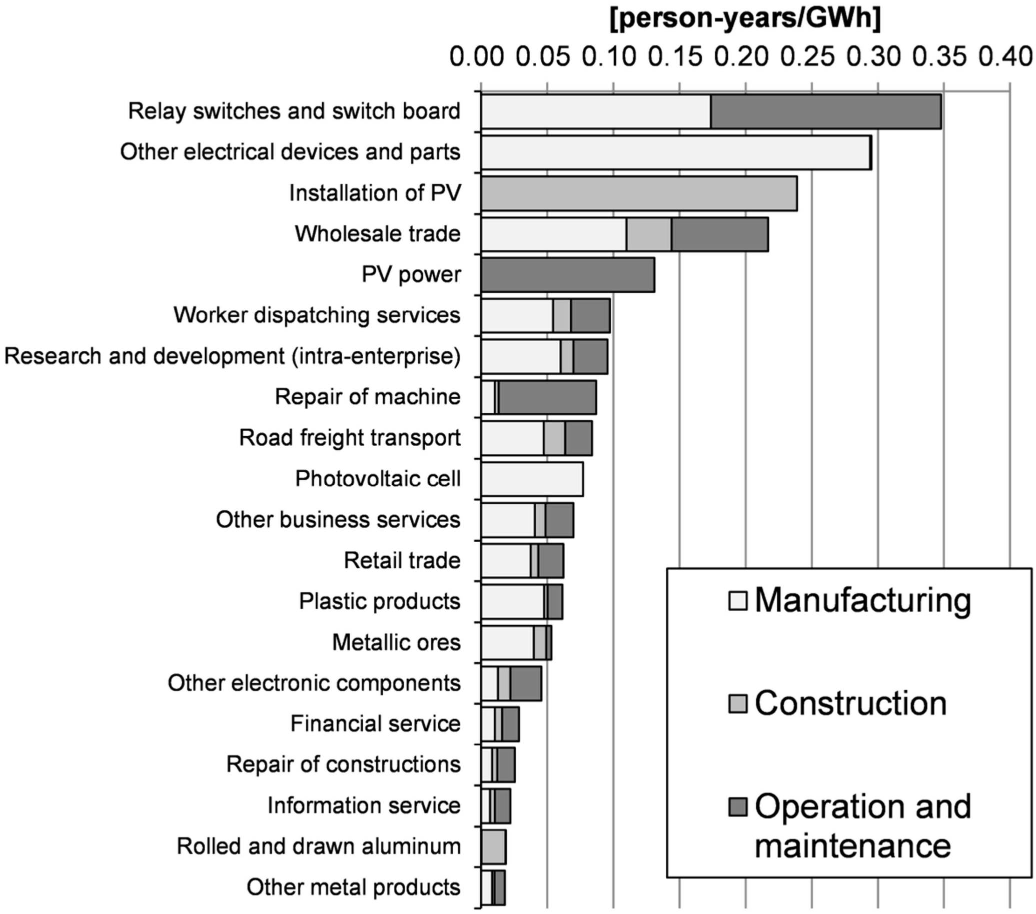
Resource survey: 0.019-0.057
Manufacturing: 0.084
Construction: 0.10-0.21
Operation and maintenance: 0.55-0.62
Additional construction: 0.04-0.11
Routine operation and maintenance: 0.51
Disposal: 0.017
[person-years/GWh]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-50%
-25%
0%
25%
50%
Fluctuation in final demand



35%
42%
0.69
[person-years/GWh]
23%
Manufacturing
Construction
Operation and maintenance


[person-years/GWh]
0
0.05
0.1
0.15
Wind power
Construction of wind turbine
Non-life insurance
Road freight transport
Other general industrial machinery and equipment
Wholesale trade
Other general industrial machines and parts
Tower of wind turbine
Nacelle of wind turbine
Blade of wind turbine
Other business services
Worker dispatching services
Crude petroleum and natural gas
Steel pipes and tubes
Metal products for construction
Financial service
Repair of constructions
Retail trade
Research and development (intra-enterprise)
Glass fiber and glass fiber products, n.e.c.
Manufacturing
Construction
Operation and maintenance


30%
2.8
[person-years/GWh]
52%
18%
Manufacturing
Construction
Operation and maintenance


[person-years/GWh]
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40
Relay switches and switch board
Other electrical devices and parts
Installation of PV
Wholesale trade
PV power
Worker dispatching services
Research and development (intra-enterprise)
Repair of machine
Road freight transport
Photovoltaic cell
Other business services
Retail trade
Plastic products
Metallic ores
Other electronic components
Financial service
Repair of constructions
Information service
Rolled and drawn aluminum
Other metal products
Manufacturing
Construction
Operation and maintenance

Highlights

- Employment intensity for the life cycle of geothermal power generation is estimated.
- An extended input-output table is created for the estimation of job creation.
- Published financial statement data are used to estimate the input structure.
- These estimates can enhance reliability and transparency of the geothermal sector.
- Geothermal power generation can offer constant employment.