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Creation and Application of the 2015 Input-Output Table for Analysis of Next-generation Energy Systems: Analysis of the Effects of Introducing Carbon Tax

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Abstract

The Institute for Economic Analysis of Next-Generation Science and Technology, Waseda University, has prepared the *Input-Output Table for Analysis of Next-generation Energy Systems* (IONGES) and has included the renewable energy sectors in the Input-Output Table of Japan's Ministry of Internal Affairs and Communications (MIC). To date, we have prepared tables for 2005 and 2011 (hereafter 2005 Table and 2011 Table, respectively) and associated reports have been prepared. We prepared an interregional table and a table with the hydrogen-related sector added to the 2005 Table. Following these tables, the 2015 IONGES was developed and summarized in this study. Carbon pricing (CP), such as a carbon tax, leads to the development of a sustainable low-carbon society, and a precise analysis of the impact of the system on each sector of the economy is essential for the design of the CP system. As an applied analysis using the 2015 IONGES, the introduction of a carbon tax as a global warming countermeasure (GWC) tax based on existing energy-related tax systems was considered, and the effect of the use of renewable energy on the new tax burden was estimated.

Keywords: Input-Output analysis, Renewable energy, Carbon pricing, Energy-related taxes, Input-Output Table for Analysis of Next-generation Energy Systems (IONGES)

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1. Research background

Input-output analysis has been widely recognized globally as a tool for comprehensively analyzing the effects of renewable energy deployment on the environment, economy, and society. For example, the development of satellite tables from the World Input-Output Database (WIOD) (Genty et al., 2012) and studies using them, such as Önder (2021) and Dietzenbacher et al. (2020), and the development of a satellite table of energy use for the Swiss's input-output table. Korea's input-output table includes hydropower and other renewable energy sectors, and Lee et al. (2021) focused on these sectors in their analysis. Mardones and Brevis (2020) extended the Chilean input-output table to include four renewable energy sectors: solar, wind, hydro, and biomass.

To comprehensively analyze the effect of introducing renewable energy in Japan, the Waseda University's Institute for Economic Analysis of Next-generation Science and Technologies developed the Input-Output Table for analysis of Next-Generation Energy Systems (IONGES), which was created by adding the renewable energy sectors to the Ministry of Internal Affairs and Communications (MICs) Input-Output Table. We have prepared 2005 (Washizu et al., 2013; Washizu, Nakano, Arai, 2015; Nakano, Arai, Washizu, 2017) and 2011 tables (Nakano and Washizu, 2020a; 2020b; Washizu and Nakano, 2021). Additionally, regarding the 2005 Table, an interregional table that divides Japan into nine regions (Nakano and Washizu, 2018; Washizu and Nakano, 2018), and a table with hydrogen-related sectors (Nakano and Washizu; 2018) were developed. The 2015 IONGES was prepared following these studies, and the results have been reported here. In addition, the 2005 and 2011 IONGES that we developed include an embedded table (showing only the renewable energy activities that occurred each year) and an assumption table (assuming that renewable energy was introduced up to the target ratio in the year 2030 listed in the "Long-Term Energy Supply and Demand Outlook" published in 2015). In the present study, we have reported on the embedded table of 2015 IONGES[1)]. The 2005 and 2011 IONGES embedded tables that we prepared thus far have few records of the production activities related to renewable energy sectors. However, the 2015 IONGES embedded table captures some production activities related to renewable energy sectors.

In addition, there is a database in Japan that represents renewable energy sectors called the Renewable Energy-Focused Input-Output Table (REFIO) (Moriizumi, Hondo, Nakano, 2015). The database is based on the 2011 Input-Output Table, which is a vector of input coefficients for sectors related to renewable energy technologies. Please refer to Nakano and Washizu (2020b) for the main differences between the IONGES and REFIO.

The Interim Report of the Subcommittee on System Reform for Renewable Energy as Main Power Source was released in February 2020. They proposed that the mechanism for the spread of renewable energy following the feed-in tariff (FIT) system should be designed with the following power sources separated.

1. Competitive power sources: Power sources that should reduce generation costs and become

more competitive in the market, such as large-scale solar and wind power.

2. Locally sourced power sources: Power sources that increase use of local resources and improve local resilience, such as residential solar power, small-scale commercial solar power, small-scale geothermal power, small-scale hydroelectric power, and biomass power plants.

For photovoltaic (PV) and wind power generation in the first category, owing to their intermittent nature, it is essential to devise ways to give them a competitive edge by utilizing energy smoothly, efficiently, and without waste. To achieve this, it is necessary not only to develop devices and technologies, such as storage batteries but also to commercialize new businesses, such as virtual power plants, to achieve smartification of society. It is difficult to obtain the scaling effect for locally sourced power in the second category, and it is challenging to improve their production efficiency because they are generally on a small scale and broadly distributed. Therefore, it is necessary to evaluate the effects of these power sources in ways other than focusing on the power supplies themselves (e.g., ripple effects on the local economy, such as employment creation or environmental effects). Therefore, the 2015 IONGES was created considering the nature of each power source.

2. Overview of the 2015 IONGES (embedded table)

In addition to the commercial thermal, nuclear, and hydropower sectors, the 2015 IONGES includes 15 types of power generation equipment and facility construction for the renewable energy sectors and activities of the power generation sectors, as listed in Table 1 [2]. The sum of the value of annual domestic production (i.e., control totals (CT)) in the power generation sectors listed in IONGES is equal to the CT total of the power generation sectors listed in the Input-Output Table by the MIC (MIC Table). However, the concept of the power generation equipment/facility construction sector in IONGES is different from that of the power facility construction sector found in the MIC Table. The activities in the former include both the mechanical equipment and civil engineering work required for the construction of power generation facilities. In contrast, the latter's activities include only civil engineering work to construct power generation facilities. The sum of the power generation equipment and facility construction sector CTs in IONGES equals the sum of the CTs of the power facility construction sectors and the total materials included in the fixed capital formation of the electric power sector in the MIC Table.

Table 1. 2015 Renewable energy sector generation variables in IONGES (embedded table)

	Facility power generation capacity		Amount of electricity generated (MWh/year)	Facility utilization ratio	Construction unit price (10,000 yen/kW)	Operational maintenance costs (10,000 yen/kW/year)	Purchase price Excluding tax (yen/kWh)	(Machine's') service life
Solar power for residential use	4	kW	*4*	0.12	36.90	0.36	34.00	30
Solar power, n.e.c.	1,200	kW	*1,472*	0.14	30.75	0.60	27.50	30
Onshore wind power	20,000	kW	*35,040*	0.2	30.00	0.60	22.00	20
Medium and small sized water power	150,000	kW	*394,200*	0.3	56.50	2.25	36.00	20
Flash steam geothermal power	199	kW	*1,046*	0.6	80.00	7.50	25.00	40
Supplementary well for flash steam geothermal power	30,000	kW	*218,124*	0.83	79.00	3.30	26.00	40
Binary cycle geothermal power	50	kW	*394*	0.9	123.00	4.80	40.00	40
Woody biomass (class A)	30,000	kW	*217,016*	*0.826*	*29.67*	Estimated separately based on the respective sources, not using assumed values.	24.00	40
Woody biomass (class B)	5,000	kW	*34,164*	*0.780*	*53.00*		32.00	40
Woody biomass (class C)	1,990	kW	*13,474*	*0.773*	*71.36*		40.00	40
Methane fermentation gas (food residue)	50	t/day	*785*	0.300	*803.46*		39.00	30
Methane fermentation gas (sewage disposal)	161	m/day³	*1,486*	0.355	*53.58*		39.00	30
Methane fermentation gas (livestock waste)	95	t/day	*1,977*	*0.752*	*265.00*		39.00	30
Waste incinerator power (large sized city)	600	t/day	*26,685*	0.650	*474.43*		17.00	40
Waste incinerator power (medium sized city)	300	t/day	*13,350*	0.650	*578.59*		17.00	40

Note: Assumptions for power generation capacity and service life are from the Cost Estimation and Verification committee, and those for facility utilization ratio, construction unit price, operation, maintenance cost, and purchase price are from the FY2015 Report of the Procurement Price Calculation Committee. Additionally, the power generation specifications of various biomass power plants are based on their respective sources (see Nakano and Washizu (2020)). Italics indicate that the values were back-calculated based on the original source.

3. The procedure for developing the 2015 IONGES (embedded table)

3-1 Separate listing of the transmission and distribution sector

The 2015 MIC Table shows "461101 commercial thermal power generation" and "461102 commercial power generation (excluding thermal power generation)" sectors, including power transmission and distribution activities. As smart grids are considered important in next-generation energy systems, IONGES has shown the transmission and distribution sectors separately since the 2005 Table.

According to the schedule of operating expenses of power and electric utilities, the schedule of operating expenses of Power Supply Development, and statement of income of local public enterprises, transmission and distribution costs account for 24.43% of the total generation, transmission, and distribution costs. Therefore, 24.43% of the two commercial power generation CTs were used to create CTs of the transmission and distribution sectors. The input vectors of the transmission and distribution sectors were created by adding a correction to the weighted average of the input coefficients of the inputs common to the two power generation sectors. Although the input vector of the transmission and distribution division is subtracted from that of the two power generation sectors, the entire CT of the transmission and distribution sectors is placed in the two power generation sectors. As a result, the CT of the two power generation sectors did not change.

The input vector of the power generation sector consists of the material input required for power generation activities (only) and the transmission and distribution service inputs. We considered it easier to analyze the effects of technological changes in the transmission and distribution service sector, such as the spread of energy management technologies associated with smart technologies and the associated changes in the transmission and distribution service input. Electricity consumers purchase electricity from the power generation sector including the value of the transmission and distribution service.

3-2 Modification of the private power generation sector

The private power generation sector in the 2015 MIC Table includes electricity sold to the commercial power sector (i.e., there is an output from the private power generation sector to the commercial power sector). This may obscure the interpretation of the results of the analysis of the spillover effects of power generation in next-generation energy systems. Therefore, we reduced the CT of the private power generation sector by the amount of electricity sold to the commercial power generation sector (i.e., we set the output from the private power generation sector to the commercial power generation sector to zero), and added the vector of input factors corresponding to the reduced CT to the input vector of the commercial power generation sector. Instead of purchasing privately generated electricity, the utility sector directly purchases the inputs necessary to generate that electricity. To avoid distorting the original input structure of the commercial power sector, we assumed that the power source of privately generated electricity was the same as that of the commercial power sector.

3-3 Setting Japan's domestic demand for power equipment and facilities construction sector

Table 2 shows the domestic demand and composition ratio for the power generation equipment and facilities construction sector in the 2015 IONGES (embedded table). These figures include the investment of the capital formation sector related to electric power in the fixed capital matrix of the MIC Table (excluding the amount of nuclear fuel, software, and research and development), which was transferred to the industrial sector. However, the total fixed capital formation does not change because the domestic demand for power generation equipment and facilities is fully recorded in fixed capital formation.

Table 2 2015 Domestic demand for electric power facilities construction in IONGES (embedded table)

	(Million yen)	Component ratio
Thermal, nuclear and water power	2,236,601	37.3
Solar power for residential use	318,342	5.3%.
Solar power, n.e.c.	2,737,509	45.7%.
Onshore wind power	120,254	2.0%.
Medium and small sized water power	79,463	1.3%.
Flash steam geothermal power		0.0%.
Supplementary well for flash steam geothermal power	40,549	0.7
Binary cycle geothermal power	10,778	0.2
Woody biomass (class A)	34,593	0.6
Woody biomass (class B)	82,510	1.4%.
Woody biomass (class C)	1,406	0.0%.
Methane fermentation gas (food residue)	13,972	0.2
Methane fermentation gas (sewage disposal)	588	0.0%.
Methane fermentation gas (livestock waste)	13,479	0.2
Waste incinerator power (large sized city)	124,124	2.1%.
Waste incinerator power (medium sized city)	179,879	3.0%.
Total	5,994,048	100.0% (%)

In the fixed capital matrix of the MIC Table, the amount of fixed capital formation for the entire electricity sector and the amounts of wind, PV, and other renewable energy power sectors, which are part of the total amount of electricity, are represented. The domestic demand for the construction of existing electric power transmission and distribution facilities is part of the total amount of the entire electricity sector minus the amount of the wind, PV, and other renewable energy power sectors. Domestic demand quantities for constructing onshore wind power generation facilities and equipment in the IONGES is the total investment in the wind power sector in the MIC Table. The amount of domestic demand for the construction of PV power generation (mega-solar) equipment and facilities in IONGES is the total investment in the PV power sector in the MIC Table, plus the total investment in small commercial PV power generation equipment and facilities that are not included in the MIC Table. The total investment in the capital formation sector "Other renewable energy-based power" corresponds to the total investment in the construction of woody biomass class A-and B-type power generation facilities and equipment, and geothermal and replenishment of power generation facilities and equipment.

However, for the power generation equipment and facility construction sectors of solar (residential), small-and medium-sized hydropower, binary, woody biomass class C type, raw garbage methane, sewage methane, livestock manure methane, waste incineration facility power generation (large cities), and waste incineration facility power generation (regional core cities), the amount of material investment in these sectors was not deducted from the fixed capital formation vector (not moved to the industrial sectors) because it was not possible to specify where the amount of material investment in these sectors was included in the fixed capital matrix in the MIC Table. Therefore, these quantities were not deducted from the fixed capital formation vector (i.e., they were not transferred to the industrial sectors). Moreover, the total fixed capital formation of IONGES (the total domestic demand) is larger than the corresponding value in the MIC Table by the amount of investment in the power generation equipment and facilities construction sectors.

The domestic demand for each renewable energy power generation equipment and facility construction sector, excluding the total investment for onshore wind power generation equipment and facility construction, geothermal and replenishment well power generation equipment and facility construction, was calculated by multiplying the "2015 year-end value — 2014 year-end value" of the newly certified FIT installed capacity (kW) by the construction unit price in Table 1.

3-4 Setting domestic demand quantity in the renewable energy generation sector

Table 3 shows the domestic demand and composition ratio of the power generation sectors in the 2015 IONGES (embedded table). These values were calculated by dividing the domestic demand of "461102 commercial power generation (excluding thermal power generation)" by the ratio of the physical quantity of "nuclear power," "hydraulic power," and "renewable energy power generation" in the Electricity Business Handbook, and dividing the domestic demand of "renewable energy power generation" by the ratio of renewable energy power generation capacity calculated from the cumulative installed capacity of FIT-certified power generation. However, the electricity sales rate of PV power generation (for residential installation) was assumed to be 60%[3]. For sewage methane power generation and waste incineration plant power generation (in large cities and regional core cities), the on-site utilization ratio (1 – electricity sales ratio) was also assumed.

Table 3. 2015 Domestic demand in the power generation sector in IONGES (embedded table)

	(Million yen)	Component ratio	The ratio of renewable energy
Thermal, power	15,827,578	89.389%.	
nuclear power	156,840	0.886%.	
Water power	1,634,249	9.230%.	
Solar power for residential use	7,888	0.045%.	8.99%.
Solar power, n.e.c.	22,204	0.125%.	25.30%.
Onshore wind power	4,359	0.025%.	4.97%.
Offshore wind power	12	0.00007%.	0.01%.
Medium and small sized water power	1,530	0.009%.	1.74%.
Flash steam geothermal power	69	0.00039%.	0.08%.
Binary cycle geothermal power	64	0.00036%.	0.07%.
Woody biomass (class A)	7,176	0.041%.	8.18%.
Woody biomass (class B)	1,487	0.008%.	1.70%.
Woody biomass (class C)	48	0.00027%.	0.05%.
Methane fermentation gas (food residue)	9	0.00005%.	0.01%.
Methane fermentation gas (sewage disposal)	7	0.00004%.	0.01%.
Methane fermentation gas (livestock waste)	67	0.00038%.	0.08%.
Waste incinerator power (large sized city)	19,570	0.111%.	22.30%.
Waste incinerator power (medium sized city)	23,255	0.131%.	26.50%.
Total	17,706,412	100.000%.	

3-5 Input vector for the renewable energy generation equipment and facilities construction sector

The specifications of each power generation facility used to create input vectors for the renewable energy power generation equipment and facility construction sector are listed in Table 1. Generally, each input vector was created by updating the specifications to the values in Table 1 in the same way as in the 2011 Table (Nakano and Washizu, 2020a; 2020b; Washizu and Nakano, 2021). However, the cost structure of PV (residential and mega-solar) and wind power generation has been reviewed, subject to significant changes in power generation costs and technological trends.

Table 4. Cost structure data for photovoltaic equipment and facility construction

For Residential Installation				For Mega-Solar			
		BOS Breakdown				Breakdown of “Other”	
Module	0.397			Module	0.365		
Inverter	0.129					Inverter	0.610
BOS	0.082	Panel mount	0.477	Frame	0.102		
		H steel	0.111	Other	0.086	H steel	0.083
		Junction box	0.191			Junction box	0.142
		Cubicle	0.155			Cubicle	0.116
		Data measuring device	0.042			Data measuring device	0.032
		Uninterruptible Power Supply Unit	0.001			Uninterruptible Power Supply Unit	0.001
		Display device	0.023			Display device	0.017
				PCS	0.090		
				Connection fees	0.018		
Installation cost	0.188			Installation work	0.330		
Margin	0.203			Other	0.010		
Total	1.000		1.000		1.000		1.000

Source: F.Y 2016, 24th Procurement Price Calculation Committee Material 1 4) was used for residential use. For non-residential use, FY 2016, 23rd Procurement Price Calculation Committee Material 1 [5), and FY 2015, 20th Procurement Price Calculation Committee data 1[6) were used.

Table 4 shows the cost structure of residential and mega-solar PV equipment and facility construction, reflecting component prices in 2015. The cost composition of PV modules was 39.7% for residential installation and 36.5% for mega-solar installation. Compared with the assumption in the 2011 Table (Nakano and Washizu, 2020a; 2020b; Washizu and Nakano, 2021) (58.6% for residential installation and 38.9% for mega-solar), the price of PV modules for residential installation and mega-solar power has decreased considerably.

Table 5 Cost structure data for wind power facilities

Onshore wind power generation facilities		Offshore wind power generation facilities	
Tower	11.8	Tower	6.6
Blade	11.2	Blade	6.3
Speed reducer (gear)	10.1	Speed reducer (gear)	5.6
The others	8.9	The others	5.0
Converter	3.0	Converter	1.7
Pitch and yaw mechanism	3.0	Pitch and yaw mechanism	1.7
Power generator	2.4	Power generator	1.3
(Power) transformer	2.4	(power) transformer	1.3
Cast goods	1.8	A cast	1.0
Bearing (e.g., Wheel)	1.8	Bearing (e.g., Wheel)	1.0
Forged products	1.8	Forged products	1.0
Control unit	1.2	Control unit	0.7
Grid connection	14.5	Interconnection, submarine cable, substation, etc.	12
Survey cost/design	2.9	Project cost	2
Transport assembly	23.4	Transportation and Installation	19
		Construction and financing costs	12
		Foundation	22
Total	100.0 (%)	Total	100.0 (%)

Source: Table 3.4-1 in [Japan Society of Industrial Machinery Manufacturers (2017)] for the total construction cost structure of onshore wind, Figure 4.1.3-2(a) for the total construction cost structure of offshore wind, and Figure 4.1.3-2(b) for the component structure of onshore and offshore wind turbines.

Based on recent changes in technology trends, the cost structure of wind turbines, which is a prerequisite for creating input vectors for the wind power equipment and facilities construction sector, is reviewed. According to the Japan Society of Industrial Machinery Manufacturers (2017), the mainstream powertrain of wind turbines before the year 2000 was a “speed-up device (with gears) + induction generator.” However, as the 2–3 MW generators became mainstream, the trend moved towards a “permanent magnet synchronous generator + full converter + direct drive” powertrain. Until 2011, it was assumed that onshore wind turbines with relatively small generators would be geared and offshore wind turbines with large generators would be gearless. However, in a direct-drive system with low-speed rotation, the generator becomes a multipole machine with a larger diameter and greater weight. Thus, to reduce the size and cost, technologies using permanent magnet synchronous generators + full converters+ medium speed gear drives are being adopted for 5–8 MW turbines. As a result, the number of geared wind turbines, including offshore ones, is increasing.

Consequently, we assumed geared wind turbines for both onshore and offshore wind power generators in the 2015 IONGES and changed the cost structure to literature values obtained from the Japan Society of Industrial Machinery Manufacturers (2017). Table 5 lists the cost structure used to develop the input vector for the wind power equipment and facility construction sector in the 2015 IONGES.

According to the Japan Society of Industrial Machinery Manufacturers (2017), the number of wind turbines installed in FY2015 was 191 MW for foreign wind turbines compared to 56 MW for domestic wind turbines. Therefore, it is essential to estimate the import value of wind turbines. Based on a comparison, in the IEA Wind TCP Annual Report (2015), between Japan's turbine cost (EUR/kW) and the average cost outside Japan, the price difference between domestic and foreign wind turbines is assumed to be 4.02 times (ratio of domestic price to import price), and the import ratio of wind turbines to domestic demand is assumed to be 45.9%.

3-6 Development of input vectors for the renewable energy generation sectors

The vector of input coefficients for the renewable energy power generation sector was created by updating the specifications of each power generation facility, as shown in Table 1, and dividing the assumed operation and maintenance costs of the model plant by the assumed amount of electricity generated, as in the 2011 Input-Output Table (Nakano and Washizu, 2020a; 2020b; Washizu and Nakano, 2021).

Similar to the 2011 Table, the same producer price in 2015 was used for commercial electricity and electricity generated through renewable power generation in the 2015 IONGES. The difference between the FIT purchase price and the producer price of renewable electricity is indicated by a negative value in the "Difference from FIT" row in the value-added vector. Specifically, the same table format as that of the current subsidy was adopted. Additionally, in the three woody biomass power generation sectors, it is assumed that a part of the difference with FIT is also used to subsidize the purchase of inputs, such as fuel. The subsidies allocated to the purchase of fuel for B-and C-class woody biomass power plants are represented as the output of wood chips (for power generation) to government expenditure (i.e., in-kind subsidies of fuel by the government).

Although the MIC Table also includes a "wood chip" sector, the "wood chip (for power generation)" sector in the 2015 IONGES is assumed to be a sector comprising of wood chips made only from unused wood, such as thinned wood, branches, and leaves, and thus different from the wood chips in the MIC Table. Although there are some cases when ordinary woodchips are used for woody biomass power generation, it is assumed that the amount is minor, so that only "woodchips (for power generation)" derived from unused wood is assumed to be used for woody biomass power generation in 2015 IONGES.

4. Estimation results

The sum of the inverse matrix $\left[\mathbf{I}-\left(\mathbf{I}-\widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1}$ coefficients of each renewable energy equipment and facility construction sector, and power generation sector shows the spillover effect of the cost associated with the construction of renewable energy facilities or power generation for society as a whole. The bubble diagram[7)] in Fig. 1 shows the spillover effect of the cost per unit of electricity generated for each type of renewable energy. The horizontal axis of Fig. 1 shows the production inducement (= social cost) per unit of electricity generated by the power generation equipment and facility of each type of renewable energy species during its lifetime. The vertical axis shows the inducement of generation per unit of electricity. The range of the horizontal axis of the figure is calculated from the sum of the column coefficients of the inverse matrix $[\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{M}})\mathbf{A}]^{-1}$ coefficients of the power generation equipment and facility construction sectors for each renewable energy source, together with the facility utilization rate, construction unit price, and service life of each renewable energy source, as shown in Table 1. Additionally, the range of the vertical axis in Fig. 1 is the sum of the columns of the inverse matrix $[\mathbf{I}-(\mathbf{I}-\widehat{\mathbf{M}})\mathbf{A}]^{-1}$ coefficients for each renewable energy generation sector. The diameter of the bubble circle indicates the relative size of CT for each power generation. The production inducement per unit of lifetime electricity produced by the power generation facility using food waste methane is substantial because the assumed construction unit price is high, and the facility utilization rate is low. The unit construction cost of the waste incineration power generation was also high. However, the assumed equipment utilization rate and service life are relatively large, resulting in low production inducement per unit of lifetime electricity generated by the power generation equipment and facilities. For the same methane gas power generation, the production inducement per unit of lifetime electricity produced by the power generation equipment and facilities is suppressed for livestock manure methane because of the high equipment utilization rate, and the same value is suppressed for sewage methane owing to the low construction cost[8)]. For woody biomass power generation, although the production inducement at the time of power generation is high, the production inducement associated with the construction of equipment and facilities is lower than that for other renewable energies. Production inducement at the time of power generation is associated with the procurement of fuel biomass. However, if a new regional circular energy sphere (CES) is formed through procurement, this production inducement may not be regarded as a social cost. The social impact cannot be fully evaluated only by the size of the production inducement needs to be developed by another evaluation method, which remains an issue for this study. A more common to argue is developing that the value of electricity should be determined not only by its kWh value, but also by its stable supply, resilience, and ripple effects on local economies. However, further improvement in efficiency is desired for the diffusion of renewable energy, and one such innovation is the advancement of energy management technology. In the future, it is important to consider how to include the service activity of energy management in discussions concerning input-output analysis.

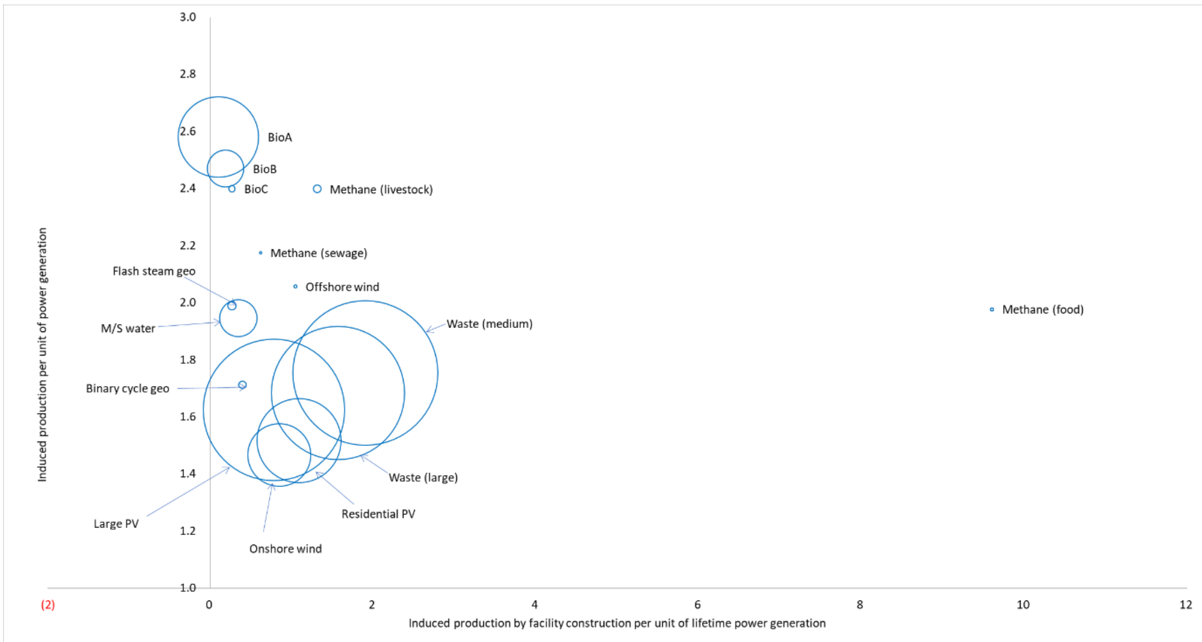

Fig. 1. Magnitude of ripple effect during construction and power generation

Note) The horizontal axis of the figure shows the production inducement per unit of electricity generated by the power generation equipment/facility of each renewable energy type during its lifetime throughout service life, and the vertical axis shows the production inducement per unit of electricity generated during power generation. The magnitude of the horizontal axis is the value obtained by converting the column sum of the inverse matrix coefficients of the power generation equipment/facility construction sector of each renewable energy type into the production inducement per unit of electricity generated using the equipment utilization rate, construction unit price, and service life in Table 1. The vertical axis indicates the sum of the inverse matrix coefficients of each renewable energy generation sector. The diameter of the circles indicates the magnitude of the gross domestic product.

This study calculated the CO_2 emission factor for each sector based on energy-origin CO_2 emissions in the 3EID[9)]. The CO_2 emission factors and emissions of the newly established renewable energy sectors were also estimated. As a result of the addition of intermediate energy input amounts in these sectors, the total amount of CO_2 emissions exceeded the total amount in the 3EID by approximately 4%[10)].

5. Applied analysis of the 2015 IONGES (embedded table): The effect of introducing a carbon tax.

5-1 Objective

Carbon pricing (CP), such as a carbon tax, leads to the development of a sustainable low-carbon society, and a precise analysis of the impact on each economic sector is essential for its institutional design. Currently, the Ministry of the Environment (MOE) and the Ministry of Economy, Trade, and Industry (METI) have established the “Subcommittee on the Use of Carbon Pricing of the Central Environment Council” and the “Study Group on Economic Approaches to Achieve Global Carbon Neutrality” respectively, and are discussing the institutional design of CP.

In this study, we used the IONGES embedded table to analyze the impact of renewable energy utilization on mitigating the impact of introducing a carbon tax, considering the existing energy-related taxation system. Sugino et al. (2013) and Sugino (2021) analyzed the effect of introducing a carbon tax using input-output analysis. Using the MIC Table, these analyses show that an increase in the carbon tax rate indicates a considerable cost burden for energy-intensive industries. However, although Sugino (2021) suggested that the introduction of renewable energy will impact cost burden, the specific effect was not measured. Washizu and Nakano (2021) used the 2011 IONGES to examine how differences in carbon taxation methods (upstream, midstream, and downstream taxation) change the tax burden of each sector. Simultaneously, they calculated the difference between the embedded table (based on the power supply composition of 2011) and the assumption table (based on the assumed power supply composition of 2030) and considered the impact of introducing renewable energy. In the following section, we reflect the tax systems of energy-related taxes in more detail in our analysis and estimate the extent to which the introduction of renewable energy mitigates the cost burden of carbon taxes on each sector.

5-2 Energy-related taxes

Table 6 shows energy-related taxes. First, petroleum and coal taxes were imposed on crude oil, coal, LNG, and imported petroleum products at the top of the supply chain. In addition to the main tax rate, a global warming countermeasure (GWC) tax has been added since 2012, and the final rate was raised in 2016. The tax rate for the GWC tax is 289 yen per ton of CO_2 emitted, which is 760 yen/kL per unit of oil (crude oil and imported petroleum products), 780 yen/t for gas (liquefied petroleum gas (LPG) and liquefied natural gas (LNG)), and 670 yen/t for coal. In addition, there are gasoline, local gasoline, oil gas, aviation fuel, diesel fuel, and power development promotion taxes, and their tax rates are listed in Table 6.

Table 6 Energy-related taxes[11)] (Unit: JPY/Unit)

	Unit	Energy taxes other than petroleum and coal taxes	Petroleum coal tax	Breakdown		Simulation of GWC tax [Note)]			
				Regular tax rate	Warm-weather tax	S1	S2	S3	S4
Crude oil	kL		2,800	2,040	760	2,620	7,860	13,100	26,200
Petroleum products (imports)	kL		2,800	2,040	760	2,620	7,860	13,100	26,200
Gasoline	kL	53,800							
Jet fuel oil	kL	18,000							
Light oil	kL	32,100							
LPG (imported)	t		1,860	1,080	780	27,00	8,100	13,500	27,000
LPG (for vehicles)	t	17,500							
LNG	t		1,860	1,080	780	2,700	8,100	13,500	27,000
Coal	t		1,370	700	670	2,330	6,990	11,650	23,300
Electric power	10^6 kWh	375,000							

Note: Each GWC tax rate is calculated based on the following assumptions: 1,000 JPY/t-CO_2 (S1), 3,000 JPY/t-CO_2 (S2), 5,000 JPY/t-CO_2 (S3), and 10,000 JPY/t-CO_2 (S4). Note for tax calculation, CO_2 conversion factors of 2.62t-CO_2/kL for crude oil and petroleum products, 2.7t-CO_2/t for LPG and LNG, and 2.33t-CO_2/t for coal are used[12)].

Table 7 Exemption or refund of global warming countermeasures tax (GWC tax) note)

	Target energy	Target Inter-industry Relations Division
Tax Exemption	Imported Gasoline, Kerosene, and Diesel Oil Used in the Manufacture of Petrochemical Products	Chemical Fertilizers, Basic Petrochemical Products, Aliphatic Intermediates, Cyclic Intermediates, and Other Organic Chemical Industrial Products
	Imported Liquefied Petroleum Gas Used in the Production Of Ammonia, Olefinic Hydrocarbons Or Maleic Anhydride	Chemical Fertilizers, Basic Petrochemical Products, Aliphatic Intermediates, Cyclic Intermediates, and Other Organic Chemical Industrial Products
	Imported Coal for Steel Production	Iron, Ferroalloy, Crude Steel (Converter), Crude Steel (Electric Furnace), Hot-Rolled Steel, Steel Pipes, Cold-Finished Steel, Plated Steel, Cast and Forged Steel, Cast-Iron Pipes, Cast-Iron Products and Forgings (Iron), Steel Shear Slitting, Other Steel Products
	Imported Coal for Coke Production	Coke (Carbon Fuel)
	Imported Coal for Cement Manufacturing	Cement, Ready-Mixed Concrete, Cement Products
	Imported Coal for Power Generation By General and Wholesale Electric Utilities In Okinawa Prefecture	Business Use Power
	Imported Heavy Oil Used for Agriculture, Forestry and Fisheries	Arable Crops (Cereals, Potatoes, Beans, Vegetables, Fruits, Sugar Crops, Beverage Crops, Other Edible Arable Crops, Fodder Crops, Seeds and Seedlings, Flowers and Flowering Plants, Other Inedible Arable Crops), Livestock (Dairy Farming, Beef Cattle, Pork, Eggs, Meat Poultry, Other Livestock), Agricultural Services (Except Veterinary Medicine), Forestry (Silviculture, Materials, Special Forest Products (Including Hunting), Sea Surface Fishery, Sea Surface Aquaculture, Inland Water Fishery and Aquaculture
	Imported Coal and Natural Gas for Private Power Generation In Caustic Soda Manufacturing Industry	Private Power Generation
	Imported Coal for Private Power Generation in the Salt Manufacturing Industry	Private Power Generation
Refund	Domestic Gasoline, Kerosene, and Diesel Oil Used in the Manufacture Of Petrochemical Products	Chemical Fertilizers, Basic Petrochemical Products, Aliphatic Intermediates, Cyclic Intermediates, and Other Organic Chemical Industrial Products
	Domestic Crude Oil and Petroleum Products Used in the Production Of Petroleum Asphalt and Petroleum Coke	Other Petroleum Products
	Light Oil and Domestic Heavy Oil Used for Agriculture, Forestry and Fishery	Arable Crops (Cereals, Potatoes, Beans, Vegetables, Fruits, Sugar Crops, Beverage Crops, Other Edible Arable Crops, Fodder Crops, Seeds and Seedlings, Flowers and Flowering Plants, Other Inedible Arable Crops), Livestock (Dairy Farming, Beef Cattle, Pork, Eggs, Meat Poultry, Other Livestock), Agricultural Services (Except Veterinary Medicine), Forestry (Silviculture, Materials, Special Forest Products (Including Hunting), Sea Surface Fishery, Sea Surface Aquaculture, Inland Water Fishery and Aquaculture
	Light Oil and Heavy Oil for Coastal Operations	Coastal and Inland Water Transport
	Light Oil and Heavy Oil for Marine Transportation and General Passenger Liner Service	Coastal and Inland Water Transport
	Diesel Oil for Railway Operators	Railway Passenger Transport, Railway Freight Transport
	Aircraft Fuel for Domestic Scheduled Air Transport	Air Transport
	Heavy Oil Used To Supply Electricity To The Caustic Soda Manufacturing Industry	Private Power Generation

Source: Document 1-2, Subcommittee on the Use of Carbon Pricing, Global Environment Committee, Central Environment Council (1st 16meeting)[13)]

Note: For items for which the petroleum coal tax has been exempted or refunded, the Petroleum Coal Tax will continue to be exempted or refunded in addition to the Global Warming Countermeasure (GWC) tax.

For GWC tax, tax exemptions and refunds are available for various sectors. Table 7 shows the energy types and sector names of the input-output tables eligible for exemptions and refunds.

These energy-related taxes are imposed on each taxpayer, but the taxable amount is added to the energy sales price and should be passed on to the energy consumer. The purpose of introducing a carbon tax is to encourage consumers to save energy by raising the energy sales price by the amount of tax passed on. Therefore, in Section 5-3, the following analysis was conducted. The amount of taxation that each sector currently bears was calculated based on the assumption that all energy-related taxes are passed on to energy consumers and that each sector pays energy taxes according to its energy consumption. In addition, the extent to which the introduction of renewable energy would reduce the tax burden was considered.

As shown in Table 7, although the entities receiving the GWC tax exemption or refund are different from one another, as the purpose of exemptions and refunds is to reduce the tax burden on the sector of the subject industry, in the analysis in Section 5-3, it was assumed that both the tax exemption and refund would be proportional to the energy inputs in the relevant sector of the input-output table. In the analysis in Section 5-3, the effect of increasing the GWC tax rate per ton of CO_2 emissions to 1,000 yen (S1), 3,000 yen (S2), 5,000 yen (S3), and 10,000 yen (S4) is examined according to the discussion in the Subcommittee on the Utilization of Carbon Pricing of the Central Environment Council of the Ministry of the Environment [14)].

5-3 Analysis model

In this study, we use the following analytical model to calculate the extent to which the introduction of renewable energy can mitigate the effect of raising the GWC tax. Here, k is the number of fuel types, h is the number of renewable energy types, and n is the number of sectors in the Input-Output Table.

(1) The following formula was used to calculate the cost burden of domestic energy-related taxes and the current GWC tax expressed as Γ, the amount of tax burden incurred by each domestic industry for a given final demand:

$$\Gamma = \Gamma^{INT} + \Gamma^{FD} = \mathbf{t}' \cdot \mathbf{N} \cdot \left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1}\left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{fd} + \mathbf{t}' \cdot \mathbf{fuel}^{FD} \quad (1)$$

where,

$$\mathbf{t}' \cdot \mathbf{N} \cdot \left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1} = \begin{bmatrix} t_1 & \cdots & t_k \end{bmatrix} \begin{bmatrix} fuel_{11} & \cdots\cdots & fuel_{1n} \\ \vdots & \ddots & \vdots \\ fuel_{k1} & \cdots\cdots & fuel_{kn} \end{bmatrix} \left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1} \quad (2).$$

Γ is divided into two categories: Γ^{INT} which occurs in the intermediate goods production process in the supply chain, and Γ^{FD} which is generated at the final fuel demand stage. t_i is the sum of the energy-related taxes and the current GWC tax rate $(i = 1, \cdots, k)$, $fuel_{ij}$ is the input intensity (expressed in unique units) of the i-th fuel per unit of domestic output of the j-th good ($i = 1, \cdots, k, j = 1, \cdots, n$), $\mathbf{t}'$ is a row vector$(1 \times k)$ whose element is t_i and $\mathbf{N}$ is a matrix $(k \times n)$ with $fuel_{ij}$ as its element, $\left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1}$ is the Leontief inverse matrix of the 2015 IONGES (embedded table) that takes into account the imports, $\mathbf{fd}$ is the final demand vector of 2015 IONGES, and $\mathbf{fuel}^{FD}$ is the final demand vector of fuel types (expressed in unique units)$(k \times 1)$.

Although each value of $fuel_{ij}$and $\mathbf{fuel}^{FD}$ is based on 3EID[9] for the renewable energy sectors, these values were estimated in this study. Additionally, for the industrial sector that receives exemptions or refunds for the GWC tax, these values are replaced by taxable fuel input. Note that k fuel types include imported crude oil and coal.

Now, let us consider a vector consisting of only one final good (e.g., the i-th good) to be $\mathbf{fd}_i$, then

$$\Gamma_i^{INT} = \mathbf{t}' \cdot \mathbf{N} \cdot \left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1}\mathbf{fd}_i \quad (3)$$

is the amount of energy-related taxes directly and indirectly induced in Japan by producing one unit of the i-th good.

(2) The increase in the energy-related tax burden $\Gamma^{up(Sg)}$ $(g = 1,2,3,4)$ from the current GWC tax level is calculated by replacing t_i in equations (1) and (3) with $t_i^{up(Sg)}$. This $t_i^{up(Sg)}$ $(g = 1,2,3,4)$ is the combined tax rate of energy-related taxes and the GWC tax of S1 to S4 in Table 6.

(3) The introduction of renewable energy reduces the burden of energy-related taxes by reducing the fuel input for thermal power generation. Therefore, the reduced energy-related tax burden (and current GWC tax) Δ due to the introduction of renewable energy was calculated using Equation (4).

$$\Delta = \Delta^{INT} + \Delta^{FD} = \mathbf{t}' \cdot \mathbf{N}^{div} \cdot \mathbf{B}^{renew} \cdot \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{fd} + \mathbf{t}' \cdot \mathbf{N}^{div} \cdot \mathbf{fd}_{renew} \quad (4)$$

Equation (4) shows the incremental tax burden that would occur if all renewable energy generation were replaced by thermal generation. Again, Δ was divided into two categories: the cost-saving effect in the intermediate goods production process in the supply chain Δ^{INT} and the cost-saving effect at the final demand stage Δ^{FD}, where $\mathbf{N}^{div}$ is a matrix $(k \times h)$whose element is the difference between the savings in the fuel input per unit of electricity in renewable energy generation $(j = renew)$ sectors and thermal power generation $(j = thermal)$ $(fuel_{i \cdot thermal} - fuel_{i \cdot renew})$, $\mathbf{B}^{renew}$ is an $h \times n$ matrix summarizing the horizontal vectors of h types of renewable energy in the Leontief inverse matrix$\left[\mathbf{I} - \left(\mathbf{I} - \widehat{\mathbf{M}}\right)\mathbf{A}\right]^{-1}$, and $\mathbf{fd}_{renew}$ is the final demand vector of renewable electricity.

(4) The $\Delta^{up(Sg)}$ $(g = 1,2,3,4)$ which represents the state in which the GWC tax is raised from the current state to S1 through S4 in Table 6, was calculated by replacing the t_i in Equation (4) with $t_i^{up(Sg)}$.

5-4 Analysis results

Fig. 2 shows the cost burden of energy-related taxes Γ, the tax burden reduction due to the replacement of thermal power by renewable energy generation.Δ, and the tax burden if all renewable energy was generated by thermal power. First, the cost burden of energy-related taxes Γ is increased to 2.8 times more from the current 5.8 trillion yen to 16.2 trillion yen (S4 in Table 6). If we add Δ to this, that is, the size of the energy-related taxes that would have been imposed if there were no renewable energy sources (i.e., if all renewable energy generation had been generated by thermal power). The share of Δ in $\Gamma + \Delta$ is interpreted as the percentage reduction in the energy-related tax burden due to the introduction of renewable energy, which is 0.20% in the case of S4, compared to the current value of 0.04%. Table 3 shows that the share of renewable energy generation for commercial use in the embedded table is only 0.5%; therefore, the burden reduction effect is limited. However, even in this case, if the GWC tax rate is increased to S4 (10,000 yen per ton of CO_2 emission), the burden of energy-related taxes will be reduced by approximately 33.1 billion yen. In the future, the reduction rate will increase further if the ratio of renewable energy generation increases.

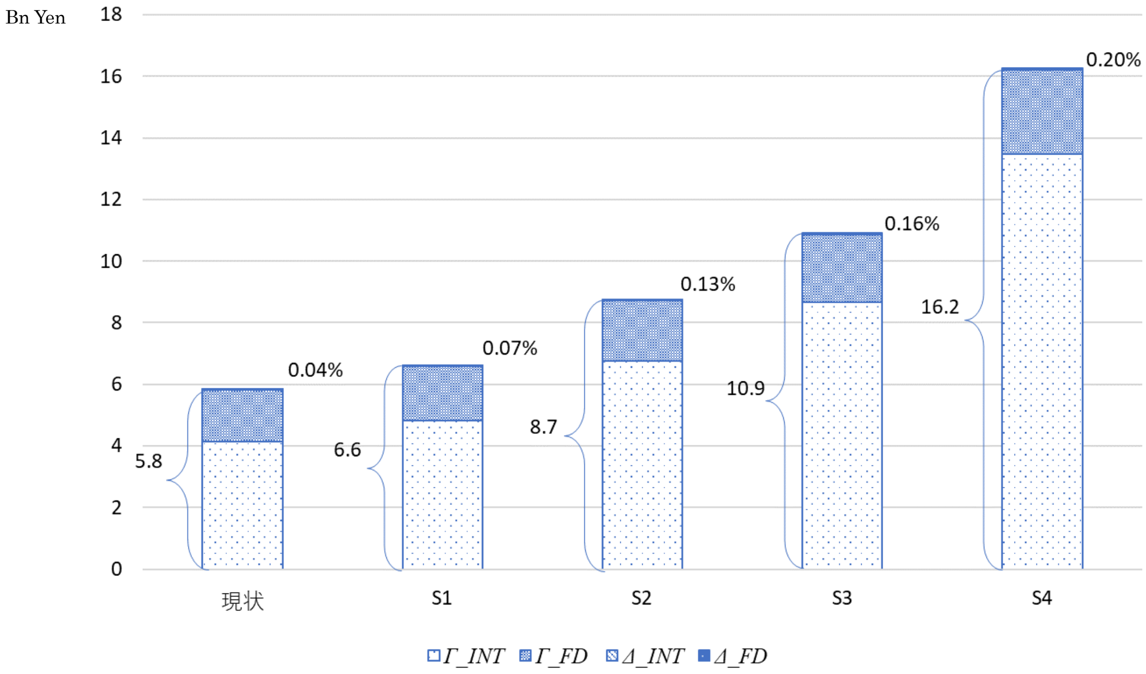

Fig. 2. Effect of the introduction of renewable energy on the reduction of the tax burden caused by the increase in the GWC tax

Note) S1 to S4 are the cases where the GWC tax rate is 1,000 JPY/t-CO_2 (S1), 3,000 JPY/t-CO_2 (S2), 5,000 JPY/t-CO_2 (S3), and 10,000 JPY/t-CO_2 (S4), respectively. Γ^{INT} is the energy-related tax burden generated in the production process of intermediate goods in the supply chain, and Γ^{FD} is the energy-related tax burden generated in the final demand stage of fuel. In addition, the Δ^{INT} is the tax burden reduction effect of the introduction of renewable energy in the production process of intermediate goods in the supply chain, and Δ^{FD} is the tax burden reduction effect of introducing renewable energy in the final demand stage. The percentage in Fig.2 shows the reduction rate in the energy-related tax burden due to the introduction of renewable energy.

Table 8 shows the top 10 industrial sectors bearing the largest tax burden of energy-related taxes on producing a unit of the i-th good and compares the current tax rate with the S4 GWC tax rate. These are the results of calculations using Equation (3). The table shows that the burden of energy-related taxes associated with the production of commercial thermal power per unit increased from 0.0339 (current rate) to 0.3345 (S4 rate). The major difference between the current and S4 cases was the sector order. Under the current tax rate, the top industries with higher tax burdens are sectors with relatively large input coefficients for transport services such as private transport, road transport, air transport, and livestock methane power generation with high raw material transportation costs, whereas under the S4 tax rate, coal products and the commercial and private thermal power generation sectors show relatively large tax burdens. In addition, energy-intensive industries such as basic petrochemical products rank high based on the S4 tax rate[14)]. A closer look at the results shows that this trend varies gradually as the tax rate changes from the current to S4 rates. When the GWC tax rate increases to S4, the tax burden on the thermal power generation and energy-intensive industries increases. Table 6 shows that the current energy tax on vehicle fuels is relatively high; therefore, the current tax burden is relatively large for industries closely related to these fuels. However, increasing the GWC tax to the S4 level would change the relative relationship between the energy tax burden on vehicles and industrial fuels. This may affect decarbonization technologies that are likely to be promoted based on market principles. Electric and fuel-cell vehicles are more likely to be promoted if the carbon tax is close to the current level. In contrast, next-generation technologies, such as carbon capture, utilization, and storage (CCUS) in large-scale energy-consuming industries, may be promoted (based on market principles) at the S4 carbon tax level and above. Raising the carbon tax level could encourage (market-based) next-generation technologies such as CCUS in large energy-consuming industries.

Table 8. Top ten sectors with large tax burdens for energy-related taxes

	Status Quo			S4		
1	573000	Private Transport	0.1741	212,000	Coal Products	0.3993
2	062000	Other Mining	0.0551	461,001	Thermal Power Generation for Business Use	0.3345
3	461016	Livestock Manure Methane Power Generation	0.0494	461,020	Private Power Generation (Thermal Power Generation)	0.2844
4	572000	Road Transport (Excluding Private Transport)	0.0421	573,000	Private Transport	0.2706
5	203000	Basic Petrochemical Products	0.0353	203,000	Basic Petrochemical Products	0.2594
6	461001	Thermal Power Generation for Business Use	0.0339	462,000	Gas and Heat Supply	0.2134
7	212000	Coal Products	0.0273	204,000	Organic Chemical Industry Products (Excluded)	0.1157
8	575000	Air Transport	0.0272	461,016	Livestock Manure Methane Power Generation	0.1043
9	161001	Wood Chips (for Power Generation)	0.0237	206,000	Synthetic Fibers	0.1000
10	461020	Private Power Generation (Thermal Power Generation)	0.0228	062,000	Other Mining	0.0981

Note) S4 is where the GWC tax rate is 10,000 JPY/t-CO_2

6. Summary and future directions

This study provides an overview of the 2015 IONGES (embedded table). The 2015 IONGES is a follow-up to the 2005 and 2011 IONGES[15)]. The production inducement effect associated with the construction of renewable energy facilities and electricity generation can be interpreted as a cost inducement. Therefore, when the cost inducement was evaluated per unit of lifetime electricity generated from one unit of power generation equipment/facility construction, the equipment utilization rate and service life were considered to impact its magnitude significantly. The cost inducement of power generation is larger in the case of woody biomass power generation and livestock manure methane gas power generation. In addition, because the Government of Japan is currently discussing the utilization of CP by raising the GWC tax, the extent to which renewable energy mitigates the effect of the tax increase was examined. The results show that renewable energy deployment has an evident effect on reducing the tax burden of energy-related taxes when the GWC tax rate is increased to 10,000 yen per ton of CO_2 emissions, even though the generation ratio of renewable energy for commercial use in the embedded table is only 0.5%. In addition, it was found that the tax burden on thermal power generation and energy-intensive industries increased as the GWC tax rate increased. However, at present, the transportation-related sectors are the industrial sectors with a relatively large tax burden. Our analysis using the input-output table has the advantage that a complex system of energy-related taxes can be precisely reflected in the analysis.

In the future, we will prepare a 2030 Assumption Table based on the number of renewable energies expected to be introduced in each sector by 2030 and the power supply composition. In response to the declaration of carbon neutrality in 2021, the 2030 target for the Long-Term Energy Supply and Demand Outlook formulated in 2015 have been updated to a more ambitious target. Furthermore, in the 2030 Assumption Table, we believe it will be necessary to include the target of "100% electrification of domestic new car sales by the mid-2030s". We plan to establish new sectors necessary for this purpose (e.g., electric vehicles, charging stations, and Li-ion battery sector).

The findings of this study can be used to analyze the effects of next-generation energy systems that utilize renewable energy. Such analyses may include the following.

1) The effects of introducing various management systems that enable the mass introduction of renewable energy sources include the reduction of output curtailment of solar power generation through the sophistication of energy management, such as demand response, and the reduction of management costs through the sophistication of remote monitoring systems for offshore wind farms.
2) The effects of increased energy efficiency and expansion of the renewable energy ratio are due to the progress of smart technologies not only in the energy sector but also in the general industrial sector (including the service sector).
3) Effects of forming a regional CES using woody biomass, methane fermentation gasification power generation, small-and medium-sized hydroelectric power generation, geothermal power generation, and other methods, in cooperation with the agricultural sector.
4) Effect of new energy technologies such as CO_2-free hydrogen and CCUS.

We plan to continue our research on these issues.

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Note)

1) In response to the Prime Minister's declaration of carbon neutrality for 2050 in his speech at the 203rd extraordinary Diet session in October 2020, the "Long-Term Energy Supply and Demand Outlook" was revised in October 2021. An assumption table will be prepared based on the revised government outlook in near future.
2) For large-scale geothermal power generation, the construction section of replenishment wells is represented instead of the construction section of power generation equipment and facilities.
3) Based on the 2015 assumption by the Procurement Price Calculation Committee.
4) The FY 2016, 24th meeting of the procurement price calculation committee document 1 https://www.meti.go.jp/shingikai/santeii/pdf/024_01_00.pdf.
5) The FY 2016, 23rd Meeting of the Procurement Price Calculation Committee Document 1 https://www.meti.go.jp/shingikai/santeii/pdf/023_01_00.pdf
6) The FY2015, 20th Meeting of the Procurement Price Calculation Committee Document 1 https://www.meti.go.jp/shingikai/santeii/pdf/020_01_00.pdf
7) As the table shows, the 2015 CTs of the offshore wind power and the large-scale geothermal power generation equipment/facility construction sector were zero. Hence, the influence coefficients of those sectors are the values in the 2011 IONGES/Assumption Table as a reference value (the value calculated under the assumption that renewable energy is introduced to the level of the long-term energy supply and demand forecast for 2030) and were used to create Fig. 2.
8) In the case of sewage methane power generation, the vector is constructed on the assumption that the power plant is attached to the existing sewage treatment facility, and the sewage treatment facility itself is excluded from equipment and facility construction activities. However, for food waste and livestock manure methane, the installation cost of the methane fermentation tank (i.e., waste treatment facility) is included in equipment and facility construction activities.
9) National Institute for Environmental Studies, "Data Book of Environmental Impact Intensity by Input-Output Table (3EID)" https://www.cger.nies.go.jp/publications/report/d031/jpn/page/what_is_3eid.htm
10) The validity of this issue will be the subject of future research.

11) Ministry of Finance, “Data on automobile-related taxes and energy-related taxes” https://www.mof.go.jp/tax_policy/summary/consumption/d10.htm
12) Ministry of the Environment, “Introduction of a tax to combat global warming
13) Subcommittee on Utilization of Carbon Pricing, Global Environment Subcommittee, Central Environment Council (16th meeting) https://www.env.go.jp/council/06earth/16shiryou1-2.pdf
14) The GWC tax exemptions and refunds are shown in Table 7 and are assumed to be implemented similarly under the hypothetical tax rates of S1–S4.
15) Although IONGES for 2005, 2011, and 2015 were prepared across these three points of time, they were not necessarily prepared with the intention of analyzing changes as a time series. Since attitudes towards renewable energy have changed during this period, we have prioritized the ease of analysis of the main issues at each point in time rather than the comparability between such points in time.

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