Analysis of Japanese power supply beyond 2020 using the GTAP-E-Power model

by

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Abstract

The GTAP-E-Power model, which disaggregates the power sector based on the framework of the GTAP-E model, has been developed recently. The GTAP-E-Power model makes it possible to analyze the effect of a change in the structure of the power sector, considering the effect of energy substitution. Since the Great East Japan Earthquake in March 2011, the structure of the power sector in Japan has changed drastically and will continue to transform toward new targets, such as zero-emission power source ratio, energy saving, energy self-sufficiency, and energy-derived CO_2 emissions. This study analyzes the effect of a change in the structure of Japanese power supply using the GTAP-E-Power model. We also update the database of the GTAP-E-Power model from GTAP 9.0 to GTAP 10.0, released in February 2020. The impacts of a change in the power structure on Japan's macroeconomy, power sector, and industry are analyzed by comparing the results of four scenarios, in which Japan's zero-emission power supply changes at a different growth rate from 2019 to 2030. In our simulations, shocks are introduced to the growth rate in real GDP, labor force, population, and Japanese zero-emission power supply. Simulations are divided into two periods. First, simulations from 2014 to 2018 are performed to update the GTAP-E-Power database to ensure that it reflects the actual values as much as possible. Next, simulations from 2019 to 2030 are performed for policy scenarios with different growth rates of zero-emission power supply in Japan.

The simulation results show that with the same growth rate of zero-emission power as the Sustainable Development Scenario of the World Energy Outlook 2019 from 2019 to 2030, the share of zero-emission power in Japan in 2030 will be close to the government's goal. The simulation results also show that an increase in zero-emission power would have a positive effect on the Japanese economy.

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1. Introduction

After the Great East Japan Earthquake in 2011, the structure of the power sector in Japan changed drastically and will continue to transform toward new targets, such as those for safety against disasters, zero-emission power source ratio, energy saving, energy self-sufficiency, and energy-derived CO_2 emissions. As pointed out in the UNISDR (2015), Japan is one of the countries with the highest absolute annual average loss caused by disasters, making it necessary to consider various aspects in securing power supply in Japan. Although nuclear power plays a major role in reducing emissions, in Japan—where there are many natural disasters, such as earthquakes—its supply must be carefully controlled.

Increasing the share of zero-emission power sources is a goal of Japan's power policy, although there are many aspects to consider to achieve it. This study analyzes the effect of the change in the structure of the power sector in Japan, especially the change in the zero-emission power source ratio, on the Japanese economy beyond 2020, using the GTAP-E-Power model. As it is desirable to use the latest database for the simulation, we upgrade the database of the GTAP-E-Power model from GTAP 9.0 to GTAP 10.0.

Section 2 analyzes Japanese time-series data of total power generated in Japan. The results of the data survey indicate a big change in the structure of power supply in Japan after 2011. This section provides an overview of Japanese power supply and policy concerning the power sector.

Section 3 describes the method to create the database of the GTAP-E-Power model—the original database of which is based on GTAP 9.0—adapted to a new aggregation of regions and sectors based on the GTAP 10.0 database, released in February 2020. As the aggregation used in this paper (29 sectors and 5 regions) is different from that of the original GTAP-E-Power aggregation (20 sectors and 16 regions), a new GTAP-E-Power database should be created.

Following a brief survey of previous studies, Section 4 presents the method for analyzing the economic effects of the change in the structure of Japan's power sector using the GTAP-E-Power model. The simulation covers two periods: from 2014 to 2018 and from 2019 to 2030. Regarding the simulations from 2014 to 2018, shocks are introduced for real GDP, labor force, and population for each country; in the case of Japan, shocks are introduced for real GDP, labor force, population, and zero-emission power.

Since the power situation in Japan has changed significantly since 2011, it is important to analyze Japan's electricity supply situation and compare the power data of Japan in 2018 with that of the GTAP 10.0 database. For the first simulation, we set appropriate shock values in the model so that the 2018 values become closer to the actual values.

For the simulations from 2019 to 2030, we first set shock values for real GDP, labor force, and the population growth rate of each country using the same method as in the simulations for 2014 to 2018. We use the projections for 2030 set by the World Energy Outlook 2019 (WEO 2019) for real GDP, and the United Nations projections for the labor force and population. Second, shocks for zero-emission power are set for four scenarios. Each scenario takes a different growth rate of zero-emission power.

Section 5 discusses the simulation results. The change in supply of zero-emission power affects the supply of other base load power and peak load power. The change of the structure of power supply introduces changes in both the macroeconomy and microeconomy, such as industrial output, exports and imports, and consumption.

Section 6 concludes. The simulation results show that if Japan were to make a great effort and keep the growth rate of zero-emission power at the same growth rate as that of the Sustainable Development Scenario of the World Energy Outlook 2019 from 2019 to 2030, then the share of zero-emission power in 2030 would be close to the government's goal. The results also show that the increase of zero-emission power has a positive effect on Japan's real GDP.

2. Background of Japanese power sector and previous research

2.1. Time-series data of Japan's total power generated

Before 2011, Japan continued to increase the share of nuclear power in its power mix. As mentioned in the Fourth Strategic Energy Plan, the Japanese energy plan before 2011 was to increase the ratio of zero-emission power sources (nuclear power and renewable energy) to reach source composition of around 70% toward 2030. The situation changed completely after the Great East Japan Earthquake of 2011. Table 2-1 shows the total power generated in Japan from 2010 to 2018 and Figure 2-1 presents the main power trend in Japan. As Table 2-1 shows, the nuclear power share continued to decrease after 2011, and finally became zero in 2014. In 2015, nuclear power plant restarted and thereafter, continued to increase although its quantity in 2018 was still very low compared with the level in 2010. Since 2011, natural gas and coal power generation have consistently been the main power sources in Japan.

Hydro power generation has been stable since 2011 and has maintained an almost constant amount of power generation. Renewable power sources, namely, solar, wind, geothermal, and biomass power, still had a far lower share of power generation than other power sources in Japan in 2018. However, when these four power sources are combined, as shown in Figure 2-1, the amount of power generated is slightly higher than that from hydro, oil, and nuclear power generation in 2018.

Table 2-1 Total power generated in Japan from 2010 to 2018
(fiscal year, 100 million kWh)

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coal Power	3,199	3,058	3,340	3,571	3,544	3,560	3,448	3,472	3,324
Oil Power	983	1,583	1,885	1,567	1,162	1,006	999	889	737
Natural Gas Power	3,339	4,113	4,320	4,435	4,552	4,257	4,351	4,211	4,029
Nuclear Power	2,882	1,018	159	93	0	94	181	329	649
Hydro Power	838	849	765	794	835	871	795	838	810
Solar Power	35	48	66	129	230	348	458	551	627
Wind Power	40	47	48	52	52	56	62	65	75
Geothermal Power	26	27	26	26	26	26	25	25	25
Biomass Power	152	159	168	178	182	185	197	219	236
Total	11,495	10,902	10,778	10,845	10,584	10,404	10,514	10,598	10,512

Source: Agency for Natural Resources and Energy of the Ministry of Economy, Trade, and Industry of Japan.

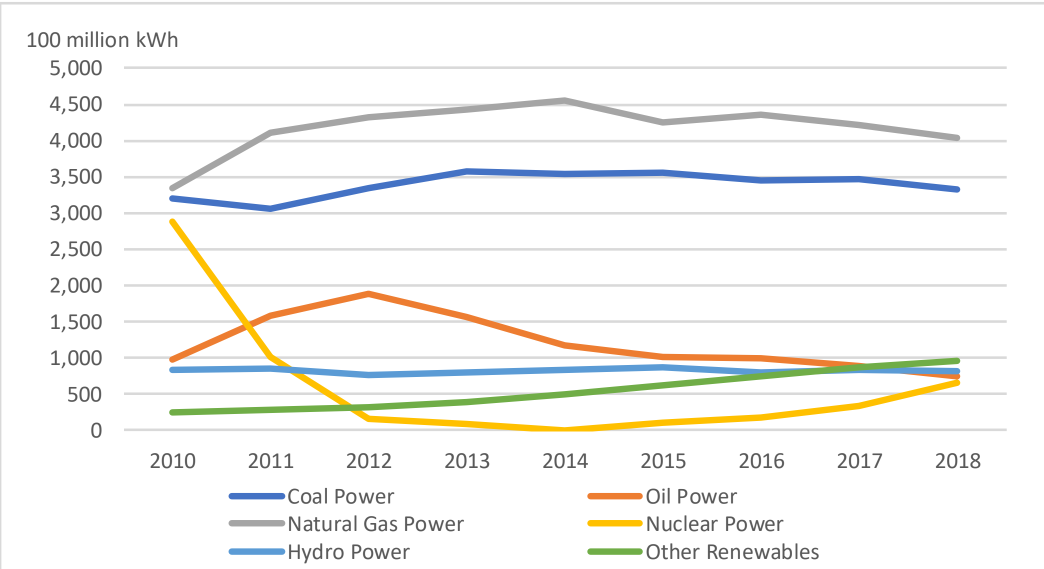

Figure 2-1 Total power generated in Japan from 2010 to 2018
(fiscal year, 100 million kWh)

Source: Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry of Japan.

Table 2-2 shows the share of power generated in Japan from 2010 to 2018 and Figure 2-2 shows the composition of power supply in Japan classified into six categories. As shown in Table 2-2, the share of coal power and that of gas power have been increasing since 2011; in particular, gas power has been growing significantly. Among the zero-emission power sources, solar power has grown the most in recent years.

Figure 2-2 shows the share of zero-emission power in Japan from 2010 to 2018. The share of zero-emission power in Japan was 34.5 % in 2010. After the Great East Japan Earthquake in 2011, it fell to 19.4 % and 11,4% in 2012. After 2012, the share of zero-emission power began an increasing trend again and recovered to 23% in 2018. Although solar power and biomass power were increasing, the share of nuclear power was still low and the share of zero-emission power was below the 2010 level in 2018.

Table 2-2 Share of power generated in Japan from 2010 to 2018
(fiscal year, percentage)

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coal Power	27.8	28.0	31.0	32.9	33.5	34.2	32.8	32.8	31.6
Oil Power	8.6	14.5	17.5	14.4	11.0	9.7	9.5	8.4	7.0
Natural Gas Power	29.0	37.7	40.1	40.9	43.0	40.9	41.4	39.7	38.3
Nuclear Power	25.1	9.3	1.5	0.9	0.0	0.9	1.7	3.1	6.2
Hydro Power	7.3	7.8	7.1	7.3	7.9	8.4	7.6	7.9	7.7
Solar Power	0.3	0.4	0.6	1.2	2.2	3.3	4.4	5.2	6.0
Wind Power	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7
Geothermal Power	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Biomass Power	1.3	1.5	1.6	1.6	1.7	1.8	1.9	2.1	2.2
TOTAL	100	100	100	100	100	100	100	100	100

Source: Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry of Japan.

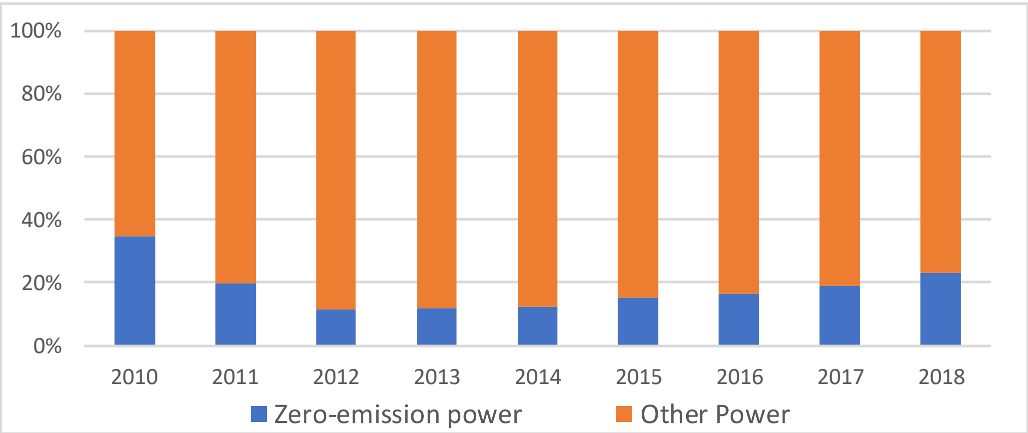

Figure 2-2 Share of zero-emission power in Japan from 2010 to 2018
(fiscal year, percentage)

Source: Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry of Japan.

2.2 Plan for the Japanese power sector

In 2014, 3 years after Great East Japan Earthquake, the Government of Japan established the Fourth Strategic Energy Plan for 2030. As pointed in the Fifth Strategic Energy Plan in 2018, its main policies were rather different from those before 2011, and involved reducing nuclear power dependency, reducing fossil resources dependency, and expanding renewable energy.

The Fifth Strategic Energy Plan revises the long-term energy supply and demand outlook for 2030 and presents design scenarios focused on 2050. The Fifth Strategic Energy Plan points out four Japanese structural issues: vulnerability due to high dependency on overseas energy resources, mid- to long-term changes in the energy demand structure (population decline, etc.), instability of resource prices (increased energy demand in emerging countries, etc.), and increasing global greenhouse gas (GHG) emissions.

Faced with these issues, the Fifth Strategic Energy Plan devises the 2030 energy mix and long-term outlook for 2050 by considering five main points: energy saving, zero-emission power source ratio, energy-derived CO_2 emissions, electricity costs, and energy self-sufficiency. For energy saving, reduction of about 50 million kiloliters of crude oil equivalent compared to before the measures is expected in FY2030 arising from thorough energy-saving measures. The zero-emission power source ratio is expected to reach about 44% in FY2030 through the introduction of renewable energy and the restarting of nuclear power plants that are recognized by the Nuclear Regulation Authority as conforming to regulatory requirements (the most stringent in the world, according to the Fifth Strategic Energy Plan).

Energy-derived CO2 emissions are expected to be about 930 million tons in FY2030. Electricity costs are expected to be 9.2–9.5 trillion yen in FY2030. Energy self-sufficiency is expected to reach 24% in FY2030 through the promotion of the introduction of renewable energy and the restarting of nuclear power plants.

3. Procedures for creating the GTAP-E-Power Database

3. 1. Overview of the GTAP-E and GTAP-E-Power models

The GTAP-E-Power model, whose content is explained in detail by Peters (2016b), is used for the simulations in this research. The GTAP-E-Power model breaks down the power sector based on the framework of the GTAP-E model.

Compared with the standard GTAP model, the main feature of the GTAP-E model is that it has a production structure with energy substitution: inter-fuel substitution and fuel-factor substitution. In the GTAP-E model, energy commodities, which include coal, oil, gas, petroleum and coal products, and electricity, are taken out of the intermediate input nest to be incorporated into the value-added nest. These energy commodities are separated into electricity and non-electricity groups, and the non-electricity group is classified into coal and non-coal groups, the latter consisting of gas, oil, and petroleum products. The production structures in the GTAP model and the GTAP-E model are shown in Figures 3-1, 3-2, and 3-3.

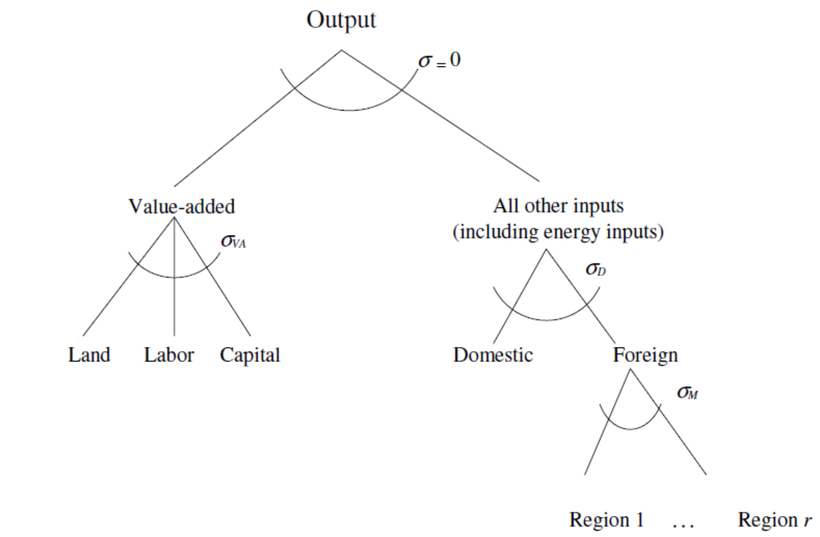

Figure 3-1 Standard GTAP production structure

Source: Burniaux and Truong (2002, Figure 15, p. 30).

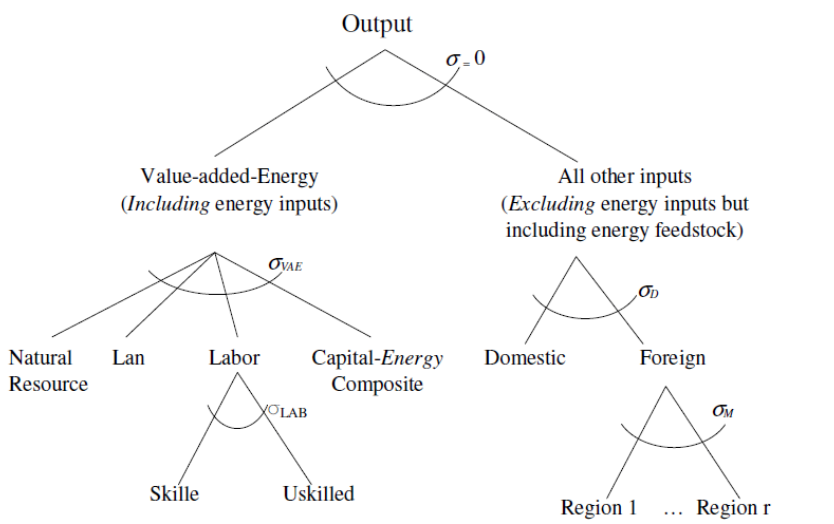

Figure 3-2 GTAP-E production structure

Source: Burniaux and Truong (2002, Figure 16, p. 31).

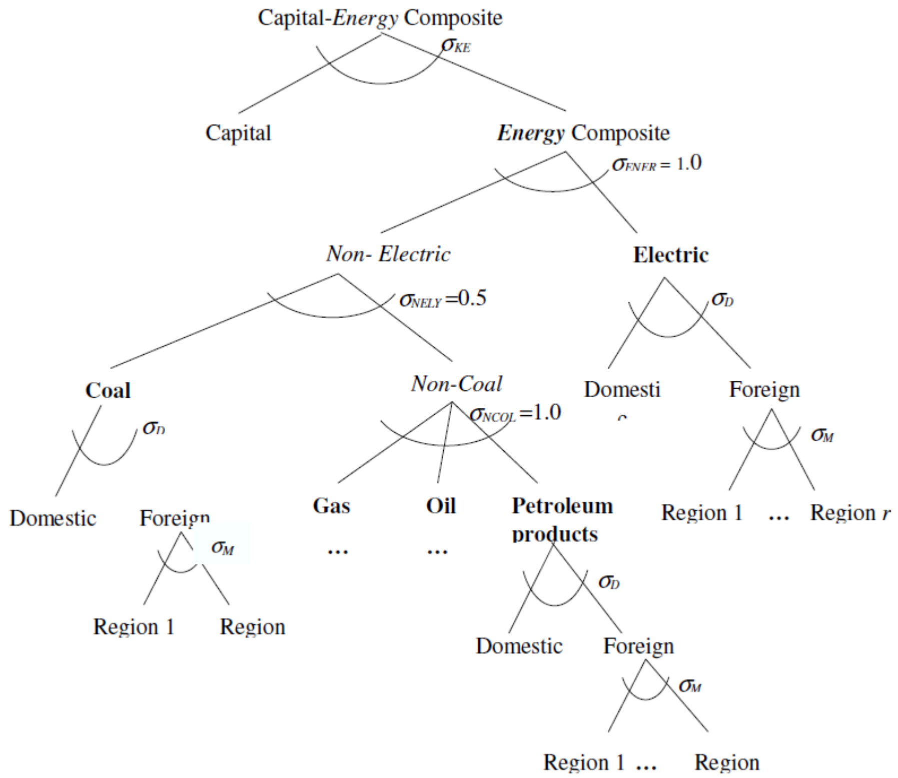

Figure 3-3 GTAP-E capital–energy composite structure
Source: Burniaux and Truong (2002, Figure 17, p. 31).

The GTAP-Power model is a computable general equilibrium (CGE) model using the framework of the standard GTAP model and breaking down the power sector. In the GTAP-Power model, electricity is classified into 12 categories: transmission and distribution ("TnD") and 11 generating technologies: nuclear, coal, gas baseload, gas peak load, oil baseload, oil peak load, hydro base load, hydro peak load, wind, solar, and "other" power-generating technologies. "Other" power includes biofuels, waste, geothermal, and tidal technologies[8].

However, the GTAP-Power model does not incorporate the energy substitution effect. The GTAP-E-Power model makes it possible to conduct simulations using the detailed electricity database of the GTAP-Power model within the framework of the GTAP-E model by introducing an additive constant elasticity of substitution in the power generation sector. The GTAP-E-Power model is used for the simulation in this research. The program, database, and parameter files required for the simulation for the GTAP-E-Power model are available to download.

The power substitution in the GTAP-E-Power model is shown in Figure 3-4. One of the characteristics of the electricity sector of the GTAP-E-Power model is that it is separated

[8] This classification is described in Peters (2016a).

into base load and peak load, according to the sector's capacity for instantaneous adjustment to meet the demand.

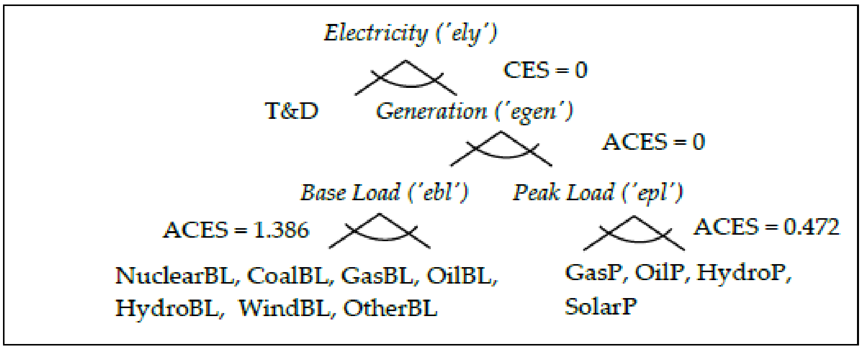

Figure 3-4 Nested electric power substitution in GTAP-E-Power
Source: Peters (2016b, Figure 2, p. 167).

3.2. Procedures for creating the GTAP 10.0 database for the GTAP-E-Power model

3.2.1. Data for the GTAP-E-Power model

The original GTAP-E-Power model database is based on the GTAP 9.0 database, whose base year is 2011, and can be created from the GTAP-Power model and GTAP-E model database. After analyzing the structure of the data and parameters of the GTAP-E-Power model database, we attempt to create the GTAP-E-Power model database for this research from the GTAP-Power model and the GTAP-E model database. To create the GTAP-E-Power database updated for the GTAP 10.0 database and to change the regions and sectors described in the original version, it is necessary to create a new GTAP-E-Power model database. The GTAP 10.0 database, whose latest benchmark year is 2014, was released for the GTAP-E database and GTAP-Power database in February 2020. We use the GTAP 10.0 database for the GTAP-E model and the GTAP-Power model to create the GTAP-E-Power database updated for the GTAP 10.0 database and we change the region and sector aggregation of the original version.

The total number of data in the GTAP-E-Power model is 67. Most of them are taken from the GTAP-Power database. Table 3-1 shows the GTAP-E-Power data taken from Basedata.Har of the GTAP-Power model, Table 3-2 shows the GTAP-E-Power data taken from Gsdvole.HAR of the GTAP-Power model, and Table 3-3 shows the GTAP-E-Power data taken from CO2.HAR of the GTAP-Power model. It should be noticed that some of data need modification. In the data of Table 3-1, the value of DFNC (No. 43) is the same as that of VDFA, and only the names are different. The same holds for DGNC and VDGA, DPNC and VDPA, IFNC and VIFA, IGNC and VIGA, and IPNC and VIPA. In Table 3-3, data taken from Co2.HAR of the GTAP-Power model are applied only for energy commodities; most of the data for the other commodities are zero.

Table 3-1 GTAP-E-Power data taken from Basedata.Har of GTAP-Power model (1)

No.	Name	Dimension	Description
1	DREL	–	GTAP data release identifier
2	DVER	–	Format of GTAP data
3	ADRV	TRAD_COMM*REG*REG	Anti-dumping duty
4	DPSM	REG	Sum of distribution parameters in household demand system
5	EVFA	ENDW_COMM *PROD_COMM*REG	Endowments—firms' purchases at agents' prices
6	EVOA	ENDW_COMM*REG	Endowments—output at agents' prices
7	FBEP	ENDW_COMM *PROD_COMM*REG	Gross factor-based subsidies
8	FTRV	ENDW_COMM *PROD_COMM*REG	Gross factor employment tax revenue
9	ISEP	TRAD_COMM *PROD_COMM*REG*DIR	Net intermediate input subsidies
10	MFRV	TRAD_COMM*REG*REG	Export tax equivalent of MFA quota premia
11	OSEP	TRAD_COMM*REG	Net ordinary output subsidy
12	POP	REG	Population
13	PURV	TRAD_COMM*REG*REG	Export tax equivalent of price undertakings
14	SAVE	REG	Savings—net expenditure at agents' prices
15	TFRV	TRAD_COMM*REG*REG	Ordinary input duty
16	TVOM	TRAD_COMM*REG	Sales of domestic product, at market prices
17	VDEP	REG	Capital stock—value of depreciation
18	VDFA	TRAD_COMM *PROD_COMM*REG	Intermediates—firms' domestic purchases at agents' prices
19	VDFM	TRAD_COMM *PROD_COMM*REG	Intermediates—firms' domestic purchases at market prices
20	VDGA	TRAD_COMM*REG	Intermediates—government domestic purchases at agents' prices
21	VDGM	TRAD_COMM*REG	Intermediates—government domestic purchases at market prices
22	VDPA	TRAD_COMM*REG	Private households—domestic purchases at agents' prices
23	VDPM	TRAD_COMM*REG	Intermediates—household domestic purchases at market prices
24	VFM	ENDW_COMM *PROD_COMM*REG	Endowments—firms' purchases at market prices
25	VIFA	TRAD_COMM *PROD_COMM*REG	Intermediates—firms' imports at agents' prices
26	VIFM	TRAD_COMM *PROD_COMM*REG	Intermediates—firms' imports at market prices
27	VIGA	TRAD_COMM*REG	Intermediates—government imports at agents' prices

Table 3-1 GTAP-E-Power data taken from Basedata.Har of GTAP-Power model (2)

No.	Name	Dimension	Description
28	VIGM	TRAD_COMM*REG	Intermediates—government imports at market prices
29	VIMS	TRAD_COMM*REG*REG	Trade—bilateral imports at market prices
30	VIPA	TRAD_COMM*REG	Intermediates—household imports at agents' prices
31	VIPM	TRAD_COMM*REG	Intermediates—household imports at market prices
32	VIWS	TRAD_COMM*REG*REG	Trade—bilateral imports at world prices
33	VKB	REG	Capital stock—value at beginning of period
34	VRRV	TRAD_COMM*REG*REG	Export tax equivalent of voluntary export restraints
35	VST	MARG_COMM*REG	Trade—exports for international transportation, market prices
36	VTSS	TARTYPE*TRAD_COMM*REG*REG	Import tariff revenue by type of tariffs paid
37	VTWR	MARG_COMM *TRAD_COMM*REG*REG	Margins on international trade
38	VXMD	TRAD_COMM*REG*REG	Trade—bilateral exports at market prices
39	VXWD	TRAD_COMM*REG*REG	Trade—bilateral exports at world prices
40	XTRV	TRAD_COMM*REG*REG	Ordinary export tax
43	DFNC	TRAD_COMM *PROD_COMM*REG	Same as VDFA: Intermediates—firms' domestic purchases at agents' prices
44	DGNC	TRAD_COMM*REG	Same as VDGA: Intermediates—government domestic purchases at agents' prices
45	DPNC	TRAD_COMM*REG	Same as VDPA: Intermediates—household domestic purchases at agents' prices
46	IFNC	TRAD_COMM *PROD_COMM*REG	Same as VIFA: Intermediates—firms' imports at agents' prices
47	IGNC	TRAD_COMM*REG	Same as VIGA: Intermediates—government imports at agents' prices
48	IPNC	TRAD_COMM*REG	Same as VIPA: Intermediates—household imports at agents' prices

Table 3-2 GTAP-E-Power data taken from Gsdvole.HAR of GTAP-Power model

No.	Name	Dimension	Description
56	PROD		Set PROD_COMM Complete enlarged commodity set
57	ERG		Set ERG_COMM Complete enlarged commodity set
58	GWH	NEWERG*REG	GWh for each EGT
59	SNAT	ERG_COMM*NEWCOM *REG	Values of energy commodities in new sectors (domestic, basic)
60	EC		Set ERG_COMM Complete enlarged commodity set
61	EDF	ERG_COMM *PROD_COMM*REG	Usage of domestic product by firms, Mtoe
62	EDG	ENDW_COMM *PROD_COMM*REG	Usage of domestic product by government, Mtoe
63	EDP	ERG_COMM*REG	Usage of domestic product by households, Mtoe
64	EXI	ERG_COMM*REG*REG	Volume of trade, Mtoe
65	EIF	ERG_COMM *PROD_COMM*REG	Usage of imported product by firms, Mtoe
66	EIG	ERG_COMM*REG	Usage of imported product by government, Mtoe
67	EIP	ERG_COMM*REG	Usage of imported product by households, Mtoe

Table 3-3 GTAP-E-Power data taken from CO2.HAR of GTAP-Power model

No.	Name	Dimension	Description
49	CODP	TRAD_COMM*REG	Emissions from private consumption of domestic product, $MtCO_2$
50	COIP	TRAD_COMM*REG	Emissions from private consumption of imported product, $MtCO_2$
51	CODG	TRAD_COMM*REG	Emissions from government consumption of domestic product, $MtCO_2$
52	COIG	TRAD_COMM *PROD_COMM*REG	Emissions from government consumption of imported product, $MtCO_2$
53	CODF	TRAD_COMM *PROD_COMM*REG	Emissions from firms' consumption of domestic product, $MtCO_2$
54	COIF	REG	Emissions from firms' consumption of imported product, $MtCO_2$

The data shown in Table 3-4 can be taken from Basedata.HAR of the GTAP-E model. They concern carbon taxes and CO_2 emissions quotas.

Table 3-4 GTAP-E-Power data taken from Basedata.HAR of GTAP-E model

No.	Name	Dimension	Description
41	NTAX	REG	Nominal carbon tax in USD per ton of carbon
42	GSHR	REG	Government share of permit revenue
55	CO2Q	REG	CO_2 emissions quota, $MtCO_2$

3.2.2. **Parameters for the GTAP-E-Power model**

Parameters for the GTAP-E-Power model can also be created from the GTAP-Power model and GTAP-E model database, consulting the parameters of the original version of the GTAP-E-Power model.

The total number of parameters in the GTAP-E-Power model is 31. Table 3-5 shows the GTAP-E-Power parameters taken from default.prm of the GTAP-Power model, and Table 3-6 shows those taken from default.prm of the GTAP-E model. It is possible to take data in Table 3-7 from the GTAP-E model database for sectors other than power, and to modify data for power sectors; most data take the value zero. Data in Table 3-8 are new parameters of the GTAP-E-Power model. They take the same number: 1, 0.5, 0, 1.386 (SBBL), or 0.472 (SBPK).

Table 3-5 GTAP-E-Power parameters taken from default.prm of GTAP-Power model

No.	Name	Dimension	*
1	DREL		GTAP data release identifier
2	DVER		Format of GTAP data
5	RDLT	NEWERG*REG	Investment allocation binary coefficient
6	RFLX	ERG_COMM*NEWCOM *REG	Expected rate of return flexibility parameter
13	SLUG		Binary parameter for factor mobility: 1=sluggish 0=mobile
14	ESBT	PROD_COMM	Elasticity of intermediate input substitution
15	ETRE	ENDW_COMM	CET between sectors for sluggish primary factors

Table 3-6 GTAP-E-Power parameters taken from default.prm of GTAP-E model

No.	Name	Dimension	Description
3	SUBP	UP_COMM*REG	CDE substitution parameter
4	INCP	UP_COMM*REG	CDE expansion parameter
7	EGEN	REG	Elasticity of substitution in government energy subconsumption
8	EGNN	REG	Elasticity of substitution in government non-energy subconsumption
9	EGUG	REG	Elasticity of substitution in the top of government consumption nest
10	EPEN	REG	Elasticity of substitution in household energy subconsumption
11	TRBL		Set TR_BLOCK emissions trading blocs
12	MAPB		Mapping REGTOBLOC from REG to TRBL

Table 3-7 GTAP-E-Power parameters taken from default.prm of GTAP-E model and modified

No.	Name	Dimension	Description
16	ESBD	TRAD_COMM	Armington CES for domestic/imported allocation (can be taken from GTAP-Power model too)
17	ESBM	TRAD_COMM	Armington CES for regional allocation of imports (can be taken from GTAP-Power model too)
18	SUB1	TRAD_COMM*REG	CDE substitution parameter
19	INC1	TRAD_COMM*REG	CDE expansion parameter
24	EFVE	PROD_COMM*REG	Elasticity of substitution in value-added subproduction
25	SBTR	PROD_COMM*REG	Elasticity of intermediate input substitution at regional level
26	SBDR	TRAD_COMM*REG	Armington CES for domestic/imported allocation at regional level
27	SBMR	TRAD_COMM*REG	Armington CES for regional allocation of imports at regional level

Table 3-8 New parameters for GTAP-E-Power model

No.	Name	Dimension	Description
20	EFEN	PROD_COMM*REG	Elasticity of substitution in energy subproduction
21	EFKE	PROD_COMM*REG	Elasticity of substitution in capital–energy subproduction
22	EFNC	PROD_COMM*REG	Elasticity of substitution in non-coal subproduction
23	EFNL	PROD_COMM*REG	Elasticity of substitution in non-electricity subproduction
28	SBTG	PROD_COMM*REG	Substitution between T&D and generation
29	SBBP	PROD_COMM*REG	Substitution between base load and peak load
30	SBBL	PROD_COMM*REG	Substitution in baseload nest
31	SBPK	PROD_COMM*REG	Substitution in peak load nest

4. Methodology for analyzing the change in the structure of the Japanese power sector

4. 1. Overview of previous studies

As for the study of the impact of power trends on the Japanese economy, several CGE model studies have been conducted on the theme of disasters. In the case of Japan, studies concerning earthquakes have been the main concern. The methods used in these studies can be useful to analyze the effects of electricity on the economy using CGE models. Hagiwara (2001) evaluated the impacts of the 1995 Great Hanshin-Awaji Earthquake using the Kobe CGE model (two regions and 22 sectors)and analyzed the impact of change in capital stock and final demand on production in Kobe city from 1995 to 1997. The study concluded that the damage caused on the supply side, that is, the reduction of capital stock, was particularly serious in the electricity, gas, and water sector.

Ishikura and Ishikawa (2011) analyzed the impact of the reduced use of electric power for the whole of Japan and for the Tokyo metropolitan area using a spatial CGE model. They investigated the effect of a shock to the productivity of the electricity sector in the Tokyo metropolitan area resulting from the reduced electricity supply capacity caused by the Great East Japan Earthquake of 2011. Yamazaki and Ochiai (2011) analyzed the impact of restricted electricity supply in the Kanto area on the whole of Japan and on eight Japanese regions following the Great East Japan Earthquake. The authors used the Japanese multi-regional CGE model developed by the Japan Center for Economic Research. For setting the exogenous values of the simulation, the study reduced the quantity of endowment commodities (capital and labor) and demand for electricity of households in the Kanto area.

These studies treated electricity as an aggregate sector and did not classify electricity generating technologies. Tachi and Ochiai (2011) also used the Japanese multi-regional CGE model developed by the Japan Center for Economic Research, and modified the production function of the electricity sector to obtain exogenous conditions for nuclear, hydroelectric, and thermal power in an analysis of the case in which Japan completely discontinues nuclear electric power.

Long-term climate mitigation policy studies often analyze the effects of Japan's electricity policy. Many of these studies perform complex and large-scale analysis combining multiple models. Sugiyama et al. (2019) employed six energy–economic models developed by different institutions for the assessment of Japan's long-term climate mitigation policy. The six models used in this research are the most widely used among the many models that have been developed to assess Japanese energy and environmental policy: the AIM/CGE model, AIM/Enduse model, DNE21 model, DNE21+ model, IEEJ model, and TIMES-Japan model.

Both the AIM/CGE model and the AIM/Enduse model[10] are developed by the National Institute for Environmental Studies. The AIM/CGE model is a global, top–down, and dynamic recursive CGE model, used mainly to analyze macroeconomic impacts. Fujimori et al. (2012) described four blocks in the AIM/CGE model: production, income distribution, final consumption, and market. The production block represents the structure of the production functions. There are three institutional sectors in the income block: enterprises, government, and households. The AIM/Enduse model is a partial, bottom–up, and dynamic recursive model for each country. In the AIM/Enduse model, a macroeconomic service demand model and GHG emission estimation based on a technology model are combined.

The other four models are partial equilibrium models. The DNE 21 model, developed by The University of Tokyo, and the DNE 21+ model, developed by the Research Institute of Innovative Technology for the Earth, are both global, intertemporal partial equilibrium models. Both the IEEJ model of the Institute of Energy Economics, Japan and the TIMES-Japan model of the Institute of Applied Energy are intertemporal and partial equilibrium models for each country[11].

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[10] A detailed description of the AIM/CGE model is available at AIM Project Team (2009).

[11] Sugiyama et al. (2019) classified these four models.

4. 2. Methodology for analyzing the change in the structure of the Japanese power sector using the GTAP-E-Power model

The simulation in this study covers two periods: from 2014, the base year for the GTAP 10.0 database, to 2018; and from 2019 to 2030.

Regarding the simulations from 2014 to 2018, shocks are introduced for real GDP, labor force, and population for each country; in the case of Japan, shocks are introduced for real GDP, labor force, population, and the supply of zero-emission base load and peak load power. World Bank data are used for real GDP growth rate, and United Nations data are used for labor force and population in each country. For Japan's electricity data, we use data from the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry of Japan.

Since the power situation in Japan has changed significantly since 2014, it is important to analyze Japan's electricity supply situation in detail and compare the power data of Japan in 2014 with that of the GTAP 10.0 database. It should be noticed that there is a rather significant difference between the result of the simulations from 2014 to 2018 concerning the supply of electricity and the data of the Agency for Natural Resources and Energy when the shocks occur only for the growth rate of real GDP, labor force, and population. Therefore, it is necessary to adjust the result of the power supply. When power supply is classified into detailed categories, it becomes difficult to adjust all the power supply data. For the result of the power supply period 2014–2018 to reflect reality, we classify categories of the power generation sector as follows: zero-emission baseload power, including NuclearBL, HydroBL, and WindBL (BL represents base load), Coal power (base load), Gas power (base load), Oil power (base load), Other base load, Gas and oil power (peak load), and Solar and hydro power (peak load)[12].

Two simulations are necessary to analyze the effect of the change in Japanese power supply. In the first simulation, the basic closure is changed by setting the variable afreg (REG) as endogenous and the variable qgdp (REG) as exogenous. To obtain the shock value to the zero-emission power, the variables aoall ("NucHyWdSBL," "JPN"), aoall ("OtherBL," "JPN") and aoall ("SolarHP," "JPN") are set as endogenous and the variables qo("NucHyWdSBL," "JPN"), qo("OtherBL," "JPN"), and qo("SolarHP," "JPN") as exogenous. By setting the variable Expand[13] as exogenous, we can obtain the growth rate of capital stock, qo("capital,"REG), which is necessary to attain the targeted GDP growth rate. For the labor force and the population, shocks are given to

[12] In the GTAP 10.0 database, hydro power for peak load is zero and the share of OilBL is only 0.1%.

[13] Francois et al. (1996) explained the variable Expand in detail.

the variables qo for endowment commodities, as in the basic closure. In the next simulation, which uses the basic closure, by setting the growth rate of productivity, capital stock, and productivity of the Japanese zero-emission power sector obtained from the former simulation, and the growth rate of labor force and population, we can update the data based on 2014 to 2018 taking into account the change in the Japanese power sector.

Table 4-1 shows the share of Japan's power in 2018 calculated from the data of the Agency for Natural Resources and Energy and the results of the simulation by the GTAP-E-Power model before and after adjustment. When only real GDP, population, and labor force are given to the model as shock values, the result of the power data in 2018 is as shown in the column before adjustment and often differs from the actual Japanese data. There are still some large differences in Coal BL and GasP and OilP after adjustment; however, it is difficult to adjust all the power data, both base load and peak load. Here, we prioritize adjusting the share of zero-emission power. We adjust the power data so that the final result of the share of the total zero-emission power (nuclear, hydro, wind, solar, and other power) corresponds to the data of the Agency for Natural Resources and Energy. As a result, the value of Gas BL also becomes close to the actual data. As a reference, we compare the GTAP-E-Power data with the data obtained from the WEO 2019. The percentage of zero-emission power in Japan in 2018 based on the WEO 2019 data exceeded that based on the Japanese Agency for Natural Resources and Energy data, and reached 25%.

Table 4-1 Share of Japan's power in 2018 (percentage)

	Data from Agency for Natural Resources and Energy	Result of the GTAP-E-Power before adjustment	Result of the GTAP-E-Power after adjustment	Data from World Energy Outlook 2019
NuclearBl, HydroBL and WindBL	14.6	8.1	14.6	14.5
CoalBL	31.6	23.9	21.3	32.2
GasBL	38.3	40.9	37.2	36.7
OilBL	—	0.1	0.1	—
OtherBL	2.4	1.4	2.4	4.2
GasP and OilP	7.0	22.6	18.3	6.1
SolarP and HydroP	6.0	2.9	6.0	6.3
zero-emission power	23.0	12.4	23.0	25.0
Other power	76.9	87.6	77.0	75.0
Total	100	100.0	100.0	100.0

Sources: Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry of Japan; World Energy Outlook 2019; Results of the GTAP-E-POWER model are simulated by the authors.

For the simulations from 2019 to 2030, we first perform a simulation for Scenario 1. For Scenario 1, shock values are set only for real GDP, labor force, and the population growth rate of each country using the same method as in the simulations for 2014–2018. We use the projections by the WEO 2019 for real GDP, and World Population Prospects 2019 for the labor force and population.

We give the zero-emission power generation in the GTAP-E-Power model the same growth rate from 2019 to 2030 as the WEO 2019 in the following scenarios: Scenario 2 (Stated Policies Scenario of WEO 2019), Scenario 3 (Current Policies Scenario of WEO 2019), and Scenario 4 (Sustainable Development Scenario of WEO 2019)[14]. The WEO 2019 uses the World Energy Model and provides various settings to perform the simulation. In this study, we analyze changes in the Japanese economy without setting constraints on non-zero-emission power generation, and the setting regarding zero-emission power generation is given only for Japan[15]. Although we would not expect the simulation results of both models to match even if the same scenarios were used, considering the differences of the type of models, databases, and settings, the scenarios of the WEO 2019 would be useful references for scenarios assumed for Japan in the future.

The Stated Policies Scenario, which is a central scenario in the WEO 2019 analysis, considers policies that have already been announced. It reflects the impact of energy-related policies that governments have already implemented and an assessment of the likely effects of announced policies, as expressed in official targets and plans. In the Current Policies Scenario, such announcements are not considered[16]. The Sustainable Development Scenario sets out the major changes that would be required to reach the goals of the United Nations Sustainable Development Goals. These goals include an early peak and rapid subsequent reductions in carbon emissions—in line with the Paris Agreement on climate change, universal access to modern energy by 2030, and a dramatic reduction in energy-related air pollution.

Scenarios 2, 3, and 4 use as shock values the productivity and capital stock simulated from Scenario 1, the population and labor force growth rate used in Scenario 1, and

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[14] The scenario description and model structure are detailed in WEO (2019b).

[15] Takeda et al. (2016) studied the GTAP-Power database in GTAP 9.0 and pointed out that although the power data in the GTAP-Power database are almost consistent with other data, such as those of the IEA, emission data are rather different from IEA statistics. Considering this point, and taking into account that there is no special setting for non-zero-emission power, this study does not aim to analyze the simulation results concerning emissions.

[16] According to the WEO 2019, although the Current Policies Scenario provides such a "business-as-usual" picture, its 1.3% average annual growth in energy demand to 2040 is well below the rate seen in 2018.

different settings of the growth rate of zero-emission power. Shock values are given to industry output of zero-emission power, qo("NucHyWdSBL","JPN"), qo("OtherBL","JPN"), and qo("SolarHP","JPN"), using the same method as in the simulations for 2014–2018.

Shock values used in the simulations of this study are shown in Table 4-2 and the contents of each scenario are shown in Table 4-3.

Table 4-2 Macro shock values for all scenarios
(average annual growth rate, percentage)

	GDP growth rate			Labor force growth rate			Population growth rate		
	2014～2018	2019～2025	2026～2030	2014～2018	2019～2025	2026～2030	2014～2018	2019～2025	2026～2030
North America	2.3	2.0	2.0	0.4	0.2	0.1	0.7	0.6	0.6
Europe	2.2	1.6	1.6	-0.2	-0.3	-0.5	0.2	0.1	0.0
Japan	1.1	0.7	0.7	-0.9	-0.7	-0.7	-0.2	-0.4	-0.5
China	6.6	5.2	5.2	0.0	-0.1	-0.4	0.5	0.3	0.1
Rest of the World	2.7	2.6	2.6	1.6	1.5	1.3	1.5	1.3	1.2

Sources: The GDP growth rate from 2014 to 2018 is taken from The World Bank (2019) and GDP from 2019 to 2030 is taken from the World Energy Outlook 2019. Labor force[17] and population growth rate are taken from the United Nations Population Division (2019).

Table 4-3 Contents of scenarios

Scenario 1	Shocks are given only for real GDP, population, and labor force (without setting for power sectors).
Scenario 2	Shocks are given for real GDP, population, labor force, and zero-emission power in Japan whose growth rate is the same as the WEO 2019 Stated Policies Scenario. The average annual growth rate from 2019 to 2030 is 6.8% for Nuclear+HydroBL+WindBL, 3.2% for OtherBL, and 2.5% for SolarHP.
Scenario 3	Shocks are given for real GDP, population, labor force, and zero-emission power in Japan whose growth rate is the same as the WEO 2019 Current Policies Scenario. The average annual growth rate from 2019 to 2030 is 6.1% for Nuclear+HydroBL+WindBL, 2.6% for OtherBL, and 2.5% for SolarHP.
Scenario 4	Shocks are given for real GDP, population, labor force, and zero-emission power in Japan whose growth rate is the same as the WEO 2019 Sustainable Development Scenario. The average annual growth rate from 2019 to 2030 is 8.2% for Nuclear+HydroBL+WindBL, 4.4 % for OtherBL, and 3.4% for SolarHP.

[17] The labor force corresponds to the population aged 15–64 years.

4.3. Aggregation of regions and sectors

The GTAP-E-Power model was developed with 16 regions and 20 sectors of aggregation. As this study aims to analyze the impacts of the change in the configuration of power only in Japan, there would be little impact in other regions. Therefore, regional aggregation in this study remains at the small size of five regions.

In the original version of the GTAP-E-Power model, power generation sectors are divided into 11 categories. Since the shock values to the power sectors are relatively large, in this study, they are classified in seven categories. NuclearBl, HydroBL, and WindBL are classified as one category NucHyWdSBL, zero-emission base load power. Although OilBL in Japan is classified as an independent category, it was actually zero in the GTAP 9.0 database. With the GTAP 10.0 database, the share of the simulated supply of OilBL in 2014 remains only about 0.1%. GasP and OilP are classified in the same category GasOilP, gas and oil peak load power. SolarP and HydroP are classified in the same category SolarHP, zero-emission peak load power. As simulated output in the base year of HydroP in Japan is zero for both GTAP9.0 and GTAP 10.0, SolarHP in Japan is actually be considered as solar power.

Other sectors, especially industrial sectors, are classified in more detail than in the original version; they are classified into 21 categories. The service sector is treated collectively, and the agriculture, forestry, and fishing industries are treated collectively, too. In total, there are 29 sector classifications.

Table 4-4 shows the regional disaggregation and Table 4-5 the sectoral disaggregation in this study.

Table 4-4 Regional disaggregation

No.	New Code	Region Description	Comprising GTAP 10.0 Countries/Regions
1	NAM	North America	Canada and United States
2	EUx	Europe	European Union, United Kingdom, Switzerland, Norway
3	JPN	Japan	Japan
4	CHN	China	China and Hong Kong
5	ROW	Rest of the world	Rest of the world

Table 4-5 Sectoral disaggregation

No.	New Code	Sector Description	Comprising GTAP 10.0 Sectors
1	AGR	Agriculture, forestry, and fishing	Paddy rice, wheat, cereal grains nec, vegetables, fruit, nuts, oil seeds, sugar cane, sugar beet, plant-based fibers, crops nec, bovine cattle, sheep and goats, horses, animal products nec, raw milk, wool, silkworm cocoons, forestry, fishing
2	Coal	Coal	Coal
3	Oil	Oil	Oil
4	Gas	Natural gas extraction	Gas, gas manufacture, distribution
5	Oil_Pcts	Petroleum, coal products	Petroleum, coal products
6	TnD	Transmission and distribution	Transmission and distribution
7	NucHyWdSBL	Zero-emission baseload power	NuclearBl, HydroBL, WindBL
8	CoalBL	CoalBL	Coal (Baseload)
9	GasBL	GasBL	Gas (Baseload)
10	OilBL	OilBL	Oil (Baseload)
11	OtherBL	OtherBL	Other (Baseload: waste, geothermal, and tidal technologies)
12	GasOilP	Gas and oil (peak load)	GasP and OilP
13	SolarHP	Zero-emission peak load power	SolarP and HydroP
14	OXT	Minerals nec	Minerals nec
15	PFD	Food processing	Bovine cattle, sheep, and goat meat products, meat products, vegetable oils and fats, dairy products, processed rice, sugar, food products nec, beverages, and tobacco products
16	CHM	Chemical products	Manufacture of chemicals and chemical products
17	BPH	Basic pharmaceutical products	Manufacture of pharmaceuticals, medicinal chemicals, and botanical products
18	RPP	Rubber and plastic products	Manufacture of rubber and plastic products
19	NMM	Mineral products nec	Manufacture of other non-metallic mineral products
20	I_S	Ferrous metals	Iron and steel: basic production and casting
21	NFM	Metals nec	Non-ferrous metals: production and casting of copper, aluminum, zinc, lead, gold, and silver
22	FMP	Metal products	Manufacture of fabricated metal products, except machinery and equipment

Table 4-5 Sectoral disaggregation (2)

No.	New Code	Sector Description	Comprising GTAP 10.0 Sectors
23	ELE	Computer, electronic, and optic	Manufacture of computer, electronic, and optical products
24	EEQ	Electrical equipment	Manufacture of electrical equipment
25	OME	Machinery and equipment nec	Manufacture of machinery and equipment nec
26	MVH	Motor vehicles and parts	Manufacture of motor vehicles, trailers, and semi-trailers
27	OTN	Transportation equipment nec	Manufacture of other transportation equipment
28	OMF	Manufacturers nec	Other manufacturing: includes furniture
29	Services	Services	Water supply, construction, wholesale and retail trade, accommodation, land transport, water transport, air transport, warehousing and support activities, information and communication, finance, insurance, real estate, other business services nec, recreation and other services, other services (government)

5. Analysis of Japanese power supply beyond 2020

5.1. Macroeconomic changes

Table 5-1 shows the simulation results of the changes in average annual GDP growth rate percentages of the four scenarios defined in the previous section. As the proportion of zero-emission power increases, GDP growth has a rather positive effect in Japan.

Table 5-1 Changes in average annual growth rate of real GDP (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
North America	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
European countries	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
Japan	0.70	0.73	0.73	0.74	0.70	0.73	0.73	0.75
China	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
Rest of World	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60

Source: the authors.

Table 5-2 shows the simulation results of the changes in average annual growth rate of real exports. In Japan, when zero-emission power sources increase, exports show a growth trend. Export growth is especially evident in the Sustainable Development Scenario.

Table 5-2 Changes in average annual growth rate of real exports (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
North America	1.64	1.64	1.63	1.63	1.62	1.62	1.62	1.61
European countries	1.24	1.24	1.24	1.23	1.21	1.21	1.21	1.21
Japan	0.80	0.79	0.80	0.81	0.79	0.82	0.82	0.87
China	3.76	3.76	3.76	3.75	3.93	3.92	3.92	3.91
Rest of World	2.25	2.25	2.25	2.25	2.22	2.22	2.22	2.22

Source: the authors.

Table 5-3 shows the simulation results of the changes in average annual growth rate of real imports. In Japan, as the share of zero-emission power sources increases, imports decline. Here, too, in the Sustainable Development Scenario, a decrease in imports in Japan is the largest among the four scenarios. Increasing exports and decreasing imports have a positive effect on Japan's real GDP growth rate.

Table 5-3 Changes in average annual growth rate of real imports (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
North America	2.00	2.00	2.00	2.00	2.04	2.04	2.04	2.04
European countries	1.25	1.25	1.25	1.25	1.23	1.23	1.23	1.23
Japan	0.79	0.73	0.73	0.70	0.74	0.65	0.66	0.60
China	3.67	3.68	3.68	3.68	3.67	3.68	3.68	3.68
Rest of World	2.25	2.25	2.25	2.25	2.26	2.26	2.26	2.26

Source: the authors

5.2. Changes in power sectors

Table 5-4 shows the simulation results of the changes in average annual growth rate of power sectors in Japan. In scenario 1, whose shock values concern only GDP, labor force, and population growth rate, all power sectors increase and the growth rate of non-zero-emission power sectors is slightly higher than that of zero-emission power sectors. The annual growth rate of NucHyWdSBL, which includes nuclear power, hydro power, and wind power, remains at 0.33% and Other BL at 0.51%. In Scenarios 2, 3, and 4, the growth rates of NucHyWdSBL, Other BL, and SolarHP are fixed, while those of other power sectors change depending on the scenario. As the growth rate of zero-emission power sources increases, that of other power sources decreases. In the Sustainable Development Scenario, non-zero-emission power decreases in both the base load and peak load.

The simulations in this study give no shocks for non-zero-emission power sources. When the effects of various policies related to non-zero-emission power are incorporated into the model, the supply of non-zero-emission power may be further reduced.

Table 5-4 Impacts on Japan's industrial output: annual growth rate of power sectors (percentage)

	2019-2025				2025-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
NuclearBl, HydroBL WindBL	0.33	6.76	6.09	8.16	0.29	6.76	6.09	8.16
CoalBL	0.75	-0.65	-0.45	-1.05	0.77	-1.46	-1.05	-2.50
GasBL	0.98	-0.42	-0.22	-0.83	0.92	-1.31	-0.90	-2.35
OilBL	1.11	-0.30	-0.10	-0.72	0.92	-1.33	-0.91	-2.37
OtherBL	0.51	3.18	2.60	4.41	0.45	3.18	2.60	4.41
GasP and OilP	0.87	0.39	0.36	0.06	0.82	0.29	0.24	-0.18
SolarP and HydroP	0.60	2.48	2.48	3.37	0.61	2.48	2.48	3.37

Source: the authors

Table 5-5 and Figure 5-1 show the simulation results of the power supply configuration in 2030 in Japan[18]. Although GasBL is the largest power sector in Scenarios 1, 2, and 3, NucHyWdSBL exceeds GasBL in Scenario 4 and becomes the largest power sector.

[18] The quantity amount in 2030 is calculated by multiplying the simulation results of the quantity of the period from 2014 to 2018 by the subsequent growth rate. The share in 2030 is calculated from these amounts.

Table 5-5 Power supply configuration in 2030 (percentage)

	Scenario1	Scenario2	Scenario3	Scenario4
NuclearBl, HydroBL WindBL	13.9%	27.8%	26.0%	32.0%
CoalBL	21.3%	16.4%	17.1%	14.9%
GasBL	38.0%	29.2%	30.5%	26.5%
OilBL	0.1%	0.1%	0.1%	0.1%
OtherBL	2.3%	3.0%	2.9%	3.4%
GasP and OilP	18.6%	16.6%	16.6%	15.6%
SolarP and HydroP	5.8%	6.9%	6.9%	7.5%
TOTAL	100.0%	100.0%	100.0%	100.0%

Source: the authors

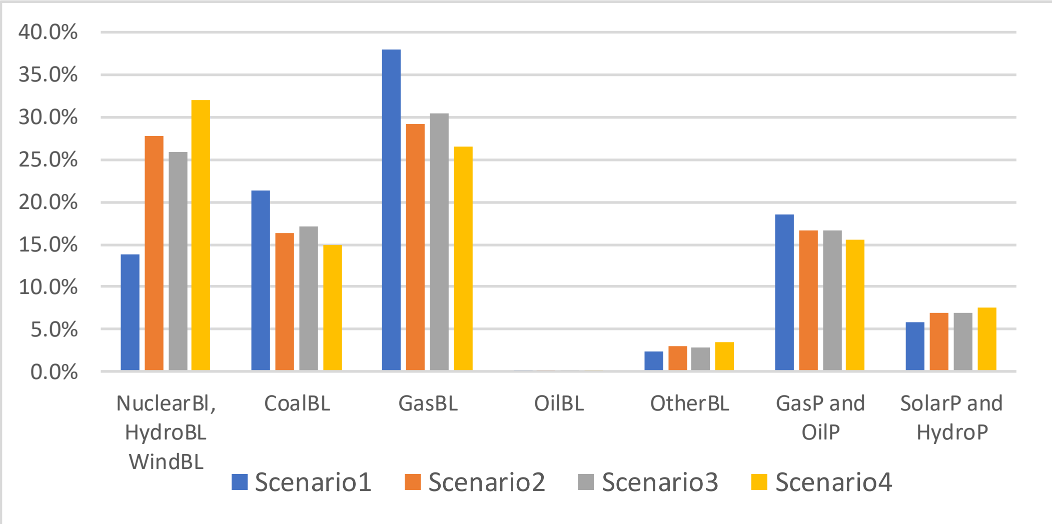

Figure 5-1 Power supply configuration in 2030 (percentage)

Source: the authors.

Table 5-6 and Figure 5-2 show the simulation results of the share of the zero-emission power and other power in 2030 in Japan. In Scenario 2 the share of zero-emission power, both base load and peak load, will be 38%, and in Scenario 3, it will be 36%. In Scenario 4 the zero-emission power will account for 43% of the total power supply in Japan, close to the government’s goal.

Table 5-6 Power supply configuration in 2030: Zero-emission power and other power (percentage)

	Scenario1	Scenario2	Scenario3	Scenario4
Zero-emission power	22%	38%	36%	43%
Other power	78%	62%	64%	57%
Total	100%	100%	100%	100%

Source: the authors.

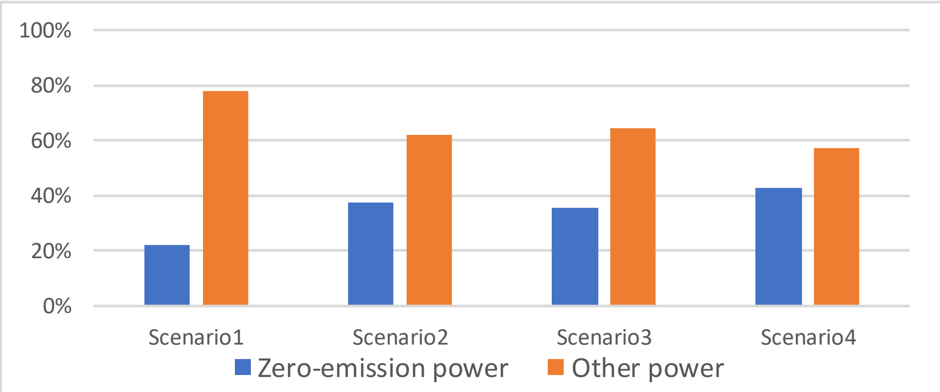

Figure 5-2 Power supply configuration in 2030: Zero-emission power and other power (percentage)

Source: the authors

Table 5-7 shows the simulation results of the share of the zero-emission power and other power for base load in 2030 in Japan. Table 5-8 shows the simulation results of the zero-emission power and other power for peak load. As for base load, the share of nuclear power, hydro power and wind power exceeds 40% in Scenario 4. Including Other BL, the share of zero-emission base load power exceeds 46%. Concerning peak load, the share of solar power is about 29% in Scenarios 2 and 3, and exceeds 30% in Scenario 4.

Table 5-7 Power supply configuration in 2030: base load (percentage)

	Scenario1	Scenario2	Scenario3	Scenario4
NuclearBl, HydroBL WindBL	18.3%	36.3%	33.9%	41.6%
CoalBL	28.2%	21.4%	22.4%	19.3%
GasBL	50.3%	38.2%	39.9%	34.5%
OilBL	0.1%	0.1%	0.1%	0.1%
OtherBL	3.1%	4.0%	3.7%	4.5%
TOTAL	100.0%	100.0%	100.0%	100.0%

Source: Authors.

Table 5-8 Power supply configuration in 2030: Peak load (percentage)

	Scenario1	Scenario2	Scenario3	Scenario4
GasP and OilP	76.2%	70.7%	70.6%	67.5%
SolarP and HydroP	23.8%	29.3%	29.4%	32.5%
TOTAL	100.0%	100.0%	100.0%	100.0%

Source: the authors.

5.3. Changes in industrial output

Figure 5-3 shows the simulation result of the changes in industrial outputs of sectors other than power in the average annual growth rate from 2026 to 2030. Table 5-9 shows the simulation results of the changes in the average annual growth rate of industrial output of sectors other than power in Japan from 2019 to 2030.

The differences by scenarios are relatively large in energy sectors, that is, coal, oil, and gas, of which extremely little is produced in Japan, and petroleum and coal products, of which large volumes are produced. As the share of zero-emission power increases, although many sectors other than energy tend to remain at the same level, some sectors tends to increase.

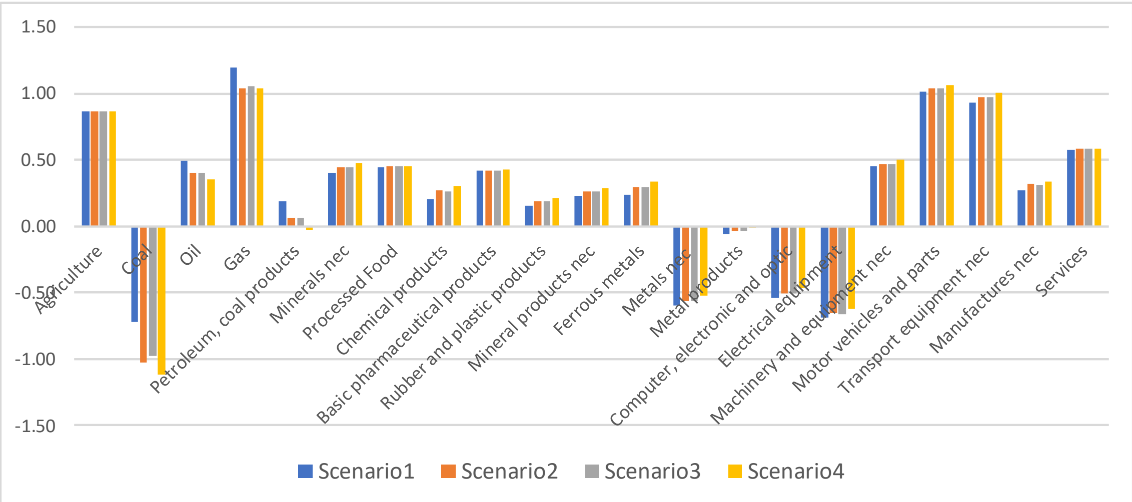

Figure 5-3 Impacts on Japan's industrial output: annual growth rate of non-power sectors from 2026 to 2030 (percentage)

Source: the authors.

Table 5-9 Impacts on Japan's industrial output: annual growth rate of non-power sectors (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
Agriculture	0.71	0.71	0.71	0.71	0.86	0.86	0.86	0.86
Coal	-0.47	-0.72	-0.68	-0.77	-0.72	-1.03	-0.98	-1.12
Oil	0.66	0.55	0.55	0.50	0.49	0.40	0.40	0.35
Gas	0.94	0.71	0.73	0.66	1.19	1.03	1.05	1.04
Petroleum, coal products	0.35	0.24	0.23	0.17	0.19	0.07	0.06	-0.03
Minerals nec	0.27	0.29	0.29	0.31	0.40	0.45	0.44	0.48
Processed Food	0.45	0.46	0.46	0.46	0.44	0.45	0.45	0.45
Chemical products	0.39	0.43	0.43	0.46	0.21	0.27	0.26	0.31
Basic pharmaceutical products	0.39	0.39	0.39	0.39	0.42	0.42	0.42	0.43
Rubber and plastic products	0.20	0.22	0.22	0.23	0.15	0.19	0.18	0.21
Mineral products nec	0.26	0.28	0.28	0.30	0.23	0.26	0.26	0.29
Ferrous metals	0.27	0.31	0.31	0.33	0.24	0.30	0.29	0.33
Metals nec	-0.53	-0.52	-0.52	-0.50	-0.60	-0.56	-0.56	-0.52
Metal products	0.02	0.03	0.03	0.04	-0.06	-0.03	-0.03	-0.01
Computer, electronic and optic	-0.42	-0.42	-0.42	-0.41	-0.54	-0.51	-0.51	-0.46
Electrical equipment	-0.50	-0.51	-0.50	-0.49	-0.69	-0.66	-0.66	-0.62
Machinery and equipment nec	0.50	0.50	0.50	0.51	0.45	0.47	0.47	0.50
Motor vehicles and parts	1.00	1.01	1.01	1.02	1.01	1.04	1.04	1.07
Transport equipment nec	0.89	0.91	0.91	0.93	0.93	0.97	0.97	1.00
Manufactures nec	0.24	0.27	0.27	0.29	0.27	0.32	0.31	0.34
Services	0.58	0.59	0.59	0.59	0.58	0.58	0.58	0.58

Source: the authors.

5.4. Changes in exports by commodity

Table 5-10 shows the simulation results of the changes in exports by commodity in average annual growth rate in Japan from 2019 to 2030.[19]. Figure 5-4 shows the simulation result of the changes in exports by commodity in the average annual growth rate from 2026 to 2030[20].

[19] As for power sectors, the growth rate of exports is obtained from the simulation results. However, its quantity is actually zero as Japan does not export electricity. The same applies for imports.

[20] The agricultural sector, which has a higher growth rate than other sectors, although the absolute amount is very small, is not included in Figure 5-4.

Exports of Japan do not change much as the scenarios of other countries do not change. However, in Scenarios 2,3, and 4, the growth rate of export values exceeds that in Scenario 1 in almost all sectors[21].

Table 5-10 Impacts on Japan's exports in non-power sectors by commodity: annual growth rate (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
Agriculture	6.27	6.21	6.22	6.20	7.41	7.41	7.42	7.42
Coal	0.48	0.45	0.46	0.46	0.01	0.01	0.01	0.06
Oil	3.27	3.30	3.32	3.36	3.34	3.34	3.35	3.45
Gas	1.19	0.49	0.58	0.40	2.50	2.50	2.56	2.59
Petroleum, coal products	0.98	1.01	1.01	1.03	0.58	0.61	0.60	0.62
Minerals nec	3.32	3.32	3.32	3.33	3.74	3.74	3.73	3.74
Processed Food	2.24	2.24	2.25	2.25	2.76	2.76	2.76	2.79
Chemical products	0.88	0.88	0.88	0.91	0.62	0.62	0.61	0.67
Basic pharmaceutical products	0.88	0.88	0.89	0.89	1.17	1.17	1.17	1.21
Rubber and plastic products	0.51	0.51	0.51	0.53	0.45	0.45	0.45	0.50
Mineral products nec	0.98	0.98	0.98	1.02	0.96	0.96	0.95	1.02
Ferrous metals	1.04	1.04	1.03	1.08	1.03	1.03	1.01	1.09
Metals nec	-0.35	-0.35	-0.35	-0.33	-0.38	-0.38	-0.38	-0.33
Metal products	-0.33	-0.33	-0.32	-0.31	-0.44	-0.44	-0.45	-0.39
Computer, electronic and optic	-0.17	-0.17	-0.16	-0.15	-0.24	-0.24	-0.24	-0.19
Electrical equipment	-0.60	-0.60	-0.59	-0.59	-0.78	-0.78	-0.78	-0.73
Machinery and equipment nec	0.72	0.72	0.73	0.73	0.72	0.72	0.72	0.76
Motor vehicles and parts	1.36	1.36	1.36	1.37	1.40	1.40	1.40	1.44
Transport equipment nec	1.52	1.52	1.52	1.54	1.66	1.66	1.66	1.72
Manufactures nec	1.04	1.04	1.04	1.07	1.27	1.27	1.26	1.33
Services	1.47	1.47	1.48	1.47	1.58	1.58	1.59	1.60

Source: the authors.

[21] In addition to agriculture, in some sectors, such as coal, oil, and gas, the amount of exports is low even if the growth rate is high.

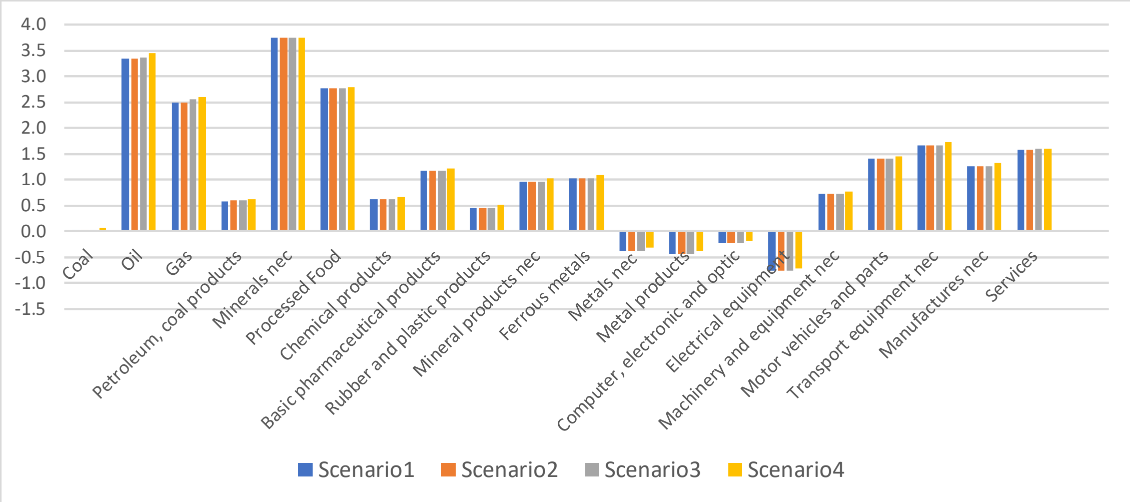

Figure 5-4 Impacts on Japan's exports by commodity: annual growth rate from 2026 to 2030 (percentage)

Source: the authors.

5.5. Changes in imports

Figure 5-5 shows the simulation result of the changes in imports in Japan by commodity in the average annual growth rate from 2026 to 2030. Table 5-11 shows the simulation results of the changes in the average annual growth rate of imports in Japan from 2019 to 2030.

We observe a difference between the energy sectors and other sectors regarding import trends. Imports in sectors other than energy do not change significantly between scenarios. On the other hand, imports in energy sectors decline as the share of zero-emission power increases.

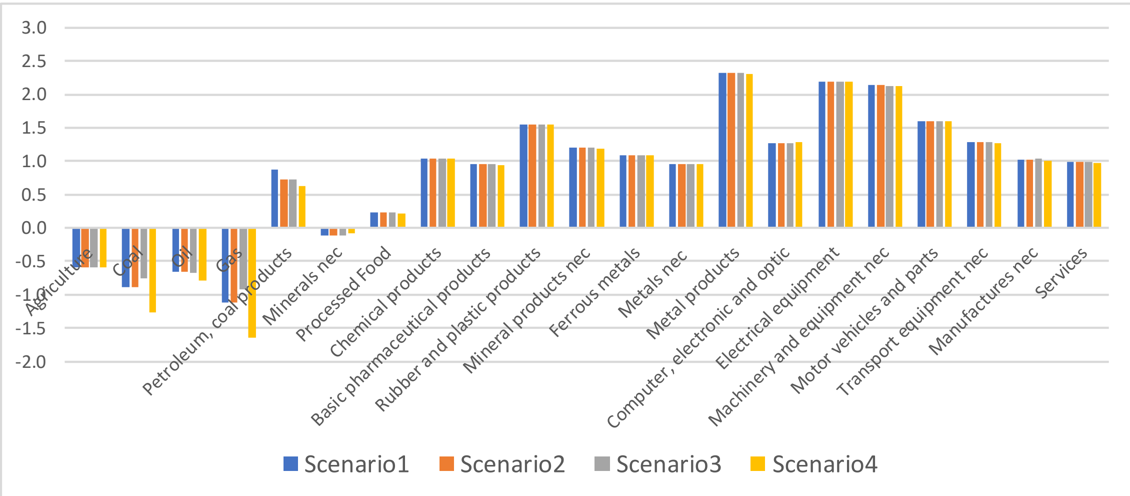

Figure 5-5 Impacts on Japan's imports by commodity: annual growth rate of non-power sectors from 2026 to 2030 (percentage)

Source: Authors.

Table 5-11 Impacts on Japan's imports in non-power sectors by commodity: annual growth rate (percentage)

	2019-2025				2026-2030			
	Scenario1	Scenario2	Scenario3	Scenario4	Scenario1	Scenario2	Scenario3	Scenario4
Agriculture	-0.38	-0.35	-0.35	-0.34	-0.59	-0.59	-0.59	-0.59
Coal	0.06	-0.50	-0.44	-0.68	-0.89	-0.89	-0.75	-1.27
Oil	-0.31	-0.46	-0.47	-0.55	-0.66	-0.66	-0.67	-0.79
Gas	0.17	-0.60	-0.50	-0.83	-1.13	-1.13	-0.92	-1.65
Petroleum, coal products	0.83	0.69	0.69	0.61	0.87	0.73	0.72	0.62
Minerals nec	-0.10	-0.07	-0.07	-0.06	-0.11	-0.11	-0.12	-0.08
Processed Food	0.43	0.46	0.45	0.46	0.23	0.23	0.23	0.21
Chemical products	0.99	0.99	0.99	0.99	1.04	1.04	1.04	1.04
Basic pharmaceutical products	0.99	1.02	1.02	1.03	0.96	0.96	0.96	0.95
Rubber and plastic products	1.53	1.53	1.53	1.53	1.55	1.55	1.55	1.55
Mineral products nec	1.22	1.18	1.19	1.17	1.21	1.21	1.21	1.19
Ferrous metals	1.15	1.11	1.12	1.11	1.09	1.09	1.09	1.09
Metals nec	1.00	1.01	1.01	1.02	0.95	0.95	0.95	0.97
Metal products	2.24	2.24	2.24	2.24	2.32	2.32	2.32	2.30
Computer, electronic and optic	1.27	1.30	1.29	1.30	1.28	1.28	1.27	1.28
Electrical equipment	2.15	2.19	2.19	2.20	2.20	2.20	2.19	2.20
Machinery and equipment nec	2.04	2.10	2.10	2.11	2.14	2.14	2.13	2.13
Motor vehicles and parts	1.55	1.56	1.56	1.57	1.60	1.60	1.60	1.60
Transport equipment nec	1.24	1.29	1.28	1.29	1.29	1.29	1.28	1.27
Manufactures nec	1.10	1.11	1.11	1.10	1.03	1.03	1.03	1.01
Services	1.00	1.03	1.03	1.04	0.99	0.99	0.99	0.97

Source: the authors.

6. Conclusion

This study analyzed the effect of the change in the Japanese power supply using the GTAP-E-Power model. The simulation results show that an increase in zero-emission power leads to a reduction in fossil fuel power. To ensure that the simulation reflects the actual economic and power data as much as possible, this study aimed to update the GTAP-E-Power model database from GTAP 9.0 to GTAP 10.0, released in February 2020, by analyzing the structure of the data and the parameters of the original version of the GTAP-E-Power model.

The simulation results show that if Japan were to make great effort and keep zero-emission power in Japan at the same growth rate as the Sustainable Development

Scenario of WEO 2019 from 2019 to 2030, the share of zero-emission power in 2030 would be about 43 %, close to the government's goal, while maintaining economic growth. This research analyzed the effect of the increase of zero-emission power, and did not consider the effects of policies concerning electricity and energy. If the effects of these policies were included in the analysis, the share of zero-emission power would increase further. The simulation results also show that an increase in zero-emission power would have a positive effect on the Japanese GDP growth rate.

In Japan, where the risk of disasters, especially that of earthquakes is very high, an increase of nuclear power would have to proceed carefully. For stable growth of zero-emission power, it would be important to increase other renewable power sources, especially solar and wind power, which have potential for future growth.

Future research should study in detail the parameters for Japan that would reflect the actual situation more precisely. It would be important, too, to incorporate the effects of a wider variety of policies concerning energy and electricity. Furthermore, by increasing the regional classification and providing settings for other areas, it would be possible to analyze the economic effects of power policies in Japan taking into consideration the economic interaction of wider areas.

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