ANALYSIS OF OPTIMAL POWER GENERATION MIX IN JAPAN TO 2050, USING DYNAMIC MULTI-SECTOR ENERGY ECONOMIC MODEL

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Overview

In order to explore future energy system trajectories of countries and to determine actual energy policies, global energy models which can give quantitative assessments have been developed. The developed model, named 'Dynamic Multi-sector Energy Economic Model (DMSEE)', elaborates energy and material sectors with engineering data in bottom-up method and other economic sectors with GTAP (Global Trade Analysis Project[1]) database[2] in top-down method (**Figure 1**). DMSEE model is able to give some implications to discuss energy policy while taking the inter-industrial linkage between energy sectors and the other economic sectors. The authors analyze optimal power generation mix in Japan and its impact on the economic growth to 2050, based on DMSEE model.

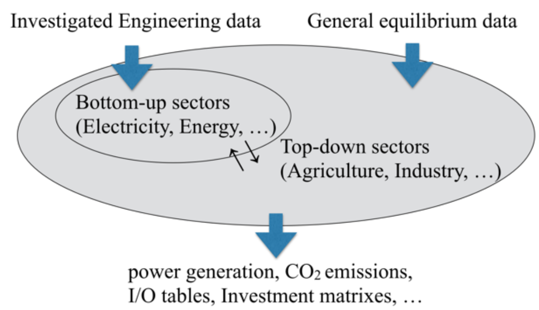

Figure 1. The overview of DMSEE from inputs to outputs.

Methods

DMSEE is a linear programming model, maximizing utility function of consumptions. Target region is Japan, and exports are set constantly. It has 11 time points from 2020 to 2070 with 5 years' time interval. Especially for electricity sector, hourly electricity outputs are calculated, satisfying with hourly load curve. **Table 1** shows the classification of sectors. In addition, the authors focus on material production sectors, because the amount of energy consumptions in the sectors occupies 36.6% of the total (4.95×10^{18} J)[3] and technological development is expected in order to reduce carbon emissions. Electricity sector has 8 power generation activities, 3 power storage activities and 3 transmission/distribution activities. Petroleum/coal products sector has 11 commodities such as gasoline, jet fuel oil, cokes and so on. The constraints of this model are formulated on the basis of demand and supply balance as shown in following equation (1) and (2). 'B' and 'T' are indexes, representing bottom-up and top-down sectors respectively.

Table 2. The classification of sectors.

Energy sectors, Material sectors (Bottom-up sector)	electricity, coal, oil, gas, petroleum/coal products, steel, non-metallic minerals, paper, gas distribution
Other sectors (Top-down sector)	agriculture, fishing, mining, food/drink, fiber, lumber, chemical, non-ferrous metal, machine, transport machines, other manufacturing, construction, land transport, marine transport, air transport, others

$$\boldsymbol{h}_{\mathrm{B}} + \boldsymbol{g}_{\mathrm{B}} + \boldsymbol{a}_{\mathrm{B}} + \boldsymbol{i}_{\mathrm{B}} = \boldsymbol{c}_{\mathrm{B}}\,, \boldsymbol{a}_{\mathrm{B}} = A_{\mathrm{BT}} \cdot \boldsymbol{p}_{\mathrm{T}} + A_{\mathrm{BB}} \cdot \boldsymbol{p}_{\mathrm{B}}\,, \boldsymbol{i}_{\mathrm{B}} = C_{\mathrm{BT}} \cdot \boldsymbol{p}_{\mathrm{T}} + C_{\mathrm{BB}} \cdot \boldsymbol{p}_{\mathrm{B}}\,, \tag{1}$$

$$\boldsymbol{h}_{\mathrm{T}} + \boldsymbol{g}_{\mathrm{T}} + \boldsymbol{a}_{\mathrm{T}} + \boldsymbol{i}_{\mathrm{T}} = \boldsymbol{c}_{\mathrm{T}}\,, \boldsymbol{a}_{\mathrm{T}} = A_{\mathrm{TT}} \cdot \boldsymbol{p}_{\mathrm{T}} + A_{\mathrm{TB}} \cdot \boldsymbol{p}_{\mathrm{B}}\,, \boldsymbol{i}_{\mathrm{T}} = C_{\mathrm{TT}} \cdot \boldsymbol{p}_{\mathrm{T}} + C_{\mathrm{TB}} \cdot \boldsymbol{p}_{\mathrm{B}}\,. \tag{2}$$

$\boldsymbol{h}$: household consumptions, $\boldsymbol{g}$: government consumptions, $\boldsymbol{a}$: intermediate consumptions, $\boldsymbol{i}$: investment consumptions, $\boldsymbol{c}$: sum of consumptions, $\boldsymbol{p}$: productions, (Each vector has elements equal to the number of time points.), A_{XX}: intermediate input coefficient of X sector commodities consumed by X activities, C_{XX}: investment coefficient of X sector commodities consumed by X activities (X means Bottom-up or Top-down.)

The matrix A is derived from GTAP database, and C is from GTAP database and Japanese fixed capital formation matrix. Especially for electricity sector, C is assumed on LCA (Life Cycle Assessment) analysis of each technology, referring to [4].

Results

The model calculates following 4 scenarios. In addition, nuclear power plants (NPPs) are allowed to be newly installed after 2030.

1. BAU (Business As Usual) case
2. \$50 case: \$50 /t-CO_2 from 2025
3. \$300 case: \$300 /t-CO_2 from 2025
4. \$300_noN case: \$300 /t-CO_2 from 2025 and prohibition of new construction of NPPs

The results by DMSEE model, which elaborates only electricity sector, are shown below, and the results by the model which includes material production sector as well will be presented at the conference. **Figure 2** shows the optimal power generation mix in \$50 case, and **Figure 3** describes the optimal power operation of \$50 case in July 2050. DMSEE is also an economy model, therefore, these power operations are decided considering economic interaction from all other sectors. **Figure 4** shows the annual power generation mix and CO_2 emissions in each case in 2050.

Figure 5 is GDP growth standardized by value in 2015. DMSEE can yield SAM (Social Account Matrix) for each time point. Therefore, GDP, imports, exports and other inter-industrial data can be also calculated.

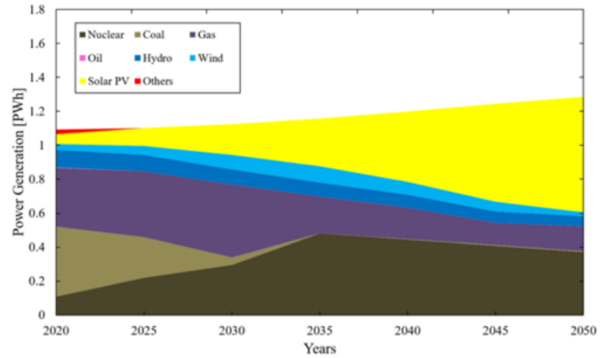

Figure 2. The power generation mix in \$50 case.

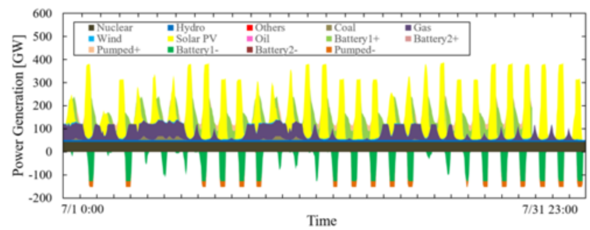

Figure 4. The power variation of \$50 case in July 2050.

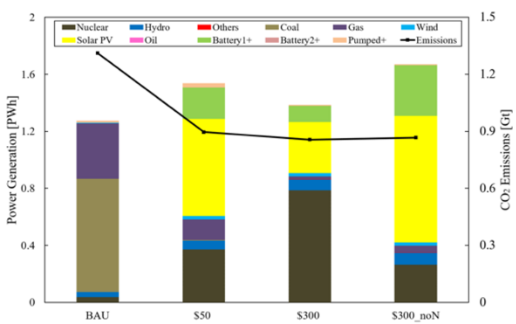

Figure 3. The power generation mix and CO_2 emissions in 2050.

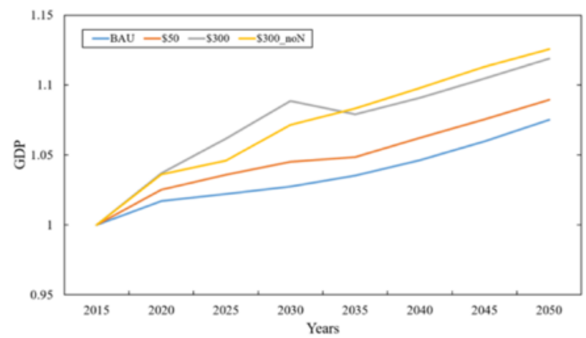

Figure 5. GDP growth (standardize by value in 2015).

Conclusions

The authors are developing an original energy economic model, DMSEE, which can analyze energy and economic sectors by taking into account its supply chain through inter-industrial linkage. DMSEE elaborates not only energy sectors but also material production sectors. The model can give more realistic suggestions for global environmental problem based on energy and economic interaction to 2050.

References

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