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Investigating cost-effective policy incentives for renewable energy in Japan: A recursive cge approach for an optimal energy mix

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ADB Working Paper Series

INVESTIGATING COST-EFFECTIVE POLICY INCENTIVES FOR RENEWABLE ENERGY IN JAPAN: A RECURSIVE CGE APPROACH FOR AN OPTIMAL ENERGY MIX

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Abstract

The Great East Japan Earthquake (GEJE) and Fukushima nuclear disaster that occurred in 2011 gave a sharp reminder to Japan's energy security to reconsider the reduction of nuclear power dependence with a better energy mix. We use a recursive CGE model based on Japan's renewable energy input-output model to analyze the energy composite of power generation and consumption to investigate cost-effective policy incentives to achieve an optimal energy mix with the goal of reducing the nuclear power dependence to less than 5% within 20 years. Moreover, we create scenarios of (1) nuclear power decommission, (2) renewable energy promotion, and (3) virtual power plant (VPP) implementation with public R&D expenditure and power infrastructure investment. The simulation results show that renewable energy could gradually replace nuclear power with capital-use subsidies. Most important of all, the implementation of VPPs could reduce both the fiscal costs and social costs of promoting renewable energy while facilitating power generation.

Keywords: recursive CGE model, renewable energy, Japan, optimal energy mix

JEL Classification: C6, Q4

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1. INTRODUCTION

The Fukushima nuclear disaster triggered by the Great East Japan Earthquake (GEJE) in 2011 gave a sharp reminder to people around the world, and gave governments and society a greater incentive to advocate the use of renewable energy for power generation. According to METI (2018), wanting to reduce the 25.1% nuclear power dependence, in 2010, Japan actively employed various policies to encourage household and electricity sectors to use more renewable power, such as solar power, wind power, and geothermal power. These policy incentives include subsidizing the implementation of power generation equipment and better electricity buy-in rates.

In order to reduce the risk of nuclear disaster, the Government of Japan and society at large began a prudent reconsideration of advocating the use of renewable energy for power generation. Japan temporarily suspended all nuclear reactors for technical inspection after the GEJE. Nuclear power generation was at one point reduced to zero in the year 2014 (METI 2018) but gradually increased afterwards. As a consequence, the share of Japan's nuclear power generation dropped to 2.8% of the total power generation while 22 reactors were scheduled for decommissioning, the cost of which would be a vital issue for power companies. On the other hand, the renewable energy sources for power regeneration increased from 9.5% (2010) to 16.1% (2017). Despite a satisfactory trend for renewable energy, the overcapacity of solar power in the Kyushu region of Japan resulted in a shutdown of solar power generation facilities for a number of days. Such issues highlight that the key for renewable energy not only lies in power generation but also in allocation.

Up to 2019, Japan actively employed various policies to encourage household and energy sectors to change their power use from fossil to renewable sources such as solar, wind, and geothermal power. These policy incentives included subsidizing the implementation of power generation equipment and legislating electricity buy-in rates. The major reason for a substantial increase in the number of household solar power generation facilities installed is the feed-in tariff (FIT) regulation, which could be considered a production subsidy at a fixed price for a power generation company to buy electricity generated by households. However, this FIT system faced termination in 2019, and therefore the regulations for promoting renewable energy should be changed to a cost-effective policy.

The study uses a recursive CGE model focused on energy sectors to create scenarios for policy simulation on nuclear power decommissioning plan while subsidizing renewable power for policy analysis. The structure and data in the study are based on the extended input-output table of renewable energy developed by Washizu, Nakano, and Arai (2015). The energy composite path is illustrated with a review of various indicators such as changes in sectoral output and price. The fiscal and social costs are examined for cost-effectiveness. The simulation results enable quantitative analysis in order to open the black box of renewable energy subsidy and the cost of nuclear decommissioning through policy incentives. Such a framework could be referred to policy options to determine an optimal energy mix, assisting power companies in developing appropriate measures to confront critical challenges for energy transmission.

After this introduction, the study proceeds as follows: Part 2 comprises a literature survey and focuses on methodology and mainstream renewable energy; Part 3 introduces and illustrates our CGE model structure, parameter calibrations, and its dynamic framework; in Part 4, we explain the data and scenarios we use for policy simulations; finally, in Part 5, the simulation results will be demonstrated and we will further interpret their implications and make policy recommendations as concluding remarks.

2. LITERATURE SURVEY

For simulation studies, Komiyama, Shibata, and Fujii (2013) discussed issues regarding the optimal Japanese energy composite from an engineering perspective while Ban (2016) focused on the social impact made by renewable energy. Based on the extended input-output table of renewable energy developed by Washizu, Nakano, and Arai (2015), the study uses a dynamic CGE model to create scenarios for simulating policy on abolishing nuclear power while subsidizing renewable power. The energy composite path is illustrated with a review of various indicators such as changes in sectoral output, price, and external trade while its fiscal and social costs are examined for cost-effectiveness. Japan's energy policy and structure have changed significantly from increasing energy self-sufficiency to diversifying the energy sources after the GEJE. Yamazaki and Takeda (2017) analyze the environmental impacts of Japan's energy circumstance with examinations on renewable energy in the "New policy scenario" suggested by the International Energy Agency (IEA). In the implementation of a feed-in tariff (FIT) system based on a multi-regional, recursive dynamic CGE model, it was found that a nuclear power phase-out policy would decrease the GDP with more greenhouse gas emissions. Japan's energy-intensive policy that generates negative externalities should be carefully considered.

Modeling an energy mix optimization has always been required along with the transition of energy sources and infrastructure. Allan et al. (2008) criticize the rebound effects for consumer service would restrict the analysis, and reduce efficiency; instead, they used a CGE model to analyze system-wide ramifications of policy intervention for industrial energy efficiency. By using a mathematical model, Incekara (2019) interprets Turkey's 2018–35 power generation plan with policy suggestions aimed at improving pollution levels with a view to fulfilling the commitment to the Kyoto Protocol. Fuzzy multi-objective linear programming (MOLP) was applied to the private sector's energy target with the aim of minimizing the costs of energy-related products and CO₂ emissions. The simulation results suggested that Turkey's use of renewable energy would increase substantially; however, the costs of energy infrastructure and technology advancement were not discussed and this could lead to questions on policy feasibilities. Kriechbaum, Scheiber, and Kienberger (2018) point out that the energy grid system requires transition to support the integration of renewable energy sources while several aspects are essential for modeling a grid-based multi-energy system. With spatial consideration of necessary data, the resolutions of energy infrastructure could be identified and such work is expected to contribute to more efficient electricity converters in a grid-based energy system. An economic assessment remains desirable to provide policy analysis on incentive setting for implementing the system and evaluating its cost-effectiveness.

The power grid is the key infrastructure for providing a reliable and sustainable power supply in the face of a continuous growth in demand. Gabbar and Zidan (2016) indicate that the Canadian government and energy stakeholders are looking for new power technologies for integrating the use of power generation with cost-effectiveness and environmental friendliness. A spatial analysis and geographic information system (GIS) are applied for identifying transmission, distribution, and generation sites. The modeling results have provided an informative key performance index (KPI) as the aspects of cost, quality, reliability, and environmental friendliness may serve as vital references for grid system implementation and design. Given the increasing popularity of renewable energy use among regional households, the implementation of virtual power plants (VPPs) have become an important issue. Kasaei, Gandomkar, and Nikoukar (2017) point out that the high penetration of renewable energy sources such as wind and solar power still cause uncertainty as regards a steady power supply, and thus such variable outputs should aggregate through collections of other power generators, and storage systems to control the load for a better energy management system. Such a system has contributed to the concept of the VPPs.

Despite the feature of zero marginal cost occurrence for power generation by renewable energy, the variable nature and uncertainty of the power supply remains the main concern for improving the energy mix. Pandžić, Kuzle, and Capuder (2013) considers weekly self-scheduling of a VPP of energy sources, a storage system with a conventional power plant to construct the optimal power allocation based on a linear programming model for long-term contracts. While the renewable energy source is used as backup energy after reaching the peak, such a variable could enable flexible operation and reduce uncertainty. It was also assessed that the storage capacity could be the key determinant for increasing the renewable energy resource ratio. Lima et al. (2018) use a stochastic programming method to address the optimal operation of a VPP. Forecast data from the European Centre for Medium-Range Weather Forecasts (ECMWF) were applied to calculate the utilization of renewable resources with the decomposition methods and risk management. Based on their computational results, the efficiency of decomposition methods is determined by parallel solutions.

Along with the technology advancement, Adu-Kankam and Camarinha-Matos (2018) believe that VPPs will eventually overcome the stochastic nature of distributed energy resources with smart grid implementation as the key power infrastructure. Zajc, Kolenc, and Suljanović (2019) also emphasize the role of science and technology advancement for VPPs in the smart distribution and control of such service provision. Especially the downstream communication protocols between VPPs, transmission, and a distribution system would lead the electricity market to making optimal energy mix choices. With such a trend, strategic and dynamic collaborative network principles need to be formed. Yu et al. (2019) indicate that market price and power load demand are the major uncertainty factors for VPPs. Optimization with a mathematical descriptive could help identify the stochastic uncertainty systematically. The price could substantially affect the incentive for implementing renewable energy infrastructure, while the system should be designed based on evidence of the overall social welfare improvement evaluated by stakeholders.

3. CGE MODEL STRUCTURE

Our recursive dynamic CGE model was developed on the basis of the static model by Huang and Hosoe (2016). It is a single-country and open-economy model and distinguishes 18 sectors (Table 1) and suffix of variables (Table 2). The model structure demonstrates a multisectoral economy from activities of production, consumption, and capital accumulation through policy intervention. For domestic production, Y_j is the composite factor used by the j -th sector composite factor production function (Cobb–Douglas), while $F_{h,j}$ is the h -th factor input by the j -th sector.

$$Y_j = b_j \prod_h F_{h,j}^{\beta_{h,j}} \quad \forall j \quad (1)$$

$$F_{h,j} = \frac{\beta_{h,j} p_j^y}{(1 + \tau_{h,j}^f) p_{h,j}^f} Y_j \quad \forall h, j \quad (2)$$

Table 1: Sector Abbreviation

Sector	Description	Sector	Description
AGR	Agriculture	COA	Coal
MAN	Manufacture	GAS	Natural gas
ETS	Electricity transmission	PET	Petroleum
STL	Steel	NCU	Nuclear power
RAD	Research and development	SOL	Solar power
TEQ	Transportation equipment	WIN	Wind power
CON	Construction	GEO	Geothermal power
TRS	Transportation	WAT	Hydropower
SRV	Service	ELY	Electricity

Note: We aggregate the 124 sectors of the renewable energy input-output table into 18 sectors by distinguishing power generation from conventional fossil fuel (COA, GAS, PET) and renewable energy (SOL, WIN, GEO, WAT). Other manufacturing sectors (AGR, MAN, STL, TEQ, SRV) are also listed to review the impact on economic activity. In this input-output table, separation of power generation and transmission helps us distinguish electricity generation (ELY) and transmission (ETS) to analyze the implementation of virtual power plants under the implantation policy through government expenditure on research and development (R&D) and power infrastructure investment.

Table 2: Model System Suffix

Type of Goods/Factors in Suffix	Symbol	Abbreviations
Energy goods	ei, ej	COA, PET, GAS, WIN, GEO, SOL, WAT, ELY
Nonenergy goods for industries	ni, nj	$\{i\} \{ei\}$
Energy goods for households	$ei2, ej2$	PET, GAS, WIN, GEO, SOL, WAT, ELY
Nonenergy goods for households	$ni2, nj2$	$\{i\} \{ei2\}$
Nonelectricity goods	ne	$\{i\}$ ELY
Factor	h, k	CAP, LAB
Mobile factor	h_{mob}	LAB
Time period	t	0, 1, 2, ..., 30

Note: The model system and formula used in the dissertation are stated in the following section. For the dynamic model, the time suffix t is not shown for simplicity unless needed.

Table 3: Parameter Calibrations

Parameter	Value
Rate of return of capital (ror)	0.05
Depreciation rate (dep)	0.04
Depreciation rate (dep) for nuclear power	3.2
Population growth rate (pop)	0.01
Armington elasticity parameters (σ, ψ)	0.9–7.35
Elasticity of substitution among energy sources (σ^e)	1.1
Elasticity parameter in the investment function (ς)	1.0

Note: In the model structure, the parameters serve as adjustment to cope with the reality situation. The calibration of the parameters is sourced from existing literature (Hosoe 2014; Huang and Hosoe 2017). The depreciation rate for nuclear power is set at eight times more than the setting for other sectors, indicating the decommission policy after the GEJE to reduce power dependence share by 2030. The Armington elasticity parameters are sourced from the GTAP Database version 9.0 while other parameters are assumed by the authors.

The factor demand function of labor and capital is determined as $F_{h,j}$, while for household consumption, the goods are distinguished into energy and nonenergy goods X_{ni2}^p and X^{pe} , and the household demand for nonenergy goods, S^p , is private saving, and T^d is the direct tax revenue.

$$X_{ni2}^p = \frac{\alpha_{ni2}}{p_{ni2}^q} \left(\sum_{h,j} p_{h,j}^f F_{h,j} - S^p - T^d \right) \forall ni2 \quad (3)$$

$$X^{pe} = \alpha^e \left(\sum_{h,j} p_{h,j}^f F_{h,j} - S - T^d \right) / p^{xpe} \quad (4)$$

The household demand for the energy composite good is determined as X^{pe} , while in regard to energy composite aggregation from other energy resources, the energy composite aggregation function for nonelectricity sectors is defined as X_{ne}^e ; the energy good demand function for nonelectricity sectors is $X_{ei,ne}$, and the energy composite aggregation function for the household is X^{pe} .

$$X_{ne}^e = o_{ne} \left(\sum_{ei} \kappa_{ei,ne} X_{ei,ne}^x \right)^{1/\chi} \forall ne \quad (5)$$

$$X_{ei,ne} = \left(\frac{o_{ne}^{\chi} \kappa_{ei,ne} p_{ne}^{xpe}}{p_{ei}^g} \right)^{1/(1-\chi)} X_{ne}^e \forall ei, ne \quad (6)$$

$$X^{pe} = o^p \left(\sum_{ei2} \kappa_{ei2}^p X_{ei2}^{p\chi} \right)^{1/\chi} \quad (7)$$

Further, the energy goods demand for the household X_{ei2}^p is the function from the goods production function, while nonelectricity goods $ax_{ni,ne}$, the ax indicates the production function coefficient, which helps us to adjust the power generation efficiency increase by the technology improvement.

$$X_{ei2}^p = \left(\frac{o^{p\chi} \kappa_{ei2}^p p^{xpe}}{p_{ei2}^q} \right)^{1/(1-\chi)} X^{pe} \forall ei2 \quad (8)$$

$$ax_{ni,ne} = \frac{X_{ni,ne}^0}{Z_{ne}^0} \quad (9)$$

The electricity good is denoted as $ax_{i,ELY}$, while the intermediate energy good ax_{ne}^e input requirement coefficient, and intermediate good $X_{ni,ne}$ serve the demand function for nonelectricity sectors; the energy composite good X_{ne}^e is in the demand function for nonelectricity sectors, while the intermediate good $X_{i,ELY}$ determines the demand function for the electricity sector with the unit cost p_{ne}^z function for the nonelectricity and electricity sector.

$$ax_{i,ELY} = \frac{X_{i,ELY}^0}{Z_{ELY}^0} \quad (10)$$

$$ax_{ne}^e = \frac{X_{ne}^{e0}}{Z_{ne}^0} \quad \forall j \quad (11)$$

$$X_{ni,ne} = ax_{ni,ne} Z_{ne} \quad \forall ni, ne \quad (12)$$

$$X_{ne}^e = ax_{ne}^e Z_{ne} \quad \forall ne \quad (13)$$

$$X_{i,ELY} = ax_{i,ELY} Z_{ELY} \quad \forall i \quad (14)$$

$$p_{ne}^z = ay_{ne} p_{ne}^y + \sum_{ni} ax_{ni,ne} p_{ne}^q + ax_{ne}^e p_{ne}^{xe} \quad \forall ne \quad (15)$$

$$p_{ELY}^z = ay_{ELY} p_{ELY}^y + \sum_i ax_{i,ELY} p_i^q \quad (16)$$

Finally, the felicity/composite consumption good production function CC are defined in the form of dynamic model $CC = a * (\prod_i X_i^{p_i}) * (X^{pe} * \alpha^e)$ (17).

For the investment activity performed by government, based on Huang and Hosoe (2017), the consumption is exogenous while the growth at the assumed population growth rate (pop), that is, in terms of the collection of taxes, import tariffs, and a lump-sum direct tax on households, provides subsidies for recursive change.

The government budget is balanced by a lump-sum direct tax. The aggregate investment good for the j -th sector $II_{j,t}$ is made of various investment goods purchased from the i -th sector $X_{i,t}^v$ with a Cobb-Douglas-type production function.

The recursive dynamics are instilled in the original CGE model structure, which links economic activities *between* periods. In the t -th period, private savings S_t^p are generated with a constant saving propensity ss^p growing over time at the population growth rate pop . Following Hosoe (2014), these savings are endogenously allocated among investment for the j -th sector $II_{j,t}$ according to its expected relative profitability in the next period:

$$II_{j,t} = \frac{p_{CAP,j,t+1}^f F_{CAP,j,t+1}^\zeta S_t^p + \varepsilon_t S_t^f}{\sum_j p_{CAP,i,t+1}^f F_{CAP,i,t+1}^\zeta p_t^k} \quad (18)$$

P_t^k denotes the price of the investment good $II_{j,t}$, and $P_{CAP,j,t+1}^f$ and $F_{CAP,j,t+1}$ denote the price and the amount of capital service in the j -th sector in the next period, respectively. The last two variables can be replaced by the t -th period variables $P_{CAP,j,t}^f$ and $(1+pop)F_{CAP,j,t}$ by assuming a myopic expectation. An elasticity parameter ζ determines the sensitivity of sectoral investment allocation to a gap of profitability among sectors. The putty-clay type is assumed in capital installed in the j -th sector in the t -th period $KK_{j,t}$.

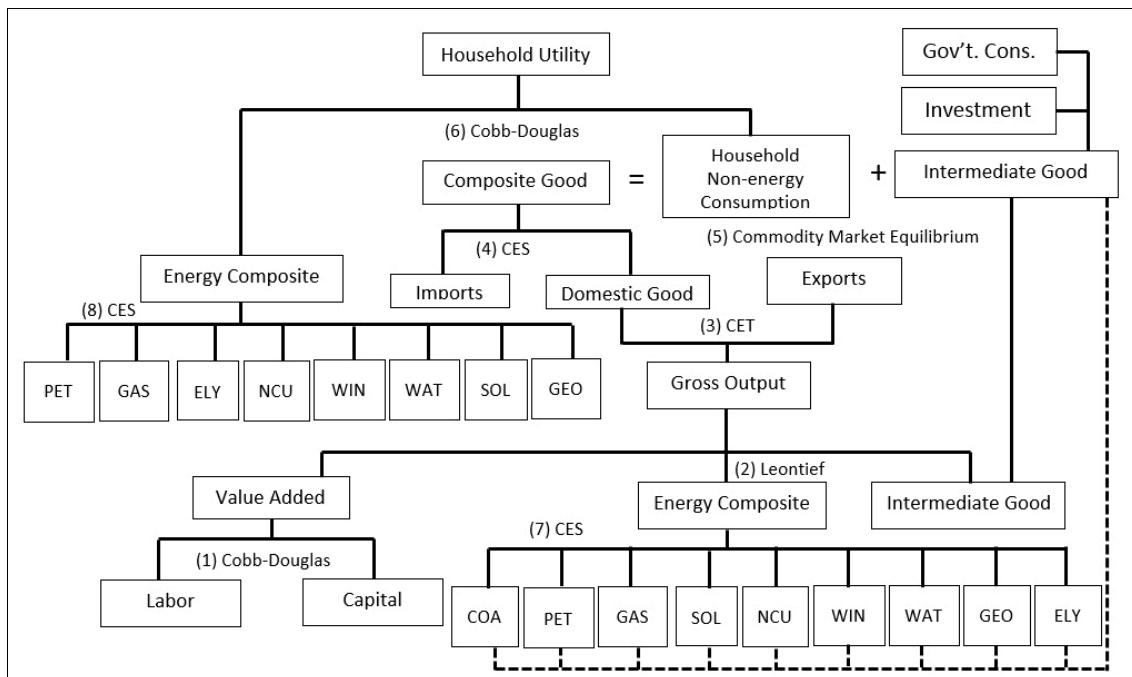
The capital is assumed to be immobile between sectors but could be accumulated depreciating at the rate of dep , $KK_{j,t+1} = (1-dep) KK_{j,t} + I_{j,t}$. That is, lost capital in a disaster cannot be rebuilt immediately by being mobilized from other sectors. Labor endowment is exogenously growing at the population growth rate pop and is mobile among sectors. Thus, the capital accumulation is calculated as: $KK_{j,t+1} = (1 - dep)KK_{j,t} + I_{j,t} \forall j, t$ (19).

Finally, welfare is determined by equivalent variations (dynamic model), which are the consequences of household consumption after the new equilibrium of output price change:

$$EV_t = \left[\frac{(CC_t^1 - CC_t^0)/a}{(\prod_{niz} \alpha_{niz}^{\alpha_{niz}}) * e^{\alpha e}} \right] \quad (20)$$

Our CGE model structure is presented in Figure 1.

Figure 1: CGE Model Structure



Note: Based on Huang and Hosoe (2016), we revise the CGE model structure with more renewable energy sources. The activities *within* a period with nested constant elasticity of substitution/transformation (CES/CET) functions: (1) substitution between capital and labor, (2) intermediate input and composite factor input with energy composite input for a production function of gross output, (3) transformation for domestic goods supply and exports, and (4) substitution between domestic goods and imports (Armington 1969). (5) Armington's composite goods are used by a representative household and government for investment and intermediate input. (6) Household utility depends on the consumption of various nonenergy goods and an energy composite. We assume a Cobb-Douglas-type utility function. Social welfare costs are measured by Hicksian equivalent variations (EVs), based on the consumption losses of the representative household. In analysis of energy incidence, substitution of electricity with other energy sources is crucial. It is assumed that (7) the energy composite for nonenergy sectors is developed from the five energy goods (crude oil and natural gas, coal, petroleum, electricity, and town gas), while conventional Leontief's fixed coefficient technology for the five energy sectors is assumed, i.e., no substitution among energy sources. (8) In the energy composite for households, petroleum, natural gas, electricity, natural gas, and other renewable energies (without coal) are used.

Note: COA (coal), PET (petroleum), GAS (natural gas), ELY (electricity), NCU (nuclear power), WIN (wind power), WAT (hydropower), SOL (solar power), GEO (geothermal power).

4. DATA AND SCENARIOS

For constructing a CGE model to make simulations on Japan's renewable energy policy and consequences, we use an input-output table developed by Washizu, Nakano, and Arai (2015) based on Japan's 2005 table (released in 2011). The extended table contains 124 sectors including aggregated sectors of renewable energy such as solar, wind, and geothermal power. Moreover, the power generation and transmission systems are disaggregated. This feature is very helpful for us in analyzing the potential VPP system with the inclusion of specific R&D investment. As regards the estimate of production efficiency and Japan's R&D expenditure, we calibrate from the SciREX Policy Intelligence Assistance System – Economic Simulator (SPIAS-e), which is developed through collaboration between several government science agencies, ministries, and universities (Kuroda et al. 2018).

The principal target for simulation is to use policy to reduce the nuclear power dependence to less than 5% within 20 years. A description of three scenarios along with subsidy and efficiency rates (Table 4) is presented below:

Table 4: Policies and Capital-Use Subsidy Rates

	NCU	SOL	WIN	GEO	RAD	ETS
Scenario 1: Nuclear power decommission	400%	n.a.	n.a.	n.a.	n.a.	n.a.
Scenario 2: Renewable energy promotion	400%	75%	50%	50%	n.a.	n.a.
Scenario 3: VPP implementation	400%	75%	50%	50%	4.2%*	10%
Efficiency improvement rates	n.a.	7.6%*	7.6%*	7.6%*	n.a.	10%

* Estimated based on SPIAS-e.

Note: For the target of reducing nuclear power dependence below 5% within 20 years in all three scenarios, the capacity-use subsidy is the incentive to reduce nuclear power generation (NCU). Capital-use subsidy is also used as an incentive to promote renewable energy in scenarios 2 and 3. Given the restriction of implementation, we assume 75% of subsidy rate for solar power (SOL) and 50% for wind (WIN) and geothermal (GEO) power. In scenario 3, the implementation of a virtual power plant (VPP) will be carried out with a 10% investment in an electricity transmission system (ETS) and 4.2% government expenditure on research and development (R&D) of energy sectors. Meanwhile, based on SPIAS-e, production efficiency is expected to be actualized from the 10th year of the policy.

Scenario 1: Nuclear power decommission

Provide capital-use subsidy as an incentive for the nuclear power sector to gradually reduce the nuclear dependence to 5% within 20 years; increase the depreciation rates as decommission policy.

Scenario 2: Renewable energy promotion

Provide capital-use subsidy on solar (SOL), wind (WIN), and geothermal (GEO) power in order to increase the renewable energy share to 30% within 20 years.

Scenario 3: Virtual power plants (VPPs) implementation

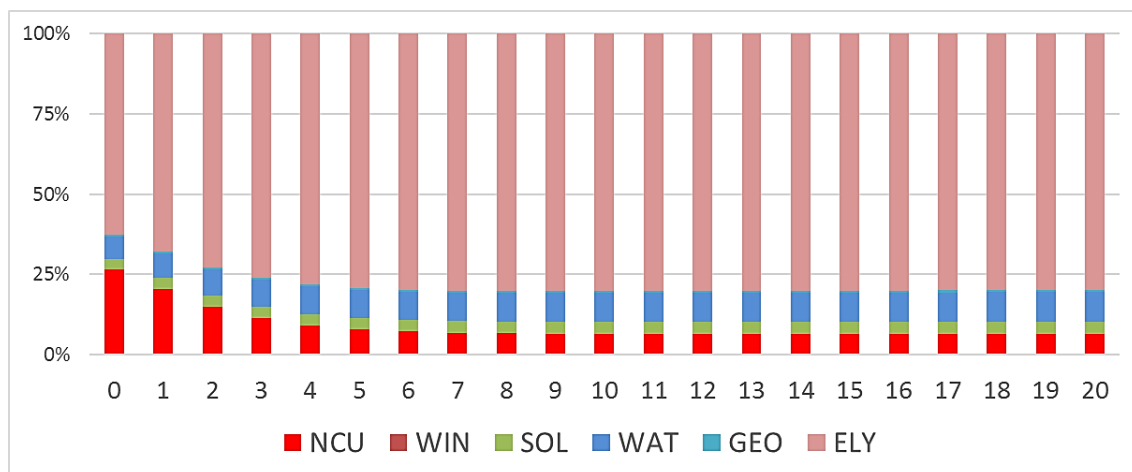
Provide capital-use subsidy on electricity transmission (ETS) as power infrastructure investment for VPP system implementation; increase public R&D expenditure on energy and material sciences for 20 years. The VPPs implantation and efficiency improvement for power generation efficiency improvement will be assumed to be fully actualized from the 10th year.

5. SIMULATION RESULTS AND CONCLUDING REMARKS

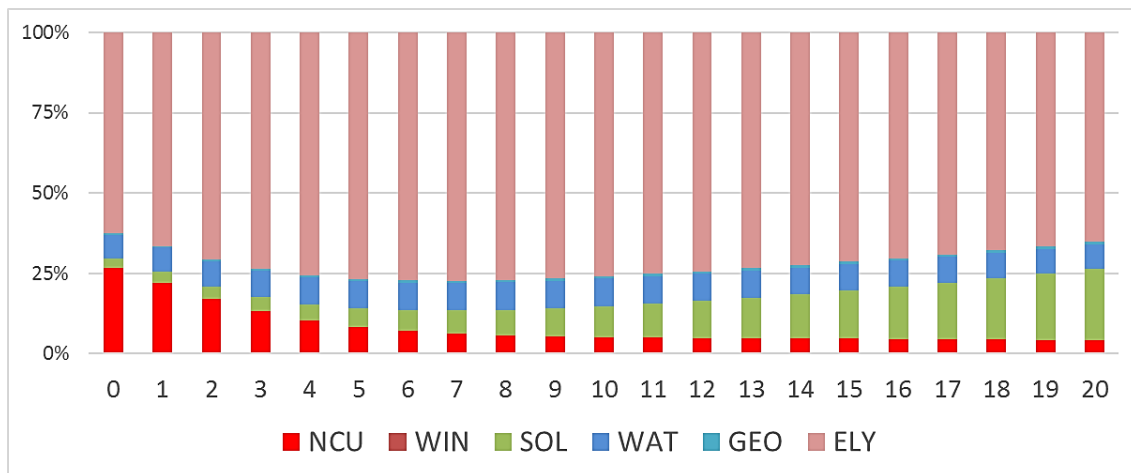
The research provides policy assessments and visualized policy options with potential costs and paths to achieve the policy target of less than 5% nuclear dependence while increasing the share of renewable energy within 20 years. By using a dynamic CGE model with Japan's renewable-energy input-output table, the study demonstrated the policy simulation results of the three scenarios for an optimal energy mix (Figures 2–4) by providing capital-use subsidies to energy sectors. Simulation results show that the renewable policy could not grow simply through a nuclear power decommissioning policy. Moreover, the implementation of R&D and VPPs could further facilitate the renewable energy allocation with a reduction of fiscal and social costs. The capital-use subsidy policies were examined in order to abandon nuclear power with the promotion of renewable energy. Without a policy incentive, renewable energy cannot grow while the share of nuclear power is being reduced. R&D investment could improve the efficiency of power generation, accelerating the reduction of nuclear power dependence.

With regard to the output and price change, the simulation results show that the policy could stimulate renewable energy output while its price is substantially reduced (Figures 5 and 6). Meanwhile, other manufacturing sectors reveal no substantial change, indicating that such a policy could help facilitate the energy structure. Other than the costs of a nuclear decommissioning policy, the fiscal cost of VPP implementation is 10.4% higher than a renewable energy promotion policy (Figure 7) with a reduction of 20.1% on social costs, thereby easing the overcapacity problem (Figure 8).

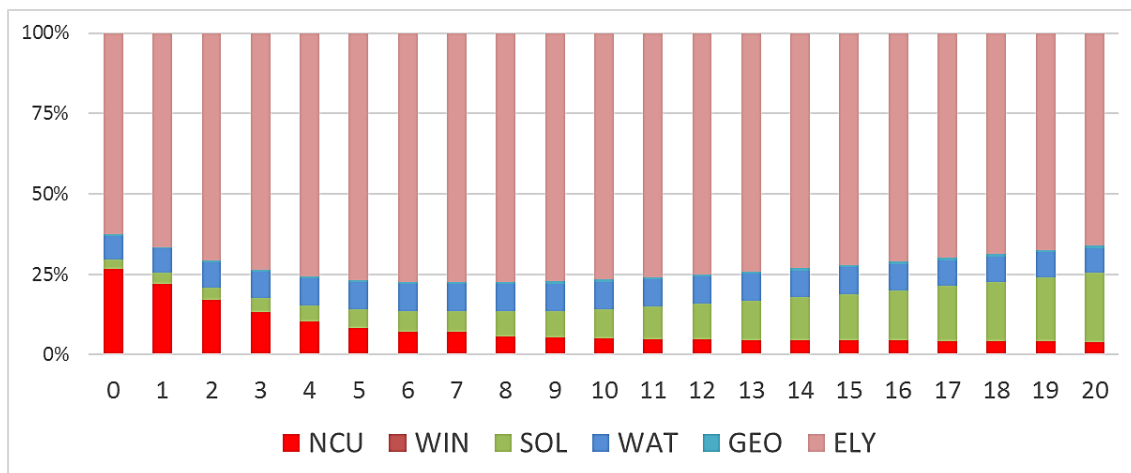
Figure 2: Scenario 1: Nuclear Power Decommission



Note: Figure 2 shows the optimal power generation mix in the scenario of nuclear power decommissioning policy. It could be found that the high depreciation rates and capital-use tax on nuclear power would reduce nuclear power generation substantially to less than 10% within five years. Nevertheless, without other incentive policy on renewable energy, power generation by renewable energy sources does not show much growth and the power generation gap is mainly substituted by coal power. Therefore, a nuclear power decommissioning policy is expected to worsen the CO₂ emission due to the use of conventional fossil fuel.

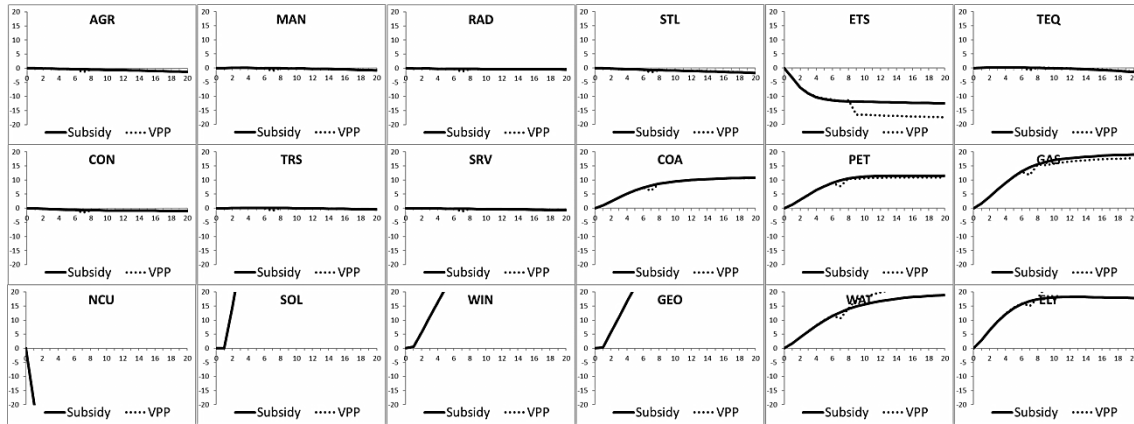
Figure 3: Scenario 2: Renewable Energy Promotion

Note: With the implementation of an incentive policy on renewable energy, it could be found that the share of solar power would increase significantly after the advancement in technology from the sixth year and gradually substitute nuclear power generation. On the other hand, geothermal power generation does not show as much change as solar power. It could be inferred that due to the type of power generation, geothermal power requires precise location and greater initial input in facilities. The flexibility of solar power generation facilities could be implemented in households relatively easier and thus solar power becomes the main source for a renewable power generation mix.

Figure 4: Scenario 3: VPP Implementation

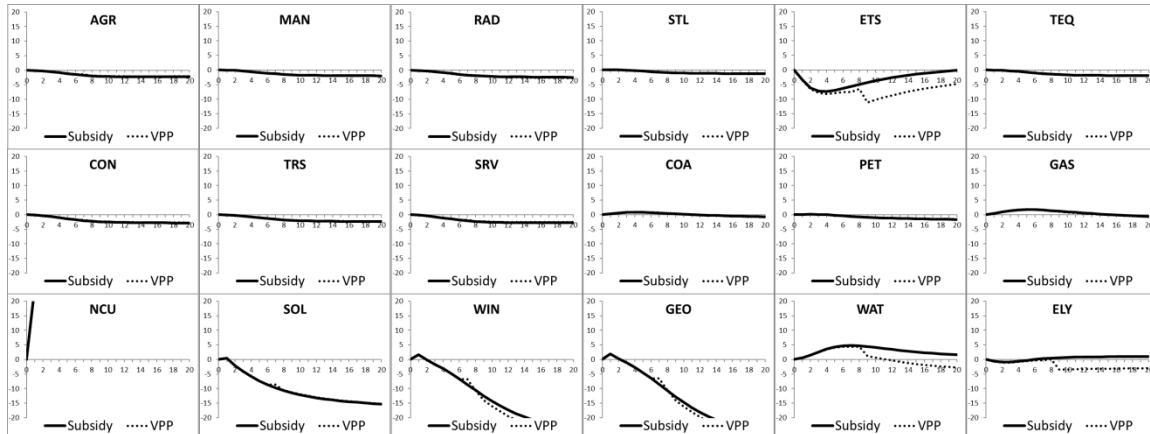
Note: While we implement a virtual power plant system by improving the power generation efficiency by 10% through investing in electricity transmission facilities based on our assumption, the power generation mix does not show much difference from the other scenario of renewable energy promotion. However, implantation fiscal and social costs have been improved with the better cost-effectiveness of such a policy. This would be explained through other indicators from the following figures.

Figure 5: The Output Change: Comparison of Nuclear Power Decommission Policy with Renewable Energy Incentive and VPP Implementation



Note: Nuclear power generation shows a sharp decrease under the decommission policy while other conventional fossil fuels such as coal, petroleum, and gas increase significantly. Meanwhile, renewable energy sources such as solar, wind, geothermal, and even water power generation provide an even greater increase in power generation. With the implementation of VPPs, it could be found that the output of electricity transmission sector decreases by 15% because of improvement of efficiency, while other energy sources had some vibrations for output increase, indicating that a VPP could improve the electricity allocation in a more efficient mix.

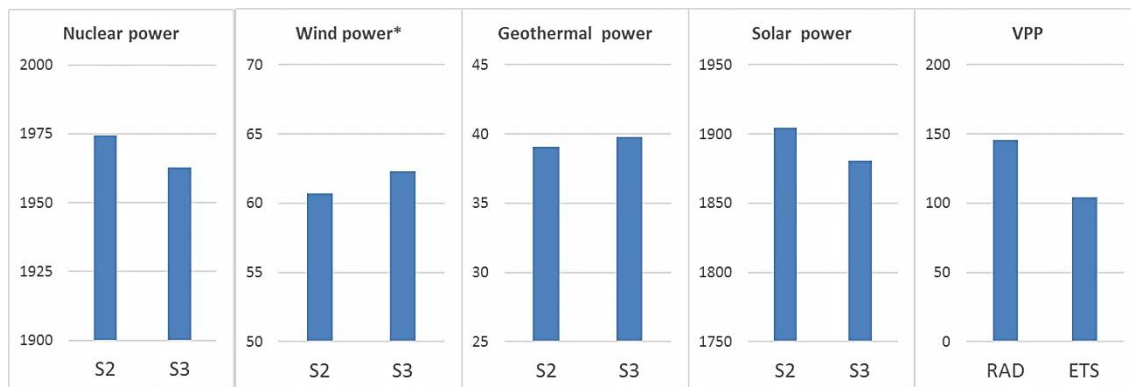
Figure 6: The Output Price Change: Nuclear Power Decommission Policy with Renewable Energy Incentive and VPP Implementation



Note: The indicators of output price change indicate the technology improvement and the incentive for using such energy sources. With the policy incentive for renewable energy, the output prices decrease substantially in solar, wind, and geothermal power. Due to the limitation of dam construction, the output price of a water energy source does not decrease like other renewable energy sources. However, it is interesting to find the decrease in output prices of an electricity transmission system, electricity and water power generation, implying that the investment in a VPP could further facilitate a higher energy mix performance from all sorts of power generation.

Nevertheless, the simulation results provide visualized consequences and impact the social economy as regards the policy implementation on nuclear decommission, renewable-energy promotion, and VPP implementation. The cost-effectiveness examined in the scenarios suggests that the power transmission system could help reduce both fiscal and social costs, indicating comprehensive plans for promoting renewable energy. While confronting the overcapacity and inefficiency of power generation from renewable energy sources, it would be indispensable for governments at all levels to help the energy sector to develop a VPP system to strengthen the power resilience. The VPP system includes a storage system that could also be of importance against large-scale natural disasters.

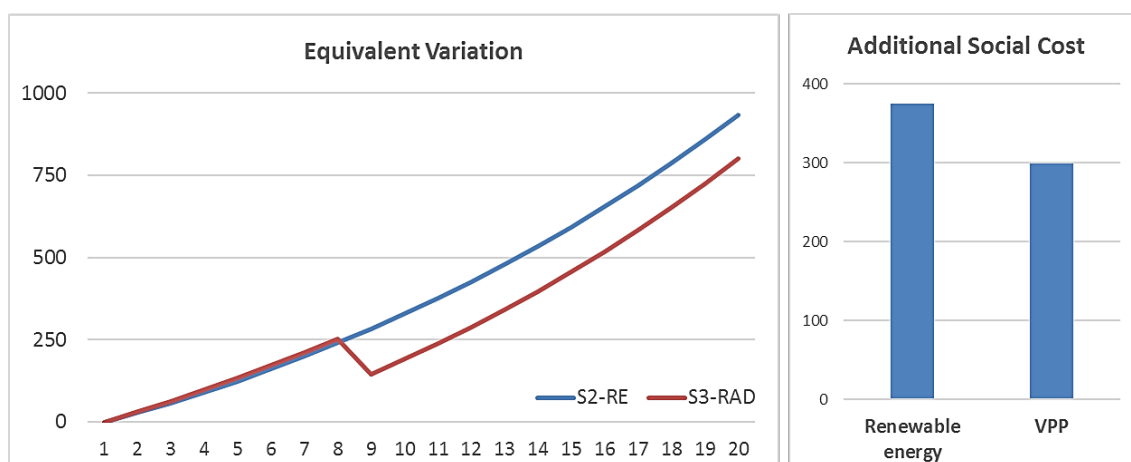
Figure 7: Annual Fiscal Costs of Policy Incentives
(billion JPY)



* Million JPY.

Note: When we compare the annual fiscal costs of capital-use subsidy on renewable energy and implementation of VPPs, it shows that the implementation of a VPP would actually reduce the fiscal cost because of the improvement of power generation efficiency by 1 and 2%, respectively, in nuclear and solar power. The reason why geothermal and wind power do not show a reduction could be due to their limited implementation geographically in power generation in the year 2005. It is also notable that the capacity of wind power (as of 2005) is relatively small compared with other energy sources, but the implementation of a VPP could increase its capacity. The fiscal costs of R&D and power infrastructure investment in energy and VPP implementation are approximately 150 billion and 100 billion JPY, respectively.

Figure 8: Welfare Analysis: Social Costs of Promoting RE Compared with VPP Implementation
(unit: billion JPY)



Note: The social costs of policy represent the household utility in equivalent variation between the policy interventions that cause changes in the price and the quantity of consumption. Based on the simulation results of output and price, the implementation of a VPP could increase the power generation efficiency so that the allocation of electricity from energy sources could be better facilitated, easing the social costs while the technology could be fully installed from the 10th year. The VPP and technology input also show lower social cost than the renewable energy capital-use subsidy. Such consequences imply that the VPP system could lead to higher cost-effectiveness simply by providing incentives for renewable energy.

Although the model is a single-country model, the optimal energy mix has reflected the choice of power generation method among all energy sources. The recursive CGE model based on Japan's 2005 renewable energy input-output table provided evidence-based analysis on setting incentives for renewable energy after the termination of FIT, and these informative outcomes could also provide policy implications for the development of a renewable energy input-output table in many other countries.

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