Economic Impact Assessment of Immediate Shutdown of All Nuclear Power Plants in Japan

YAMAZAKI Masato※

Abstract

This study assesses the environmental and economic impacts of the immediate shutdown of all Japan's nuclear reactor fleet. For the assessment, we regard a gradual nuclear power phase-out scenario as the basis for a 40-year operational time limit of plants as a reference scenario. A multi-regional, recursive dynamic computable general equilibrium model based on Version 8.1 of the Global Trade Analysis Project database is constructed. The simulation results indicate that an immediate nuclear shutdown increases CO₂ emissions through an increase in fossil fuel electricity generation and decreases real GDP losses in Japan. From a sectoral view, an immediate nuclear power shutdown has a negative impact on Japan's energy intensive and trade-exposed sectors. In addition, we find that an immediate nuclear shutdown has a negative after-effect on the economy. This is caused by shrinking investment spending during the immediate nuclear power shutdown. Overall, we find that the Japanese economy would face significant economic and environmental impacts from an immediate nuclear power shutdown. However, our model does not incorporate potential negative costs associated with nuclear usage, such as the risk of a nuclear accident or the cost of final disposal sites for nuclear waste, which may be sizeable. To derive conclusions for Japanese energy policy, we must consider the potential negative costs of nuclear usage. The results of this simulation study represent the first step in answering key questions on energy policy.

1. Introduction

After the nuclear power plant accident in Fukushima in March 2011, Japan's energy policy stands at a crossroads. Many Japanese people have been skeptical about the use of nuclear energy as the country's power source. Consequently, all of the country's...
nuclear power plants are out of operation until the plants can be inspected thoroughly. On the other hand, the Japanese economy has suffered from high electricity prices due to the shutdown of the nuclear power plants, as Japan has had to import expensive natural gas from foreign countries. There appears to be no national consensus among the population and between civil society and the Japanese government regarding future nuclear energy plans.

In response to public anxiety about the remaining idle nuclear plants, Japan's nuclear safety standards have become stricter than before the Fukushima nuclear accident. In line with the Electricity Utilities Industry Law (1964), a nuclear reactor is required to undergo scheduled inspections. According to the law, scheduled inspections must be conducted on all reactors after 13 months of operation. Four months after the Fukushima nuclear accident, in July 2011, the Japanese government required electricity power companies to conduct stress tests on their nuclear reactors under scheduled inspections as a step toward resuming operations. In September 2012, a new organization in charge of regulating nuclear power, the Nuclear Regulation Authority (NRA), was launched. In April 2013, the NRA proposed new safety standards requiring many improvements by electric power companies of nuclear plants. For instance, the standards require construction of sturdy buildings for emergencies, replacement of wiring, and installation of improved ventilation systems. The standards took effect from July 2013. In order to resume operation of the idle nuclear reactors, electric power companies have to take measures to meet the standards and pass the NRA's inspections. Even if an electric power company passes the NRA's inspections, the local government of the area where the nuclear power reactor is located is required to give permission for the suspended reactors to resume activity. By October 2014, all nuclear reactors in Japan remained idle. Thus, Japan has to manage balancing its electricity supply and demand without operating nuclear power reactors. The electricity shortage has been met by a corresponding increase in fossil fuel power generation.

The purpose of this study is to provide an understanding of the national and long-term economic and environmental (carbon dioxide, CO₂) impacts of the immediate nuclear shutdown of Japan's nuclear reactors using a multi-region (country), multi-sectoral, recursive dynamic computable general equilibrium (CGE) model based on the Global Trade Analysis Project (GTAP) database Version 8.1.

The rest of this paper is organized as follows. Section 2 provides the main structure of this study's CGE model. Section 3 describes the data to build the model. Section 4 presents the simulation scenarios and results of the economic and environmental impact of the immediate nuclear shutdown in Japan. Section 5 concludes.
2. Model Structure

2.1. Structure of Production Sector

We construct a multi-sector, multi-region recursive dynamic CGE model with 12 regions and 22 production sectors. The regions and sectors are listed in Tables 1 and 2 respectively. The model consists of three types of agents: representative households, a government, and production sectors. The representative households supply production factors, that is, land, natural resources, capital, and labor, to each factor market to earn and allocate income for the purchase of goods and for savings. In line with Fischer & Fox (2007), we acknowledge the choice between labor and leisure. In other words, the representative household determines the level of consumption and leisure with which to maximize its utility.

Capital and labor are assumed to be mobile within a region and land and natural resources are sluggish factors. In the model, the production technology of production sectors is described as constant-return production technology. We assume a perfectly competitive market in which firms take all prices given and minimize their unit production cost by choosing an input mix. The government levies taxes on output, labor input, and capital use by firms. An endogenous lump-sum income transfer from the government to the representative household ensures that the expenditure levels of the government are maintained at an initial level.

In previous models, such as Takeda et al. (2014), Fischer & Fox (2007) and Rutherford & Paltsev (2000), there are only two types of production sectors. We extend the researchers’ models by constructing the following three types of production sectors: a fossil fuel production sector, a non-fossil fuel production sector excluding the electricity sector, and an electricity sector. Fossil fuel production sectors include the extraction of crude oil (CRU), coal (COL), and gas (GAS). The production technology of these sectors is modeled using a nested constant elasticity of substitution (CES) (Figure 1). The level of output is modeled as the CES composite of the level of natural resources input and non-resources input. The elasticity of substitution between these inputs, which is described as $ES_S(j)$ in Figure 1, can be calibrated using an input–output (I–O) table and the price elasticity of supply. The Leontief aggregation of non-resource inputs means that there is no substitutability among non-resource inputs.

Figure 2 shows the model structure of non-fossil fuel production sectors excluding the electricity production sector. The output of this sector is modeled as the Leontief composite of non-energy goods and the energy–primary factor composite. The
energy–primary factor composite is the CES composite of the energy composite and the primary factor composite. We assume that the refined petroleum and coal products sector (P_C) and the chemical products sector (CHM) use crude oil as feedstock, which is categorized as a non-energy good. We use the feedstock ratio data of Lee (2008).

In the model, electricity is generated using the following nine distinct technologies: oil-fired, coal-fired, gas-fired, nuclear, hydropower, solar photovoltaic, geothermal, wind, and biomass. The structure of electricity production is shown in Figures 3 and 4. Figure 3 indicates that the level of electricity generation is modeled as the CES composite of the specific capital and the non-resource composite. The non-resource composite is composed of intermediate goods, energy goods, labor, and ordinary capital. \( E_{RS}(j) \) represents the elasticity of substitution between the specific capital and the non-resource composite. We can calibrate \( E_{RS}(j) \) using the I–O table and the price elasticity of electricity supply. Although Figure 3 depicts the structure of oil-fired power generation, the same structure is applied to all electricity generation technology excluding renewables. Renewables are assumed to use ordinary capital instead of specific capital in order to model variable private investment for renewables. We set the price elasticity of electricity generation for each electricity generation technology as follows: 1.5 for fossil fuel power generation technologies, 0 for nuclear and hydropower generation technology, and 1 for renewables. In other words, the elasticity parameter, \( E_{RS}(j) \) in Figure 3, is set to be zero for nuclear and hydropower electricity generation to control the path of these types of electricity generation over time. This model allows imperfect substitution among the quality of the electricity

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Regions</th>
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<tbody>
<tr>
<td>JPN</td>
<td>Japan</td>
</tr>
<tr>
<td>EUR</td>
<td>EU27</td>
</tr>
<tr>
<td>USA</td>
<td>USA</td>
</tr>
<tr>
<td>CAN</td>
<td>Canada</td>
</tr>
<tr>
<td>ANZ</td>
<td>Australia and New Zealand</td>
</tr>
<tr>
<td>RUS</td>
<td>Russia</td>
</tr>
<tr>
<td>CHN</td>
<td>China</td>
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<td>IND</td>
<td>India</td>
</tr>
<tr>
<td>BRA</td>
<td>Brazil</td>
</tr>
<tr>
<td>ASI</td>
<td>Other Asia</td>
</tr>
<tr>
<td>OPC</td>
<td>OPEC</td>
</tr>
<tr>
<td>ROW</td>
<td>Rest of the world</td>
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generated by different technologies. Figure 4 shows the aggregation structure of electricity generated by different technologies.

Table 2  List of 22 sectors

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Sectors</th>
<th>Symbol</th>
<th>Sectors</th>
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<tbody>
<tr>
<td>FSH</td>
<td>Fishery</td>
<td>AGR</td>
<td>Agriculture</td>
</tr>
<tr>
<td>OMN</td>
<td>Other mining</td>
<td>LUM</td>
<td>Wood and wood products</td>
</tr>
<tr>
<td>PPP</td>
<td>Paper and pulp products</td>
<td>FPR</td>
<td>Food products</td>
</tr>
<tr>
<td>CRP</td>
<td>Chemical products</td>
<td>TWL</td>
<td>Textile and wearing apparel</td>
</tr>
<tr>
<td>NMM</td>
<td>Non-metallic minerals</td>
<td>TRN</td>
<td>Transport equipment</td>
</tr>
<tr>
<td>NFM</td>
<td>Non-ferrous metals</td>
<td>OMF</td>
<td>Other manufacturing products</td>
</tr>
<tr>
<td>I_S</td>
<td>Iron and steel</td>
<td>TRS</td>
<td>Transport sector</td>
</tr>
<tr>
<td>CRU</td>
<td>Crude oil</td>
<td>CNS</td>
<td>Construction</td>
</tr>
<tr>
<td>COL</td>
<td>Coal</td>
<td>TRD</td>
<td>Trade</td>
</tr>
<tr>
<td>GAS</td>
<td>Gas</td>
<td>SER</td>
<td>Other services</td>
</tr>
<tr>
<td>OIL</td>
<td>Petroleum and coal products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELE</td>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
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Figure 1  Production structure of fossil fuel production sectors

Labor, capital, other intermediate inputs
Figure 2  Production structure of non-fossil fuel production sectors (excluding electricity generation sectors)

Figure 3  Structure of electricity generation
2.2. Structure of Representative Households

The utility function for the representative household is modeled as a four-stage nested CES function. The nesting structure is shown in Figure 5. The level of utility depends on savings, leisure, and consumption. The Cobb–Douglas aggregate of savings and the leisure–consumption composite mean that a constant rate of household...
income is saved. The representative household decides the level of leisure, which means that the level of labor supply is determined endogenously. In addition, the representative household consumes energy composite goods, which are the CES composite of energy-related goods, and non-energy composite goods, which are the CES composite of the other goods. A representative household maximizes its utility by choosing an optimum savings, leisure, and consumption mix, subject to its budget and time constraint.

2.3. Model Dynamics

The time span of the first period from 2007 to 2010 is three years and that of each continued periods from 2010 to 2040 is five years. Each economy is linked by household savings, which represent the source of investment. The investment expands the capital stock of the next period, which represents endogenous capital accumulation.

Following Paltsev et al. (2005), we employ a putty-clay approach in which only newly installed capital can move across sectors in a region. Conversely, extant capital stock cannot move across sectors. As explained in Subsection 2.1, the path of nuclear and hydropower generation over time is exogenously determined in the model. Therefore, we can control the electricity generation level of each.

The other primary factors, such as labor and natural resources, grow exogenously in the model. We assume the following two types of technology improvement: labor and capital productivity improvement and autonomous energy efficiency improvement (AEEI). Labor endowment in each region changes over time according to the reference case projection of world population by region (EIA, 2013).

3. Data

3.1. Benchmark Data and Parameters

We employ Version 8.1 of the GTAP database that uses a benchmark year of 2007 and includes CO₂ emissions data corresponding to the I–O table of the GTAP database (Narayanan et al, 2012). The original GTAP database has a single electricity sector that aggregates fossil fuel power, nuclear power, hydropower, and renewables. To study energy policy in detail, we disaggregate the single electricity generation sector into the following nine electricity generation technologies: oil-fired (ELE_O), coal-fired (ELE_C), gas-fired (ELE_G), nuclear (ELE_N), hydro (ELE_H), solar photovoltaic (ELE_RS), geothermal (ELE_RG), wind (ELE_RW), and biomass (ELE_RB), using a simple disaggregation method explained. We assume that each fossil fuel electricity
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sector inputs all corresponding fossil fuel inputted by the original single electricity sector. The other inputs are apportioned among all of the electricity sectors to reproduce the actual power source share in each region. Figure 6 shows the power source share of each region’s electricity market in the benchmark year.

**Figure 6  Benchmark power source share of regions**

### 4. Simulation and Results

#### 4.1. Policy Scenarios

This study conducts a quantitative assessment of the economic and environmental impact of the immediate nuclear power shutdown in Japan. To conduct the assessment, this study employs a gradual nuclear power phase-out scenario as a reference scenario. In the reference scenario, 1) all nuclear reactors that approach a 40-year operational time limit are assumed to be decommissioned, 2) nuclear plants that were in the planning stage at the time of the Fukushima nuclear accident are assumed to be constructed in accordance with the plans, and 3) the reference scenario does not allow any new reactor plant construction proposed after the accident.

Figure 7 shows the path of Japan’s nuclear power generation capacity for each scenario. The dotted line in the figure represents the path of nuclear power generation.
capacity in the reference scenario. Nuclear capacity is phased out gradually. The grey line in the figure represents the path of nuclear power generation capacity for the immediate shutdown of all nuclear power reactors in Japan. In the immediate nuclear power shutdown scenario, shutting down plants equates to being out of operation permanently.

As explained in subsection 2.1, the amount of specific capital of the nuclear power sector determines the output of nuclear power generation in the model. In the simulation, the specific capital of the nuclear power sector can be controlled exogenously in accordance with the reference scenario and the immediate nuclear power shutdown scenario.

It is important to note that this model does not consider any subsidy policy for renewables, such as feed-in tariffs. Renewable power generation changes according to market principles.

![Figure 7 Path of Japan's nuclear power generation capacity](image)

### 4.2. Simulation Results for Electricity Generation and Price

Figure 8 shows the simulation results for Japan's electricity generation by technology type in the reference case, in which all nuclear reactors in Japan are phased out gradually. Figure 9 shows the simulation results for Japan's electricity generation by technology type in the immediate nuclear power shutdown scenario. In both sce-
Figure 8 Simulation results of power source share by technology and electricity price, reference case

Figure 9 Simulation results of power source share by technology and electricity price, immediate shutdown
scenarios, the electricity shortage is made up mainly of an increase in fossil fuel power generation, especially gas-fired and coal-fired technologies. Renewable electricity generation increases gradually over time in both scenarios. However, the path of nuclear power generation does not affect the path of renewable electricity generation remarkably. With regard to the electricity price, a gradual nuclear power phase-out increases the electricity price gradually. On the other hand, in Figure 9, the electricity price surges after the immediate nuclear power shutdown and calms after the spike.

4.3. Simulation Results for Environmental Impact

Figure 10 shows the simulation results of Japan’s CO₂ emissions for two scenarios, the reference scenario and the immediate nuclear power shutdown scenario. The dotted line represents the path of Japan’s CO₂ emissions in the reference scenario. The grey line represents the path of Japan’s CO₂ emissions in the immediate nuclear power shutdown scenario. In both scenarios, as the supply of nuclear power decreases, the generation of fossil fuel and renewable electricity increase in response to rises in electricity prices. In the model, fossil fuel has a larger capacity to generate and supply electricity than renewable electricity in response to electricity price increases. This is the reason that the immediate nuclear power shutdown increase CO₂ emissions by approximately 11.8% compared to the gradual phase-out scenario in 2015. As nuclear
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plants are decommissioned gradually, the gap in CO₂ emissions decreases.

4.4. Simulation Results for Economic Impacts

As depicted in Figure 9, the immediate nuclear power shutdown makes the price of electricity surge. The spike of electricity prices leads to GDP losses in Japan. Figure 11 shows that the immediate nuclear power shutdown decreases Japan's GDP by about 0.6% from 2015 to 2025 compared to the reference scenario. In 2025, the gap in nuclear power capacity between the two scenarios decreases compared to 2015. This indicates that an immediate nuclear power shutdown would have a negative after-effect on the economy; if this were not the case, the GDP gap would have decreased in proportion to the gap in nuclear power capacity between the two scenarios. The negative after-effect is caused by decreased investment spending when Japan's GDP drops as a result of the immediate nuclear shutdown. Investment spending determines GDP in not only the current term but also the future term.

Figure 12 shows the impact on the sector's output in the two scenarios and the impact of the immediate nuclear power shutdown on the sector's output as the percentage changes from the reference scenario on the line with triangles. Figure 12 represents the impact on energy intensive and trade-exposed (EITE) sectors. In this simulation, the EITE sectors consist of Fisheries (FSH), Other mining (OMN), Paper and pulp products (PPP), Chemical products (CRP), Non-metallic minerals (NMM),

![Figure 11 Simulation results for Japan's GDP](image-url)
Non-ferrous metals (NFM), and Iron and steel (I_S). On the other hand, Figure 13 represents the impact for non-energy intensive and non-trade-exposed (NEINT) sectors and all industries in the model excluding EITE sectors. Figure 12 shows that the im-
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Immediate nuclear power shutdown has a negative impact on the EITE sector’s output. On the other hand, the immediate nuclear power shutdown has a positive impact on the NEINT sector’s output. This is explained as follows. The immediate nuclear power shutdown causes the transfer of labor and investment from EITE sectors to NEINT sectors, which is more profitable under a higher electricity price.

5. Conclusion

This study conducted a quantitative assessment for the environmental and economic impacts of the immediate shutdown of Japan’s entire fleet of nuclear reactors. For the assessment, we constructed a multi-regional, recursive dynamic CGE model based on Version 8.1 of the GTAP database. This study disaggregated the original single electricity production sector in the GTAP database into nine distinct electricity generation technologies: oil-fired, coal-fired, gas-fired, nuclear, hydro, solar photovoltaic, geothermal, wind, and biomass. It is important to note that this simulation held the following assumptions with regard to the reference scenario. 1) All nuclear reactors that come to a 40-year operational limit were assumed to be decommissioned. 2) Nuclear plants that were in the planning stage at the time of the Fukushima nuclear accident were assumed to be constructed in accordance with the plans. 3) The reference scenario did not allow any new reactor construction plans that may be proposed after the Fukushima accident. 4) This model did not consider any subsidy policy for renewables, such as feed-in tariffs.

The simulation results indicate that the immediate nuclear shutdown increases CO₂ emissions through an increase in fossil fuel electricity generation. This scenario raises electricity prices and leads to real GDP losses in Japan compared to the reference case. From the viewpoint of inter-sectoral impact, Japan’s EITE sectors decrease their output, which causes the transfer of production factors from EITE sectors to NEINT sectors. In addition, we found that the immediate nuclear shutdown causes a negative after-effect on the economy caused by the shrinkage of investment spending amid the immediate nuclear power shutdown.

Overall, we found that the Japanese economy would face significant economic and environmental impacts from an immediate nuclear power shutdown. However, our model does not incorporate the potential risks of a nuclear accident or the cost of nuclear waste final disposal sites. These potential negative costs associated with nuclear usage may be sizeable. To derive conclusions for Japanese energy policy, we must consider the potential negative costs of nuclear usage. The results of this simulation study represent the first step in answering important questions on energy policy.
Further research on the potential negative impacts of nuclear power usage should be conducted before conclusions about Japanese energy policy can be drawn.

References


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