Chapter 11

Calibrating the Mix of Electric Power Generation Types

Ken Itakura
Faculty of Economics, Nagoya City University

December 2011

This chapter should be cited as
Itakura, K. (2011), 'Calibrating the Mix of Electric Power Generation Types', in Kimura, F. and X. Shi (eds.), *Deepen Understanding and Move Forward: Energy Market Integration in East Asia*. ERIA Research Project Report 2010-25, Jakarta: ERIA. pp.298-310.

CHAPTER 11

Calibrating the Mix of Electric Power Generation Types

KEN ITAKURA

Faculty of Economics, Nagoya City University

The shift in electric power generation types has gained attention in the context of climate change and more recently by the devastating nuclear fallouts in the aftermath of the Japanese earthquake. On the one hand, shifting away from fossil fuels to renewable energy sources would mitigate greenhouse gas emissions; on the other hand shifting from nuclear to fossil fuels is an immediate response to urgent situations. The shift of electric power sources will have economic impacts on production, consumption, and international trade. To capture the quantitative impacts through economic linkages, we implemented simulations with a global CGE model and database by asking the question: what would be the economic impact of shifting source of power generation away from nuclear in Japan? Simulation results show that reductions in the use of nuclear for electric power generation could have profound negative impacts on the economy.

1. Introduction

The main objective of this report is to shed some light on the following question: what would be the economic impact of altering the type of electric power generation from nuclear to fossil fuels? In the aftermath of the East Japan earthquake hitting northern Japan in March 2011, an immense tsunami devastated the nuclear power plants in Fukushima, leaving the affected region under radiation risk and with power shortages. It seems unlikely that the level of support for the use of nuclear to generate electric power not only in the Tohoku region but also in other parts of Japan can be maintained, thereby motivating this research.

Originally motivated by climate change concerns, this report intended to address the same question of altering the mix of electric power generation but in the opposite direction of shifting from fossil fuels to hydro, nuclear, and other renewable energy sources. By replacing the use of fossil fuels in power generation for other energy sources, the shift was expected to contribute toward greenhouse gas abatement.

Either way of the shift in electric power generation will have economic impacts on production, consumption and international trade across the world. Industries purchase electrical supply services as a vital input into their production activities, while they are competing over the primary factors of production such as labor and capital. Households are also purchasing electrical supply services as well as other goods and services. Suppose there is a change in the price of electrical supply resulting from a shift in the mix of power generation types. The change in price will cause further changes in the demand for intermediate and primary factor inputs by industries and the final demands by consumers. Consequently, these domestic changes will have effects on international trade.

To quantitatively address the economic linkages and channels affecting industries and households across countries, we will rely on a global Computable General Equilibrium (CGE) model and its database. With this global CGE model and database we can conduct computational experiments and describe the linkages of the world economy within a coherent accounting framework. We implemented two sets of simulations by asking the following question:

What would be the economic impact of shifting the sources of power generation away from nuclear in Japan?

Simulation [A]: Reduce the electric power generated by nuclear in Japan;

Simulation [B]: Reduce the electric power generated by nuclear in Japan while maintaining the overall generation level by substituting it by fossil fuels.

Suppressing the use of nuclear power in simulation [A] will lead to a fall in supply of electricity, and I will examine how far economic activities in Japan would be curtailed. In simulation [B], electric power generation based on fossil fuels will fill the gap caused by the cut in nuclear. The extent to which substitution would mitigate the negative impacts on economic activities is considered.

In the next section, we briefly describe the global CGE model and database used in this study, and the data extension process of incorporating different types of electric power generation into the database. Design for the simulation experiments and their results are explained in the third section, followed by summary and policy implications.

Before we proceed to the following section, it is very important to make a few cautionary notes. First, this report is not about the natural disaster and its economic consequences. Rather, we are focusing only on the smooth shift between electric power generations, assuming no damage to existing physical infrastructure. Relating to this point, secondly, this report is not about the economic cost of recovery from the loss caused by the natural disaster.

2. GTAP Model, Database, and Extension

The main aim of this report is to analyze the economic impacts of shifting the electric power generation from nuclear to fossil fuels. For quantitative evaluation of such impacts our choice of applied economic model is a multi-sector multi-region CGE model. To capture intersectoral linkages among industries and consumer in a country as well as international trade flows, it is reasonable to use a multi-sector multi-region comparative static CGE model. The widely used platform for this type of CGE analysis is the Global Trade Analysis Project (GTAP) database and modeling framework (Hertel, 1997; McDougall, 2000; Narayanan and Walmsley, 2008).

The comparative static GTAP model has features of perfect competition, constant returns to scale production technology, a representative regional household, and bilateral international trade with transport margins and differentiation by place of production. Each industry produces their output of goods and services based on the constant return to scale technology by using the inputs of intermediate goods, skilled and unskilled labor, capital, land, and natural resource. Intermediated goods are produced domestically or imported from abroad. Each country is endowed with labor, capital, land, and natural resource, and these primary factors of production do not move across a country's border. A representative regional household in each country decides the allocation of expenditures on private, government, and future consumption.

Table 1. Sector Aggregation

No.	Code	GTAP 57 Sectors
1	GrainsCrops	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibers; Crops nec; Cattle,sheep,goats,horses; Processed rice.
2	MeatLstk	Animal products nec; Raw milk; Wool, silk-worm cocoons; Meat: cattle,sheep,goats,horse; Meat products nec.
3	ForestFish	Forestry; Fishing.
4	Coal	Coal.
5	Oil	Oil.
6	Gas	Gas.
7	OthMinerals	Minerals nec.
8	ProcFood	Vegetable oils and fats; Dairy products; Sugar; Food products nec; Beverages and tobacco products.
9	TextWapp	Textiles; Wearing apparel.
10	LightMnfc	Leather products; Wood products; Paper products, publishing; Metal products; Motor vehicles and parts; Transport equipment nec; Manufactures nec.
11	HeavyMnfc	Petroleum, coal products; Chemical,rubber,plastic prods; Mineral products nec; Ferrous metals; Metals nec; Electronic equipment; Machinery and equipment nec.
12	Util_Cons	Gas manufacture, distribution; Water; Construction.
13	TransComm	Trade; Transport nec; Sea transport; Air transport; Communication.
14	Electricity	Electricity.
15	OthServices	Financial services nec; Insurance; Business services nec; Recreation and other services; PubAdmin/Defence/Health/Educat; Dwellings.

Source: GTAP Database v.7.1.

The GTAP database used in this report is the version 7.1 database, which records all the domestic and international economic transaction flows for 57 industrial sectors accross 112 countries / regions in the world, benchmarked in 2004. Table 1 shows the mapping from the original 57 sectors to the aggregated 15 sectors studied in this report. Electrical supply service, “Electricity” in the code, is one of the 57 industries stored in the GTAP database, but there is no distinction between electric power generation types such as nuclear, fossil fuels, and other.

The electricity sector in the GTAP database can be viewed as an aggregate of different power generation types so that it is possible to disaggregate the original electricity sector into sub-sectors of nuclear, fossil fuels, and other. As electrical supply services are produced from both domestic and imported intermediates as well as primary factor inputs, these production inputs need to be split into sub-sectors. A similar split of database is required for electrical service supply in households' consumption, other industry's intermediate use, and international trade.

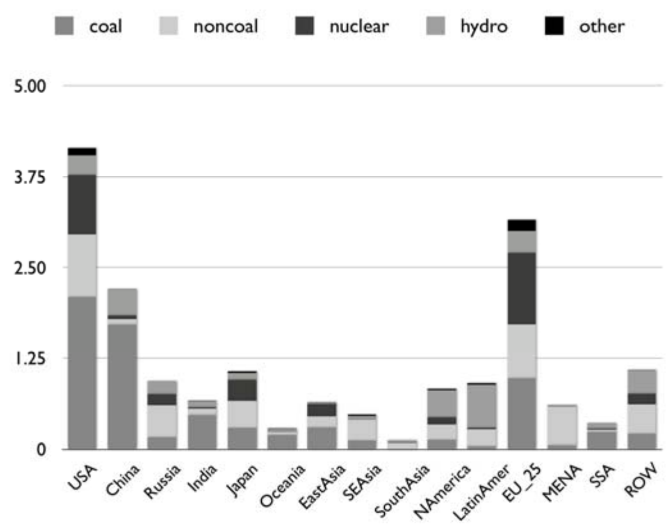
Figure 1 shows an idea of splitting the original GTAP electricity sector into sub-sectors. While subscript *i* stands for an input to the production, subscript *j* stands for a sub-sector, either nuclear, or fossil fuels, or others. As we summed over the sub-sectors, it is clear that the original input data of electricity will be recovered for all the input cells. Given these add-up conditions as constraints, the software SplitCom (Horridge, 2005) implemented the disaggregation process along with the additional data information from IEA (2008), EIA (2008), and Japanese input-output tables for 2005 by Statistics Bureau in Japan (SB, 2009).

Figure 1. Split Electricity

	nuclear	...	Electricity (GTAP)
Domestic Intermediates			
Imported Intermediates	x_{ij}	...	$\sum_j x_{ij}$
Primary Factor Inputs			
	$\sum_i x_{ij}$	...	$\sum_i \sum_j x_{ij}$

Splitting the electricity sector in GTAP v.7.1 database into sub-sectors has been performed for 112 countries, and the splitting results are shown in Figure 2 for selected countries. There is considerable regional variation in the overall level of electric power generation, with the US, China, and EU_25 having the highest levels. The size of coal-based power generation in China is almost equivalent to the US, but its share in the overall generation is overwhelmingly dominating. Following the US and EU_25, the use of nuclear power is proportionally significant in Japan.

Figure 2. Electric Power Generation by Type, 2004 (PWh)



Source: Author's estimates from IEA, EIA, SB.

Computed for the EAS countries, Table 2 reports the share of power generation types in total production. Among EAS members, Japan and Korea rely substantially on nuclear, whereas China only utilizes nuclear to a minor degree. The use of fossil fuel predominates in power generation amongst EAS countries. The large number observed in Laos for other energy sources is mainly driven by hydro-electricity.

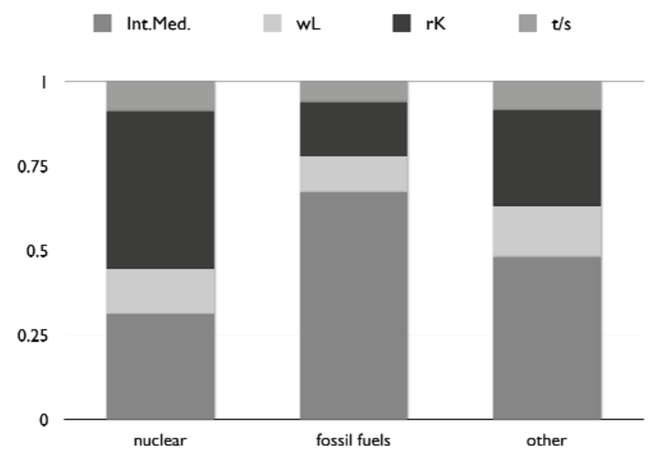
Table 2. Share of Electric Power Generation Type in EAS (%, 2004)

	Fossil	Nuclear	Other
Japan	62.6	26.5	11.0
Korea	63.0	35.7	1.3
China	81.5	2.3	16.2
Cambodia	96.3	0	3.7
Indonesia	86.4	0	13.6
Laos	3.2	0	96.8
Myanmar*	57.1	0	42.9
Malaysia	92.9	0	7.1
Philippines	66.3	0	33.7
Singapore	100.0	0	0
Thailand	93.0	0	7.0
VietNam	61.6	0	38.4

Note: * Weights are computed but not used in GTAP Database v7.1.

Source: Author's estimates from IEA, EIA, SB.

Figure 3. Cost Structure of Electric Power Generation by Type in Japan



Source: Author's estimates from SB.

Figure 3 illustrates the cost structure of electric power generation by type in Japan, estimated from the input-output tables in 2005. Total generation cost breaks down into four categories; intermediate input cost (Int.Med), labor cost (wL), rental cost (rK), and tax or subsidy (t/s). It is clear that nuclear power generation has a large rental cost share whereas fossil fuel power generation relies heavily on intermediate inputs. These variations in the cost structures imply that different power generation types would have different impacts on the rest of economy after a shift in the mix of electricity generation.

3. Simulation Experiments and Results

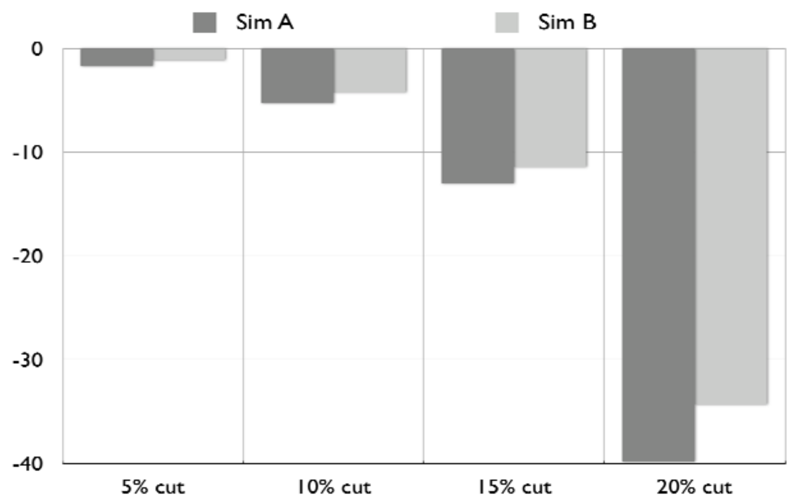
The comparative static GTAP model and database version 7.1 are used to run comparative static simulations with the software GEMPACK (Harrison and Pearson, 1996) and RunGTAP (Horridge, 2008). Two sets of simulation experiments with four different levels of changes are implemented:

Simulation A1: Cut the use of nuclear in electric power generation by 5%
A2: Cut the use of nuclear in electric power generation by 10%
A3: Cut the use of nuclear in electric power generation by 15%
A4: Cut the use of nuclear in electric power generation by 20%

Simulation B1: A1 + increase the use of fossil fuels to substitute for nuclear
B2: A2 + increase the use of fossil fuels to substitute for nuclear
B3: A3 + increase the use of fossil fuels to substitute for nuclear
B4: A4 + increase the use of fossil fuels to substitute for nuclear.

In simulation A, reductions of the use of nuclear in Japan are simulated to varying degrees. In simulation B, fossil fuels filling the electrical supply shortage caused by a cut in nuclear use. In cutting the level of nuclear-based power generation, the model is configured to allow the sub-sectors to make losses / profits while their generation activities are controlled by the simulation settings. Consequently, as a caveat, this configuration would introduce a breach in equilibrium conditions. Therefore, the simulation results should not be taken as a full equilibrium response to the exogenous shocks but they are rather coarse estimates in the process recovering to the full equilibrium conditions.

Figure 4. Impact on Real GDP in Japan (US$, billion)



Source: Author's simulation results.

As Japan reduces power generation from nuclear, then real Japanese GDP would be negatively affected. Figure 4 illustrates the negative impacts on real GDP in Japan. The deeper the cut in nuclear use for power generation, the larger the negative impact on real GDP. The substitution of fossil fuels for nuclear in simulation B was not sufficient to mitigate these negative impacts. If nuclear-based power generation in Japan was reduced by 20 per cent without any replacement, then the real GDP in Japan would decrease by approximately 40 billion US dollars, almost equivalent to one per cent of GDP evaluated in 2004. Table 3 reports the impacts on real GDP in percent terms.

Table 3. Impact on Real GDP in Japan (%)

	5% cut	10% cut	15% cut	20% cut
Simulation A	-0.04	-0.11	-0.28	-0.86
Simulation B	-0.02	-0.09	-0.25	-0.74

Source: Author's simulation results.

Recall from Figure 3 that the cost structure of nuclear-based power generation has relatively high share of rental cost. Once the use of nuclear is suppressed, then the primary factor demands for physical capital would be weakened, leading to lower rental price in Japan. The lowered rental price implies that the expected rate of return would diminish so that the resulting fall in investment negatively contributes to real GDP.

4. Summary and Policy Implications

The shift in electric power generation types has gained attention in the context of climate change and more recently by the devastating nuclear fallouts in the aftermath of the earthquake. On the one hand shifting away from the fossil fuels to renewable energy sources would mitigate green house gas emissions, on the other hand shifting from nuclear to fossil fuels is immediate response to recent events.

The shift in electric power sources will have economic impacts on production, consumption, and international trade. To capture the quantitative impacts through economic linkages, simulations with a global CGE model and database were analysed. As simulation results showed, reductions in the use of nuclear for electric power generation could have a large negative impact on the economy.

Given the variations in types of electric power generation across countries, it is desirable in policy formulation to design an appropriate mix of electric generation types based on existing facilities and feasibly planned future investments. Also, given the variations in cost structures of power generation, the economic consequences of shifting amongst different types would differ considerably.

References

Energy Information Administration (EIA) (2008). International Energy Statistics, www.eia.gov, United States.

Harrison, J. W. and Pearson, K. R. (1996). Computing Solutions for Large General Equilibrium Models using GEMPACK. Computational Economics, 9:83-127.

Horridge, M. (2003). SplitCom: Program to Disaggregate a GTAP sector, Center for Policy Studies, Monash University.

Horridge, M. (2008). RunGTAP (v3.53), Center for Policy Studies, Monash University.

International Energy Agency (IEA) (2008). Energy Balances of OECD Countries, OECD.

Narayanan, B. and Walmsley, T.L., Editors (2008). Global Trade, Assistance, and Production: The GTAP 7 Data Base, Center for Global Trade Analysis, Purdue University.

Hertel, T. W., editor (1997). Global Trade Analysis: Modeling and Applications. Cambridge University Press, New York.

McDougall, R. A. (2000). A New Regional Household Demand System for GTAP, GTAP Working Paper, No. 14, September.

Statistical Bureau (SB) (2009). 2005 Input-Output Tables for Japan, Ministry of Internal Affairs and Communications, Japan.