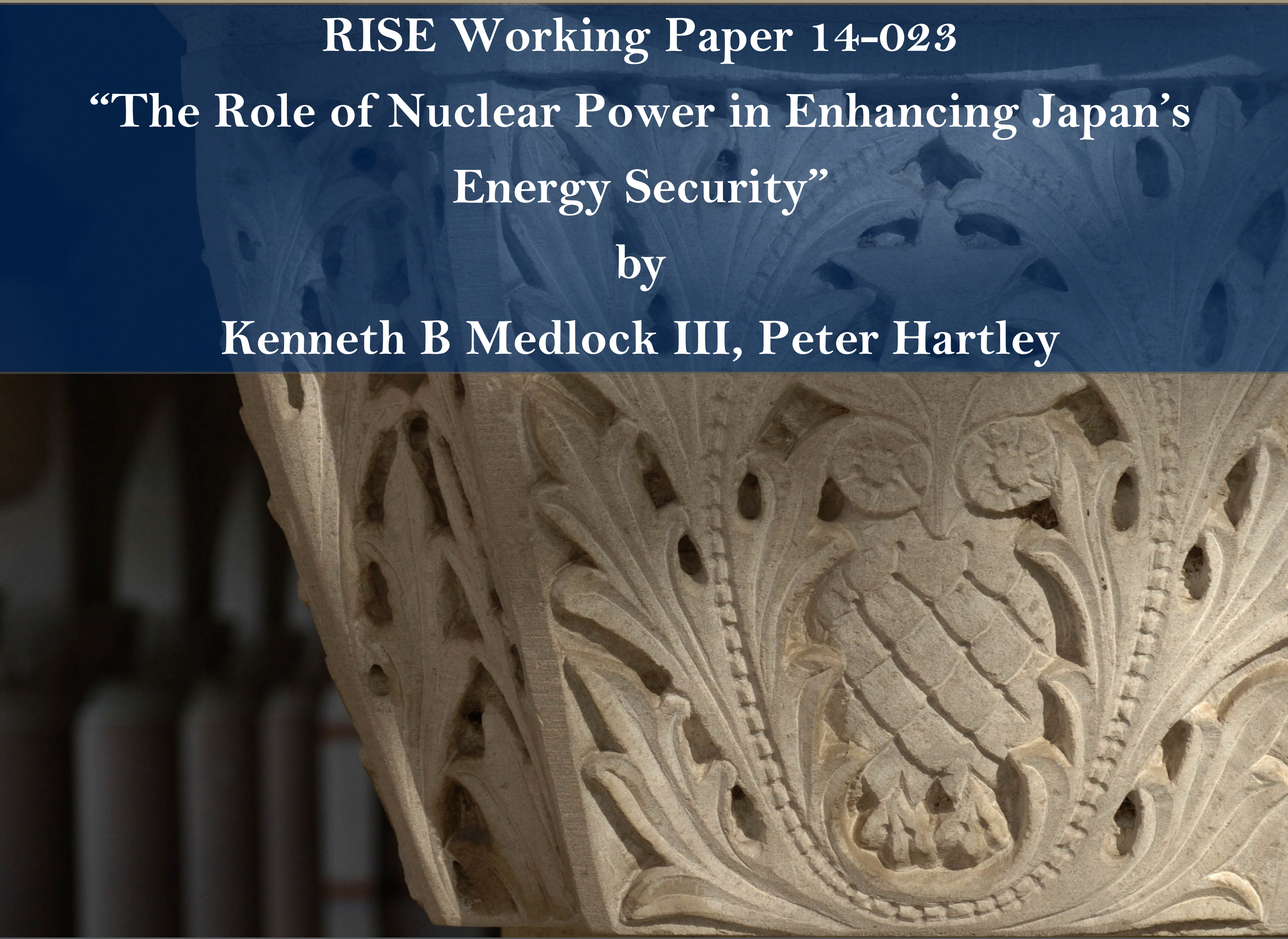
RISE | RICE INITIATIVE *for the* STUDY *of* ECONOMICS

RISE Working Paper 14-023

"The Role of Nuclear Power in Enhancing Japan's Energy Security"

by

Kenneth B Medlock III, Peter Hartley



RICE Department of Economics
Baker Hall, MS22
6100 Main Street, Houston, Texas 77005
https://economics.rice.edu

The Role of Nuclear Power in Enhancing Japan's Energy Security[1]

Dr. Kenneth B Medlock III
Visiting Professor, Department of Economics, Rice University
Energy Consultant to the James A Baker III Institute for Public Policy

Dr. Peter Hartley
Chairman, Department of Economics, Rice University

With research contributions by

Ms. Atsuko Saruhashi
Visiting Researcher, Ministry of Economics, Trade and Industry

Ms. Jill Nesbitt
Graduate Researcher, Department of Economics, Rice University

Ms. Stacy Eller
Graduate Researcher, Department of Economics, Rice University

Prepared in conjunction with an energy study sponsored by

Tokyo Electric Power Company Inc.

and

The James A. Baker III Institute for Public Policy
Rice University - March 2004

---

[1] The authors extend special thanks to Ms. Amy Myers Jaffe, Wallace Wilson Fellow for Energy Studies, James A Baker III Institute for Public Policy and Dr. Ronald Soligo, Professor, Department of Economics, Rice University for their useful comments and suggestions.

I. Introduction

Energy security is a major public policy concern in Japan. Although Japanese energy consumption is among the highest in the world, the country lacks significant domestic energy resources, with imports supplying over 81% of primary energy requirements and 99% of fossil fuel requirements.[2] This dependence exposes Japan's economy to disruptions in international energy markets.

Prompted by energy security concerns, Japan has promoted energy efficiency, becoming one of the most energy efficient countries in the world. Japan has also diversified its primary fuel requirement away from oil. Oil consumption declined from 77% of Japan's total primary energy use in 1973 to about 52% in 2002. Moreover, oil consumption has been relatively stable in recent years, rising only 0.5 million barrels per day (from 4.8 to 5.3) from1988 to 2002. This is a stark contrast to trends in neighboring China and South Korea, where oil consumption has more than doubled over the same period.

As indicated in Figure 1, increased use of natural gas and nuclear power has facilitated much of the reduction in oil dependence in Japan[3], with much of this substitution occurring in the power generation sector. In particular, as indicated in Figure 2, the share of oil in power generation has declined substantially since 1975, giving way to nuclear, natural gas, and, to some extent, coal. This shift in fuel source has been motivated by multiple factors. For one, new power generation technologies, such as combined-cycle generation, have decreased the relative cost of generating power with natural gas, thus favoring its adoption. In addition, instability in oil prices has

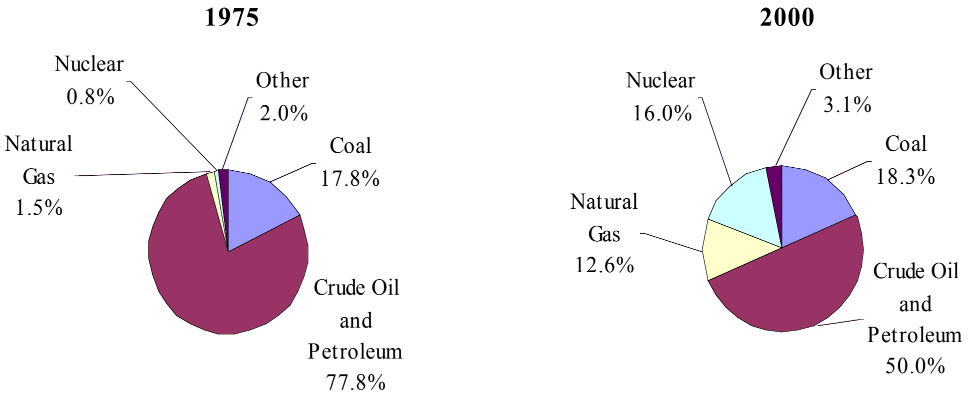
---

[2] According to IEA Energy Balances.

[3] Although not explicitly explored here, it should be noted that increasing reliance on liquefied natural gas (LNG) imports potentially presents security concerns similar to those posed by the import of oil.

disadvantaged oil as a fuel source for generating electricity. Perhaps the largest reason for this is that public policy in Japan has favored the use of fuels other than oil. A major public policy motivation for increased diversification away from oil lies in the energy-macroeconomy link that has been observed in industrialized economies. Specifically, it has been suggested that unexpected increases in oil prices have a negative impact on the macroeconomic performance of oil-importing nations. Moreover, since domestic oil prices do not perfectly track imported prices, the degree of oil import dependence influences the extent to which an oil price shock affects the macroeconomy. Therefore, economic theory suggests that a smaller share of oil in total energy would reduce the sensitivity of Japan's economy to fluctuations in oil prices. This is not meant to suggest complete independence is the best policy. In fact, the welfare gains from trade (or the import of oil) must be balanced against the expected value of reduced exposure to price fluctuations.

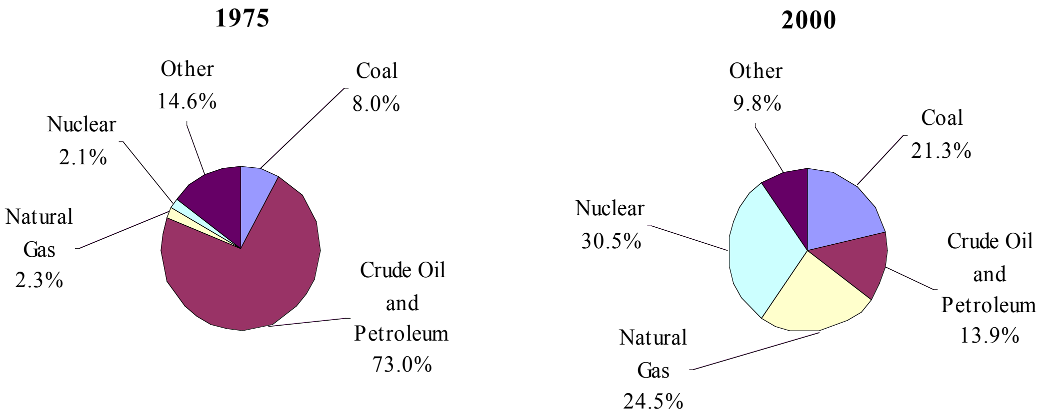
Figure 1 – Composition of Primary Energy Requirement, 1975 and 2000



Source: IEA

Expansion of nuclear power has been a cornerstone of Japanese energy policy over the past two decades. Nuclear power has been favored because it enhances energy security as an alternative source of energy[4] while allowing electric utilities to meet stated environmental objectives. Japan has plans to increase nuclear generation capacity by up to 30% (roughly 10-12 power plants) through 2010. However, nuclear accidents, such as the major incident in 1999 at Tokaimura, have undermined public confidence in atomic power. If the additional nuclear power plants are not built, Japan faces an eventual shortfall of as much as 28 gigawatts (GW), which will require turning to other energy sources to meet the deficit. This could translate into additional imports of up to 1.2 million barrels per day of oil or 186.7 billion cubic meters per day of liquefied natural gas, thus increasing Japan's exposure to potential supply disruptions.

Figure 2 – Composition of Electric Power Generation, 1975 and 2000



Source: IEA

---

[4] Although uranium also has to be imported into Japan, the amount of raw material needed to generate the required electricity is much less. In addition, Japan has pursued breeder reactor technology in order to further lessen its dependence on foreign sources of fuel.

Proponents of nuclear power point to its low operating costs and the historically stable costs for uranium fuel, especially when compared to oil or natural gas. They assert that the stable costs in particular demonstrate that nuclear power contributes to Japan's energy security, as it does not face the same commodity risk of other fuels for power generation. In addition, Japan has been able to source uranium imports from different, and arguably more reliable, foreign suppliers. However, Japan has experienced several nuclear capacity outages in recent years related to accidents or safety concerns. This has raised questions about the future of nuclear power in Japan.

The purpose of this study is to assess the marginal value of nuclear capacity in Japan as it pertains to minimizing exposure to price fluctuations in commodity markets. Specifically, we are concerned with the savings, in terms of macroeconomic output, associated with the reduction in import reliance that can be achieved by additional MW of installed nuclear capacity in the event of a market disruption. In completing this assessment of the value of nuclear power in Japan, this study builds upon three distinct components:

1. An economic model of the long term Japanese power market, where incremental capacity choices are influenced by alternative sets of assumptions with regard to nuclear power.
2. An economic model of the historical relationship between energy prices and Japanese macroeconomic performance.
3. A simulation of the Japanese power market under different assumptions with regard to generation capacity by type in an effort to address three questions:
    - **a.** What is the economic impact of unexpected changes in energy prices?
    - **b.** How does the fuel composition of energy use influence this?
    - **c.** What is the risk mitigating potential of nuclear generation capacity?

We begin with a detailed description of a model of the Japanese power sector. This is followed by a discussion of the study results in what will be referred to as the "baseline" model. Highlights include the impact of the recent forced outage of nuclear plants and the change in the generation mix over time as new investments in capacity are made. We then discuss the energy-macroeconomy link in Japan, with express attention given to the link between commodity fuel prices and Japanese Gross Domestic Product (GDP). We conclude with discussion of the different scenarios that were constructed for the purpose of answering the question at hand, "What is the energy security value of nuclear power?" To answer this question, we examine how Japan's economic performance might have fared in an energy crisis had the country never constructed nuclear facilities, and compare those outcomes to the economic impact of a future energy crisis under a "business-as-usual"-type scenario.

As will be made clear, this study demonstrates that diversity of fuels enhances Japanese economic security in times of disruption or crisis. Among the major findings of the study are:

- Diversity of fuel sources increases flexibility to keep overall costs low during sudden or prolonged disruptions or demand spikes.
- Conversely, heavy reliance on one or two fuel types can raise the economic stakes of a major disruption.
- Electricity prices are, on average, lowest when there are no constraints to construction of new capacity. While it is true that greater fossil fuel use increases exposure in the aftermath of an oil crisis, eliminating the use of fossil fuels is not an efficient policy. Certain types of generation capacity are best suited to meet particular loads.

- Related to the previous point, encouraging the use of any one fuel beyond its efficient level will generally raise overall electricity costs to the national economy. Moreover, using subsidies to artificially encourage the use of certain fuels can raise overall electricity costs to the national economy. These costs must be weighed carefully against the value of the benefit to the public good of promoting cleaner or more secure fuels such as nuclear power.
- There is a level of nuclear capacity for Japan that is cost-minimizing. Movement towards a level of nuclear capacity that is above that level or below it will raise the overall costs of electricity generation in Japan.
- The modeling exercise suggests that the most cost-effective fuel to replace nuclear power from an energy security point-of-view would be coal, environmental considerations notwithstanding. Since coal is imported from different sources than oil and gas, greater use of coal could also contribute generally to security benefits. On the other hand, while new clean coal technology avoids problems of SO_X and NO_X pollution, a potential issue is that the clean coal process does not eliminate CO_2 emissions.

According to our analysis, the energy security value of nuclear power can be significant. Nuclear power can provide stable fuel costs on a day-to-day basis, as well as protect overall national economic performance during times of disruption. These benefits are diminished in the presence of stable oil prices and reliable supply. In the case of a 25% shock to the price of oil in 2006, we find the value of nuclear power to be about 42.0 million Yen (US$382,132) per MW, or about 15.7% of the capital cost of construction of a nuclear power plant in Japan. We also examined a scenario that included a large up-front shock followed by prolonged volatility in oil prices. Under that scenario, the value of nuclear power rises to as much as 154.4 million Yen (US$1.4 million) per MW of installed capacity or the equivalent of 57.8% of the capital cost of construction of a nuclear power plant in Japan.

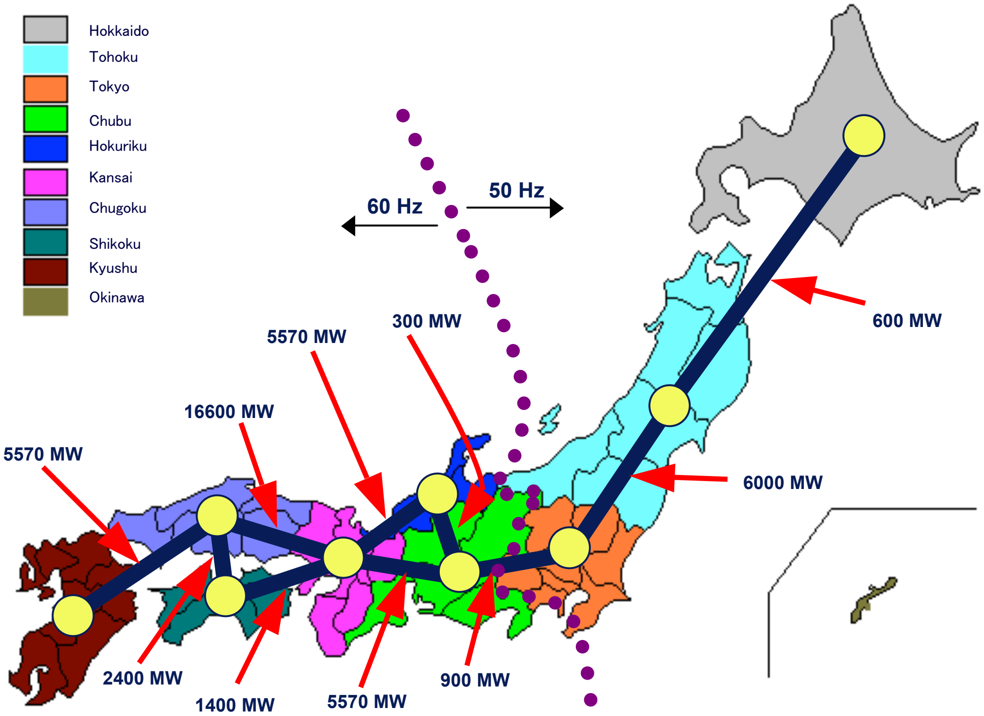
II. Modeling the Long Term Japanese Power Market

A. Supply

In order to evaluate the potential security value of nuclear power, we need to model not only the *current* Japanese power supply system but also assess how the system is likely to develop in the *future* under different scenarios. In particular, the *current* generation capacities by fuel type are just a starting point. Future observed and anticipated market conditions will alter the generation mix.

We simulated the Japanese electricity market using a simplified model based on nine distinct market areas, or "Utility Areas", with transmission links between each region. The Henwood Japanese database was the main source used to construct curves indicating the marginal cost of generation as a function of total output (the so-called "supply stacks") in each Utility Area. (Appendix Figure 1 graphs the supply stacks for the initial year of the simulation (2000), by region.) We also constructed a simplified transmission grid, using the Henwood Japanese database to obtain approximate capacity ratings for transmission links between each area. The Altos energy modeling software was used to construct and simulate the operation of the current Japanese power market and its likely future development under different scenarios. The basic model architecture is illustrated in Figure 3.

Figure 3 - Power Market Architecture, Utility Areas and Transmission Path Ratings



Many different resources were utilized in order to develop the power market model. As noted above the Henwood Japanese database was used as the main source for data on the current system. Prior to its use, however, the data was checked for accuracy against official government statistics for generation by type. The data, which are organized by generating unit, included the heat rate, fuel type, non-fuel operating costs, and capacity. Other information or assumptions, such as tax and insurance rates, required rates of return to new capital investment, and input fuel acquisition costs were obtained from, or motivated by, various other sources.

Simulations of the future power market in Japan were conducted using the Altos energy modeling software. Investment parameters (such as capital cost of construction by type of capacity, required rates of return on equity and debt, the equity fraction of invested capital, tax and insurance rates, plant operating life, and tax and book life for the investment) determine the economic viability of adding capacity to the system given current and expected future power prices. Specifically, new capacity competes with other available options to replace retired capacity or displace older, less-efficient capacity. For reference, the investment parameters are summarized in Table 1, where a comparison of US and Japanese costs is also provided. A description of each of the investment parameters is given in Table 2.

Along with the relevant investment parameters, Table 1 also shows the types of new capacity that can be added to the system: Nuclear, Coal Integrated Gas Combined-cycle (IGCC), Coal Super-critical (SC), Combined-cycle Fuel Oil (FO6 CC), Steam (simple-cycle) Fuel Oil (FO6 ST), Combined-cycle Natural Gas (NG CC), and Combustion Turbine Natural Gas (NG CT). The technologies were chosen based on their likely commercial viability in the next thirty years in Japan, taking into account also the impact of environmental policies. While Coal IGCC technology is not widely used today, it is an emerging technology where reasonable efficiency improvements are expected in the coming years. It also has other promising attributes, particularly with regard to pollution control. In the model, IGCC technology is assumed to be an available alternative by 2015. All other technologies are assumed available based on lead-time and existing plans. For example, new NG CT and FO6 ST capacity can be made available beginning in 2006. New nuclear is first available in 2012, and new NG CC, FO6 CC, and Coal SC are available in 2009. Planned capacity additions included in published utility reports are assumed to occur in the year specified without regard to cost of capital or lead-time.

Table 1 - Investment Parameters

Investment Parameters							
Plant Type	**Nuclear**	**Coal IGCC**	**Coal SC**	**FO6 CC**	**FO6 ST**	**NG CC**	**NG CT**
Capital Cost (Yen/kW)	267,502	236,031	220,296	125,883	94,413	125,883	78,677
Non-Fuel O&M (Yen/MWh)	412	397	317	655	1,777	655	1,110
Heat Rate (BTU/kWh)	10,500	9,400	8,900	8,200	9,400	7,000	9,000
Operating Life (years)	50	40	40	40	30	40	30
Spending Lead (years)	8	3	4	2	1.5	3	2
Book Life (years)	25	20	25	20	20	20	20
Income Tax	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%
Property Tax and Insurance	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Sales Tax	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Rate of Return (WACC)*	7.2%	7.3%	7.3%	7.9%	8.1%	7.9%	8.2%

Japanese vs US Costs (US$)							
Plant Type	**Nuclear**	**Coal IGCC**	**Coal SC**	**FO6 CC**	**FO6 ST**	**NG CC**	**NG CT**
Capital Cost ($/kW Japan)	$ 2,437	$ 2,150	$ 2,007	$ 1,147	$ 860	$ 1,147	$ 717
Capital Cost ($/kW US)	$ 1,700	$ 1,500	$ 1,400	$ 800	$ 600	$ 800	$ 500
Non-Fuel O&M ($/MWh Japan)	$ 3.75	$ 3.62	$ 2.89	$ 5.97	$ 16.19	$ 5.97	$ 10.11
Non-Fuel O&M ($/MWh US)	$ 2.60	$ 2.50	$ 2.00	$ 4.10	$ 11.20	$ 4.10	$ 7.00

* - WACC is the weighted average cost of capital, adjusting for the debt/equity ratio.

Table 2 – Variable definitions

Variables	**Description of variables**
Capital Cost	The capital cost of construction. Source: IEA WEIO (2004), IEA report Power Generation Investment in Electricity Markets (2003), and OECD
Non-Fuel O&M	The non-fuel cost of operation. Source: IEA WEIO (2004), IEA report Power Generation Investment in Electricity Markets (2003), Altos, and OECD
Heat Rate	The energy input required per unit of energy output. This is related to the reciprocal of thermal efficiency. Source: Henwood, Altos and IEA report Power Generation Investment in Electricity Markets (2003)
Operating Life	Years a plant will operate. Source: Altos, Henwood, TEPCo
Spending Lead	Time required prior to plant operation in which capital expenditure is incurred. Source: Altos
Book Life	Time used to determine depreciation allowances, which in turn affect tax liability. Source: Altos
Income Tax	Tax rate on income earned. Source: TEPCo
Property Tax and Insurance	Tax rate on property and insurance rate. Source: TEPCo
Sales Tax	Tax rate on sales of electricity. Source: TEPCo

Rate of Return (WACC)	Internal rate of return required on investment, or weighted average cost of capital. This accounts for the inherent risks and the debt-equity ratio of the project. Source: IEA WEIO (2004)

In the power market model, new capacity will be constructed if and only if the discounted present value of the margin between the (anticipated) wholesale electricity price and the marginal operating costs of production of the new capacity is greater than or equal to the capital cost of construction.[5] Thus, ignoring for simplicity the complications arising from tax considerations, we have as a condition for new investment

$$C_t \le \sum_{t=1}^{T} \beta^t \left[(p_t - v_t) q_t \right]$$

where C is the cost of capital, β is the discount rate on the capital investment, (p-v) is the margin earned while operating (p is wholesale price and v is operating and maintenance cost), q is the quantity sold into the market place, and T is the operating life for the investment. Note that the term β captures the internal rate of return required for the investment to take place, which is measured as a weighted average cost of capital for existing investors in the electricity generating sector in Japan. It should be noted that the model considers the cost of capital for the life of the prospective project, including the lead time required for construction prior to plant operation. For example, if the lead time of a project is 3 years, construction costs must be carried forward for three years to the date (year 1) when the project begins to generate a positive cash flow.

The amount, as well as the fuel type, of new capacity is determined endogenously, along with all current and future prices. Generally, the model considers what new

---

[5] Because capacity has to be added in discrete lumps, some new capacity may earn "rents", or a surplus of operating profits above the capital costs. Any attempt to add alternative capacity to capture such rents would be expected to result in a loss since the new capacity has a minimum efficient scale.

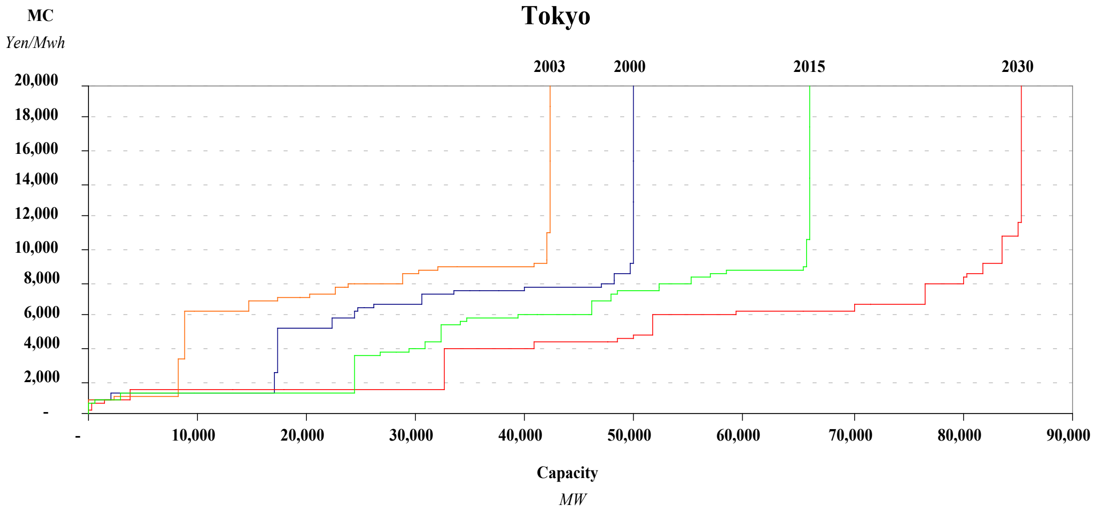
capacity today would do to prices in all future periods and asks whether the expected benefits outweigh the expected costs. If there are enough choices for the size, operating costs and commissioning date for new capacity, the model can ensure that the marginal unit of new capacity will just recover its capital costs, i.e.- no capacity is added that does not recover its costs. In the case where capacity is expected to more than recover its costs, additional capacity will be added at the same time except if the minimum feasible capacity addition would be expected to earn insufficient operating profit to cover its investment costs.

Each type of capacity will earn different operating rents at a given market price of electricity due to differences in non-fuel operating and maintenance costs, and differences in the thermal efficiencies and fuel type of the technology employed. Each type of capacity is assigned a heat rate (units: BTU per kilowatt-hour), which describes the required energy input for a given generation output.[6] The new capacity adds to existing capacity to form new supply stacks in each time period. An example of the Tokyo Utility Area is given in Figure 4, with selected years labeled for illustration. The case illustrated is Case 1. (A complete description of the various cases is given in Appendix Table 1.) Of particular interest is the significant expansion that occurs through 2030, as well as the reduction in available capacity that arose in 2003 due the staged shutdown of TEPCo's nuclear reactors. For an indication of where each type of generation can be found in the stack, please see Appendix Figure 1.

---

[6] If we convert the units into common measures, this is the reciprocal of thermal efficiency. For example, if the heat rate of a particular generation facility is given as 10,000 BTU/kWh, this implies its thermal efficiency is 34%, given that one kilowatt-hour of electricity is equal to 3,412 BTU. Similarly, the minimum heat rate in the model, 7,000 BTU/kWh for new natural gas combined cycle, implies a thermal efficiency of 48.7%. As the heat rate falls, the thermal efficiency rises, and the fuel cost of operating the plant, *ceteris paribus*, declines.

Figure 4 – Tokyo Supply Stacks for Select Years in Case 1



B. Fuel Price

The prices of the input fuels are key determinants of the supply stack at any time. Historical fuel price data were used to approximate the relationships between the prices of different fuels in Japan. Specifically, the following relationships were estimated:

$$
\begin{aligned}
P_t^{LNG} &= \alpha + \delta_1 \ln P_t^{CrudeOil} + \delta_2 \ln P_{t-1}^{CrudeOil} + \delta_3 \ln P_{t-1}^{LNG} \\
P_t^{HeavyOil} &= \alpha + \delta_1 \ln P_t^{CrudeOil} + \delta_2 \ln P_{t-1}^{CrudeOil} + \delta_3 \ln P_{t-1}^{HeavyOil} \\
P_t^{Diesel} &= \alpha + \delta_1 \ln P_t^{CrudeOil} + \delta_2 \ln P_{t-1}^{CrudeOil} + \delta_3 \ln P_{t-1}^{Diesel} \\
P_t^{Coal} &= \alpha + \delta_1 \ln P_t^{CrudeOil} + \delta_2 \ln P_{t-1}^{CrudeOil} + \delta_3 \ln P_{t-1}^{Coal} \\
P_t^{LPG} &= \alpha + \delta_1 \ln P_t^{CrudeOil} + \delta_2 \ln P_{t-1}^{CrudeOil} + \delta_3 \ln P_{t-1}^{LPG} \\
P_t^{Uranium} &= \alpha + \delta_1 \ln P_t^{Coal} + \delta_2 \ln P_{t-1}^{Coal} + \delta_3 \ln P_{t-1}^{Uranium}
\end{aligned}
$$

The regression results are reported in Table 3.

Table 3 – Estimated Fuel Price Relationships

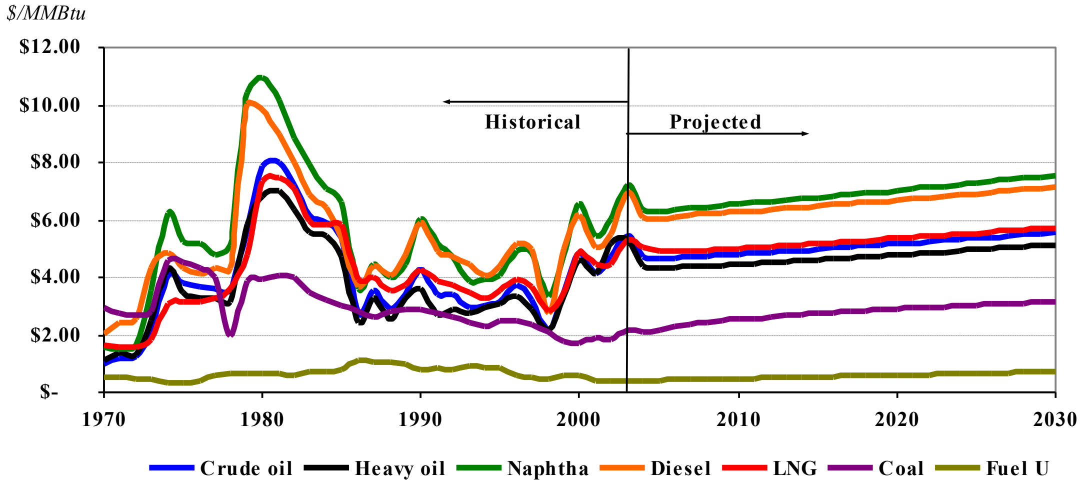
	Heavy oil	Naptha	Diesel	LNG	Coal	Uranium
α	0.149	0.353	0.933	0.566	-0.158	-0.299

std error	*0.127*	*0.172*	*0.195*	*0.179*	*0.340*	*0.183*
δ_1	**1.032**	**1.004**	**0.987**	**0.670**	**0.611**	**-0.007**
std error	*0.038*	*0.050*	*0.062*	*0.028*	*0.112*	*0.059*
δ_2	**-0.354**	**-0.379**	**-0.277**	**0.041**	**-0.424**	**0.122**
std error	*0.143*	*0.152*	*0.102*	*0.084*	*0.131*	*0.059*
δ_3	**0.290**	**0.351**	**0.178**	**0.206**	**0.823**	**0.917**
std error	*0.157*	*0.166*	*0.139*	*0.094*	*0.096*	*0.051*
Durbin-Watson	*1.848*	*1.885*	*2.645*	*1.363*	*2.485*	*2.274*
R^2	*0.990*	*0.982*	*0.982*	*0.985*	*0.931*	*0.963*

Note: *See text for definition of variables.*

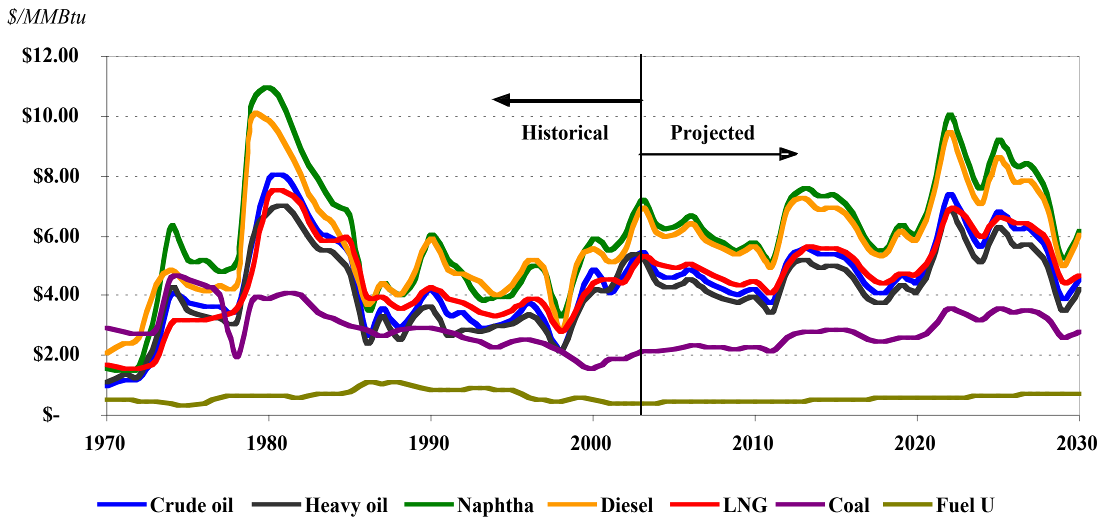
A forecast for each of the fuels is, therefore, dependent on a forecast of crude oil prices. The US Energy Information Administration's forecast for crude oil price is used as the baseline for the modeling exercise. Figure 5 depicts the historical and projected fuel prices (1970-2030) that result from this procedure.

Figure 5 – Fuel Prices: Historical and Projected (Baseline)



In order to simulate future shocks to the oil market, we modeled the random fluctuations in oil prices that have been observed in the past. Specifically, we estimated how oil prices respond to shocks over time by regressing contemporaneous price on lagged price. This procedure also gives a measure of the average size of shocks to oil prices. To simulate future shocks, we use a sampling algorithm to generate random draws from a distribution that has the same characteristics as the estimated distribution of shocks. We then mean correct the resulting shocks to ensure that the simulated price path matches the forecast baseline average coming from the EIA. This allows the model to simulate the effect of unexpected changes in fuel prices without significantly altering the long-term investment path in a particular model case. This is necessary if one wishes to compare outcomes, since any anticipated or expected change in fuel prices could alter investment decisions, particularly if fuel prices across cases differ significantly in the long run. The result of this exercise is illustrated in Figure 6.

Figure 6 – Fuel Prices: Historical and Projected (Random Shocks)



It is important to note that while the forecast variation in Figure 6 is substantial when compared to the baseline in Figure 5, the long run means are identical in both cases.

C. Demand

An important point regarding the model solution is that demands and supplies in each of the Utility Areas are determined simultaneously, along with price, at each point in time. Thus, the model yields a dynamic and spatial equilibrium. Demand in each of the Utility Areas is posited to be a log-linear function of price, GDP, population, weather and time. Longitudinal data (annual from 1965 to 2000) are used to estimate the elasticity of demand with regard to each of the determining variables. The equation estimated is given as

$$\ln D_{t,i} = A_i + b_1 \ln P_{t,i} + b_2 \ln GDP_t + b_3 \ln W_{t,i} + b_4 \ln POP_{t,i} + b_5 t$$

where *D* denotes demand, *P* denotes price, *GDP* denotes gross domestic product, *W* denotes weather, *A* is a region-specific intercept, and the subscripts *t* and *i* denote time *t* in Utility Area *i*. Note that all variables are region specific except GDP, which is that of all of Japan. The estimated parameters, b_i, are interpreted as long-run elasticities.

All data used in the estimation was obtained from Japanese government sources (see references for a complete list). The weather variable is the average annual temperature of the most populous city in the respective Utility Area.[7] Price data are constructed using data for inter-company sales and the associated revenues. In light of regulation in Japan, this is viewed as the closest available proxy for a wholesale price of electricity. The method of generalized least squares, to correct for autocorrelation in the residuals (Durbin-Watson statistic = 0.1617), is used to estimate a fixed-effect

---

[7] While we would prefer measures such as heating degree days and cooling degree days, we could not find a suitable source for these. A more disaggregated measure of weather impacts would be more important in a seasonal demand model. The weather variable we have included corrects for *years* that were significantly warmer or colder than others. The Utility Area intercept *A* corrects for *average* differences in weather conditions, among other things, across Japan.

specification. The parameter estimates, standard errors (in parentheses), and R-squared are as follows:

$$\ln D_{t,i} = A_i \underset{(0.0427)}{-0.0819} \ln P_{t,i} \underset{(0.1885)}{+0.4014} \ln GDP_t \underset{(0.0665)}{+0.1182} \ln W_{t,i} \underset{(0.0342)}{+0.8933} \ln POP_{t,i} \underset{(0.0052)}{+0.0141} t$$

$$R^2 = 0.9731$$

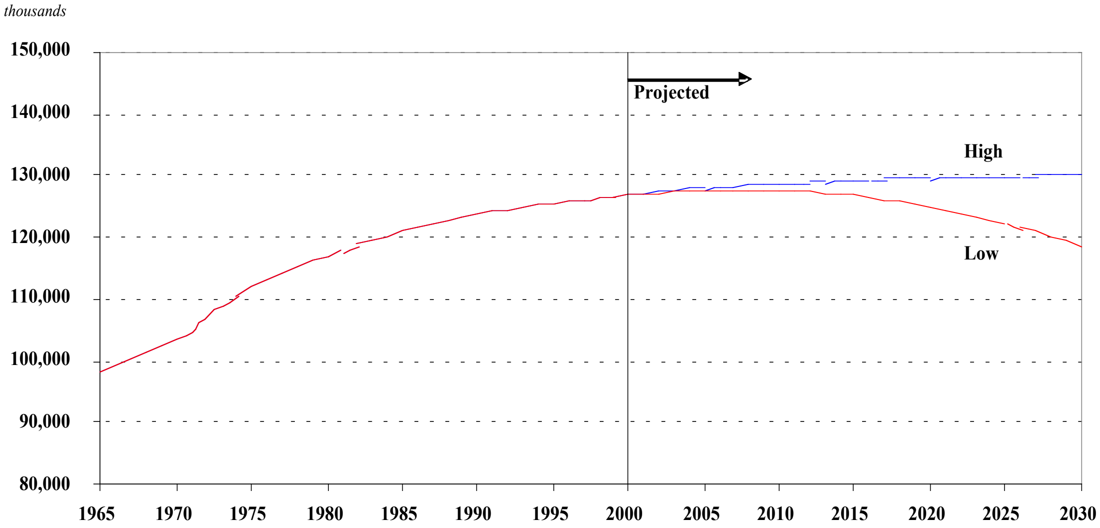
The estimated region-specific effects, along with standard errors, are:

	parameter estimate	*standard error*
Hokkaido	-23.5937	10.2765
Tohoku	-23.4150	10.7782
Tokyo	-23.1345	11.6066
Chubu	-23.1505	10.9822
Hokuriku	-23.1993	9.9114
Kansai	-23.1691	11.1324
Chugoku	-23.2794	10.4753
Shikoku	-23.4776	10.0893
Kyushu	-23.4832	10.8379

All estimated parameters are statistically significantly different from zero and of the expected sign.

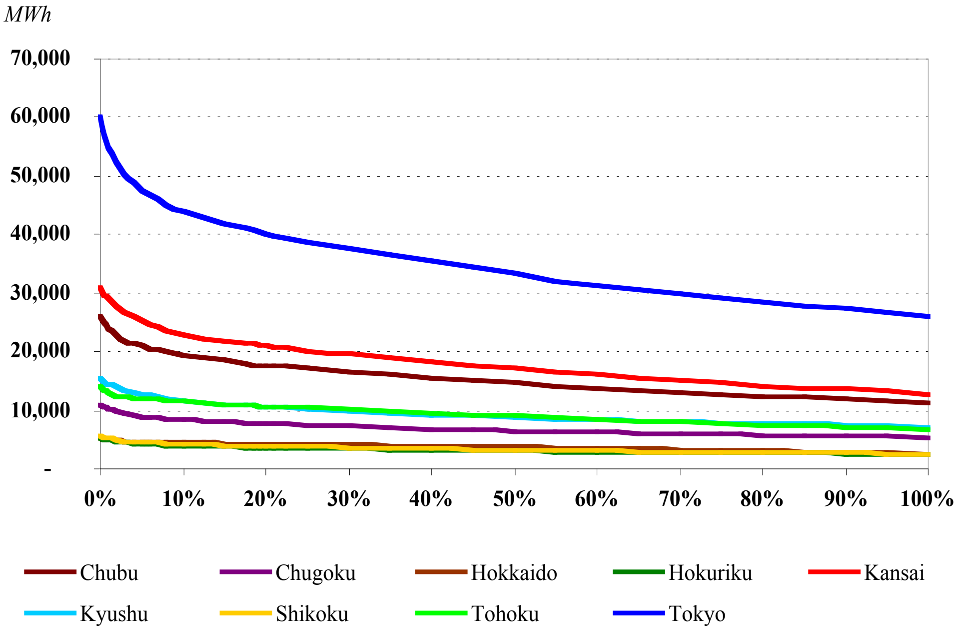
The estimated parameters are then used, along with forecasts of population, GDP, and weather, to generate demand curves for electricity as a function of the yet-to-be-determined electricity price. The GDP forecast is based on three different growth scenarios, which we call high (3.0% average annual growth rate), medium (1.75% average annual growth rate), and low (0.5% average annual growth rate). Population forecast is based on two scenarios, high and low, which are illustrated for all of Japan in Figure 7. Note that the forecast population used in the model is for each Utility Area; Figure 7 is a summary of that data. The *high* population forecast uses historical data to fit an exponential decline curve to the population growth rate. Thus, the growth rate converges to zero in the long run. The *low* population growth case uses a government forecast, which shows population declining after 2012. Weather is assumed normal, where normal is defined as the average of the past 15 years.

Figure 7 – Alternative Population Growth Assumptions



The variability of the intra-day demand for power affects the desirability of different types of capacity. For example, lower capital cost, higher variable cost facilities, such as natural gas combustion turbines, are typically favored to serve peak loads. We used historical data provided by Henwood to construct load duration curves for each Utility Area. This data is given in hourly increments for each day of the year, and is normalized for weather. We constructed approximate load duration curves that partition demand into 30 sub-time periods of different length, where the lengths vary with the load on the system. In particular, the peak demand is characterized by a more granular sub-time specification than off-peak demand. This is done because costs tend to vary much more dramatically with small changes in the load on the system when the average load is higher. A graphical summary of the representative load duration curves is given in Figure 8.

Figure 8 – Load Duration Curves for Japan



The load duration curves in Figure 8 are only representative. They are used to establish the fraction of demand that occurs during certain hours of the day. Table 4 depicts the demand fraction by sub-time and length of the associated sub-time period. For example, sub-time period 30 occurs only 0.18% of the 8760 hours in a given year. Similarly, sub-time period 10 occurs 4.70% of the 8760 hours in a given year. Using the demand fraction for the associated sub-times, if average annual load is 280,651 MWh, then the load in sub-time 30 is 56.1 MW, and sub-time 10 is 30.1 MW.

Table 4 – Example of Demand by Sub-time

Tokyo, 2000 (kWh)	280,651,146			
Sub-time Period	**Fraction of Hours**	**Hours in a day**	**Demand Fraction**	**Implied Load (kW)**
1	100.0%	24.00	3.78%	24,194
2	95.0%	22.80	3.92%	25,128
3	90.0%	21.60	3.99%	25,563
4	85.0%	20.40	4.07%	26,085
5	80.0%	19.20	4.15%	26,622
6	75.0%	18.00	4.26%	27,315
7	70.0%	16.80	4.37%	27,996
8	65.0%	15.60	4.47%	28,647
9	60.0%	14.40	4.58%	29,327
10	55.0%	13.20	4.70%	30,105
11	50.0%	12.00	4.86%	31,150
12	45.0%	10.80	5.02%	32,158
13	40.0%	9.60	5.18%	33,161
14	35.0%	8.40	5.33%	34,137
15	30.0%	7.20	5.50%	35,226
16	25.0%	6.00	5.67%	36,354
17	20.0%	4.80	2.94%	37,642
18	17.5%	4.20	3.00%	38,389
19	15.0%	3.60	3.06%	39,219
20	12.5%	3.00	3.13%	40,141
21	10.0%	2.40	2.57%	41,206
22	8.0%	1.92	2.64%	42,257
23	6.0%	1.44	1.37%	43,741
24	5.0%	1.20	1.39%	44,580
25	4.0%	0.96	1.42%	45,619
26	3.0%	0.72	1.47%	47,080
27	2.0%	0.48	1.53%	48,904
28	1.0%	0.24	0.80%	51,267
29	0.5%	0.12	0.67%	53,425
30	0.1%	0.02	0.18%	56,149

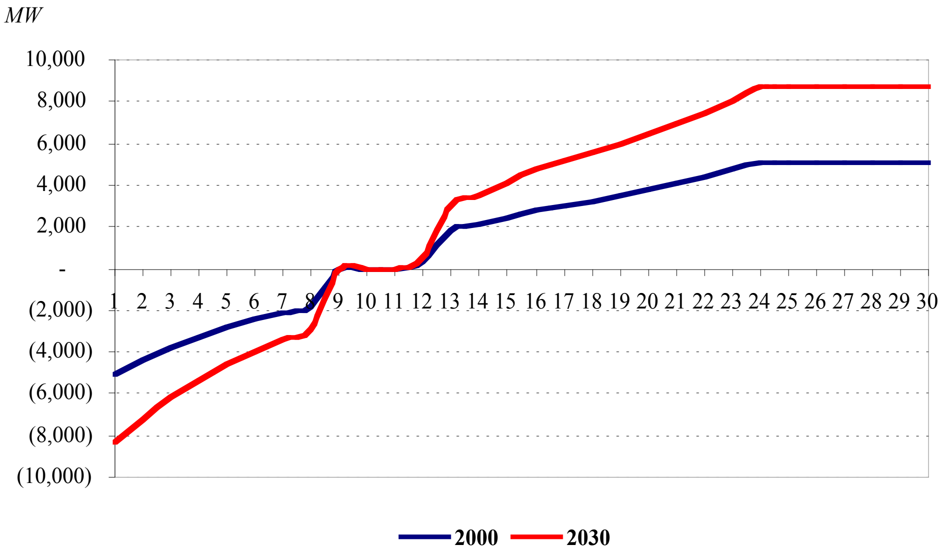
The effective additional load that is incurred as a result of the need to maintain a stated reserve margin (and ultimately system stability) is referred to as ancillary service demand. It must be added to the calculated final demand in order to better reflect committed units on the stack. The reserve margin assumed in the model is an annual average of 11.5% for all years. This varies by sub-time period, however, in order to reflect the reduction in reserve margin that occurs during very strong peaks, such as the hottest summer day in August.

D. Pumped Storage

Pumped storage is crucial to maintaining stability in the Japanese electricity market. During off-peak hours, low cost forms of generation are used to generate electricity and pump water against the pull of gravity. Later, during times of peak demand, this water is released, and the energy created as it falls through spinning turbines is re-captured in the form of electricity that can be used to supplement available thermal capacity. Thus, pumped storage influences both demand (in the off-peak hours) and supply (during on-peak hours).

Pumped storage is modeled using an assumed schedule based on historical injection/withdrawal rates for a typical day. The injection/withdrawal schedule is illustrated by sub-time in the Tokyo Utility Area in Figure 9 in capacity (MW) increments for 2000 and 2030. Similar representations for each of the 9 Utility Areas were also constructed, but we only show Tokyo here for the sake of illustration. In the figure, a negative schedule denotes withdrawal of electricity to pump water, and a positive schedule denotes the use of stored water to generate electricity that is added to the system. Since the sub-times do not chronologically correspond to the hours of a typical day, it is important to recognize the figure *does not* represent the injection/withdrawal schedule in the Tokyo Utility Area for the typical day. Rather, this is a sub-time representation, with higher numbers corresponding to periods closer to the peak demand. To illustrate, note that maximum capacity is utilized during the peak demand periods, sub-times 24 through 30, which totals 5% of the hours on the hottest 18 days of the year, or 1.2 hours per day on those 18 days, which would most likely occur in the mid-afternoon hours of the 18 hottest days of the year, whenever they may be.

Figure 9 – Pumped Storage by Sub-time for the Tokyo Utility Area



Note: See text for explanation

By definition, the actual flow out of pumped storage must match the flow into pumped storage. Therefore, the area above the negative portion of the curve and below the horizontal axis represents total withdrawals when multiplied by the (relatively long) corresponding sub-time increments. This area also is equal to the area below the positive portion of the curve and above the horizontal axis, which represents total generation from pumped storage when multiplied by the (relatively short) corresponding sub-time increments. This allows the injection and withdrawal schedules in Figure 9 to be graphed against capacity.

E. Renewable energy sources: Hydro, Solar, Geothermal, and Wind

Renewable energy sources are a potentially important part of Japan's future energy mix, particularly because they can provide lower emissions along with increased security of supply. Renewable sources currently account for approximately 12% of total MW, with hydroelectricity accounting for the large majority. The model simulations do not allow the share to increase significantly. We assume Hydro and Geothermal capacity remain fixed, and allow Wind and Solar to grow according to government targets. The assumptions regarding installed MW are summarized in Table 5.

Table 5 – Renewable Sources of Electricity Supply (Installed MW)

	Hydro	Geothermal	Wind	Solar
2000	22,586	533	41	279
2015	22,586	533	4,124	7,197
2030	22,586	533	8,249	14,392

Future installed megawatts for renewable sources of electricity are taken as exogenous to the model. It is assumed that these sources will not be economically competitive in the model time horizon, and would not be added without a government subsidy. Thus, their growth will be dependent on the degree of subsidy. The implicit assumption, therefore, is that the government will make that subsidy be whatever is required to achieve the specified target capacity regardless of what other changes are occurring. This assumption could be changed, but we would need to specify how the government would alter policy as the cost of subsidizing renewables varies. For example, a technological breakthrough in the efficiency of solar cells could make them more competitive with baseload fuels in the next three decades, which would reduce the subsidy required to achieve a given target capacity. Under these circumstances, the government may raise the target above the currently stated level, or it may allocate to other purposes the money it could save as a result of the reduced need to subsidize solar power.

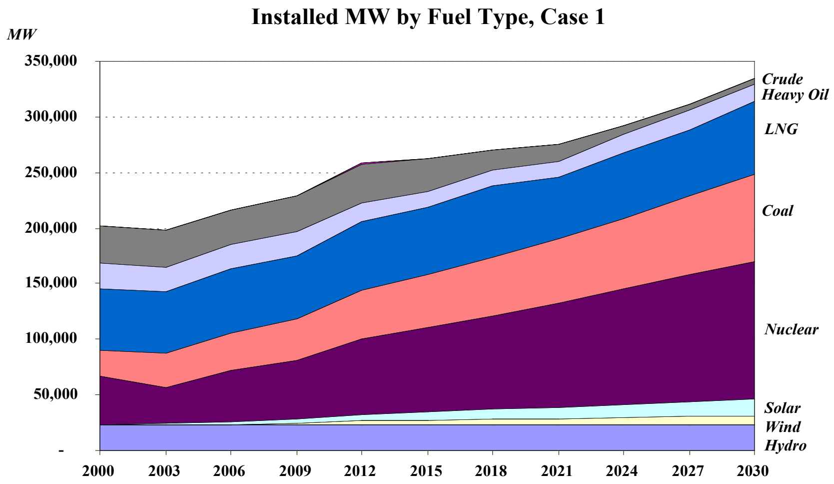
III. Summary of Baseline Model Results

The model of the Japanese power market described above was used to forecast electricity prices, installed capacities, generation mix, and demands under different assumptions regarding GDP growth, population growth, fuel input prices, and policy decisions affecting the availability of different types of generation capacity. The full spectrum of scenarios is summarized in Appendix Table 1. For the sake of brevity, we will address only three cases in this section, cases 1, 7 and 31. These cases are chosen because they illustrate the range of possible outcomes, given our assumptions regarding GDP and population growth, when there is no policy constraint placed on the type of new capacity additions.

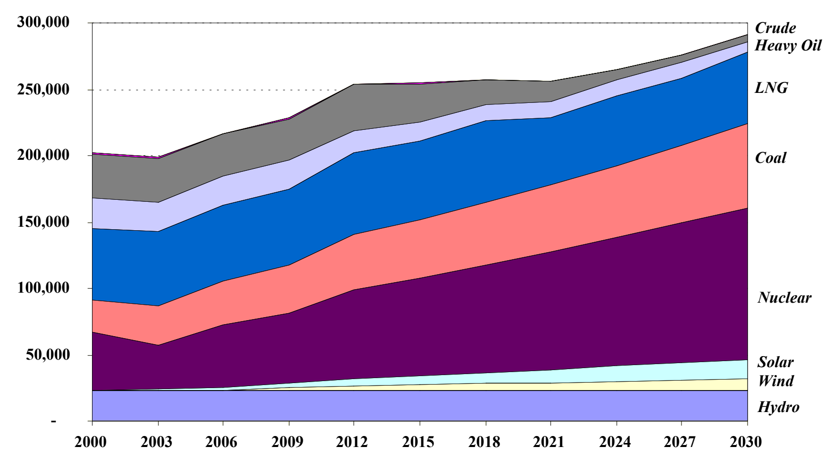
In each of these "baseline" cases, commodity fuel prices are assumed as illustrated in Figure 5, i.e. - oil prices increase steadily according to the forecast by the US EIA. All of the simulations track additions to capacity, electricity output, prices and so on through 2030. Toward the end of the forecast period, capacity choices will depend on what is expected to happen beyond 2030. The calculations implicitly assume that the real price of electricity in each sub-time period remains constant at 2030 levels for all periods beyond 2030. The explicit output, however, is only valid for the period to 2030 since this is the only period for which we have made explicit assumptions about all the relevant exogenous variables.

Case 1 assumes a GDP growth rate of 3.0% per annum through 2030, and population growth is described by the "high" case discussed above. Case 7 assumes a GDP growth rate of 1.75% per annum through 2030, and population growth is also described by the "high" case discussed above. Case 31 assumes a GDP growth rate of 0.5% per annum through 2030, and population growth is described by the "low" case discussed above. For each of the cases, the following figures illustrate installed capacity by type (Figure 10), the share of installed capacity by type (Figure 11), and the average, off-peak and on-peak prices (Figure 12a,b) for all of Japan.

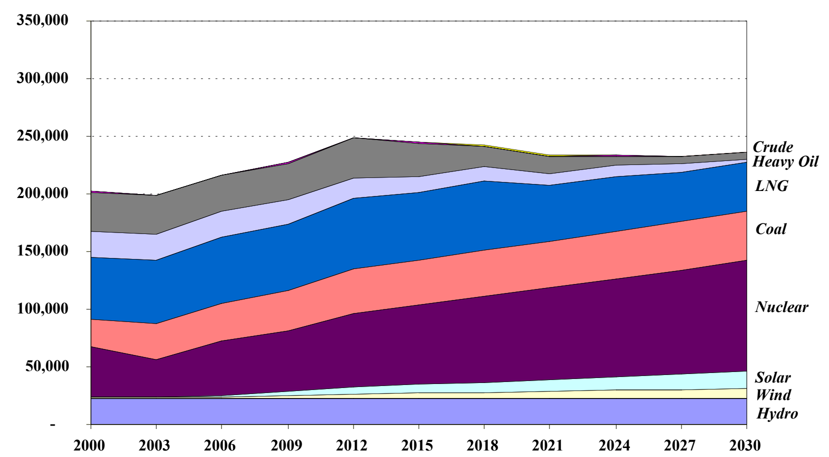
Figure 10 – Installed Capacity by Fuel Type



Installed MW by Fuel Type, Case 7



Installed MW by Fuel Type, Case 31



As would be expected, Case 1 demonstrates the strongest growth in demand relative to the other cases, and as a result, the most aggressive capacity expansion and highest prices. Case 31 is the most pessimistic regarding demand, and we see very little growth in overall capacity. Even in this case, however, new nuclear generation is constructed to replace older, retiring plants. In fact, in all cases, the share of nuclear capacity grows as the share of crude-based generation capacity declines.

Figure 11 – Share of Installed Capacity by Fuel Type, 2000 and 2030 (by Case)

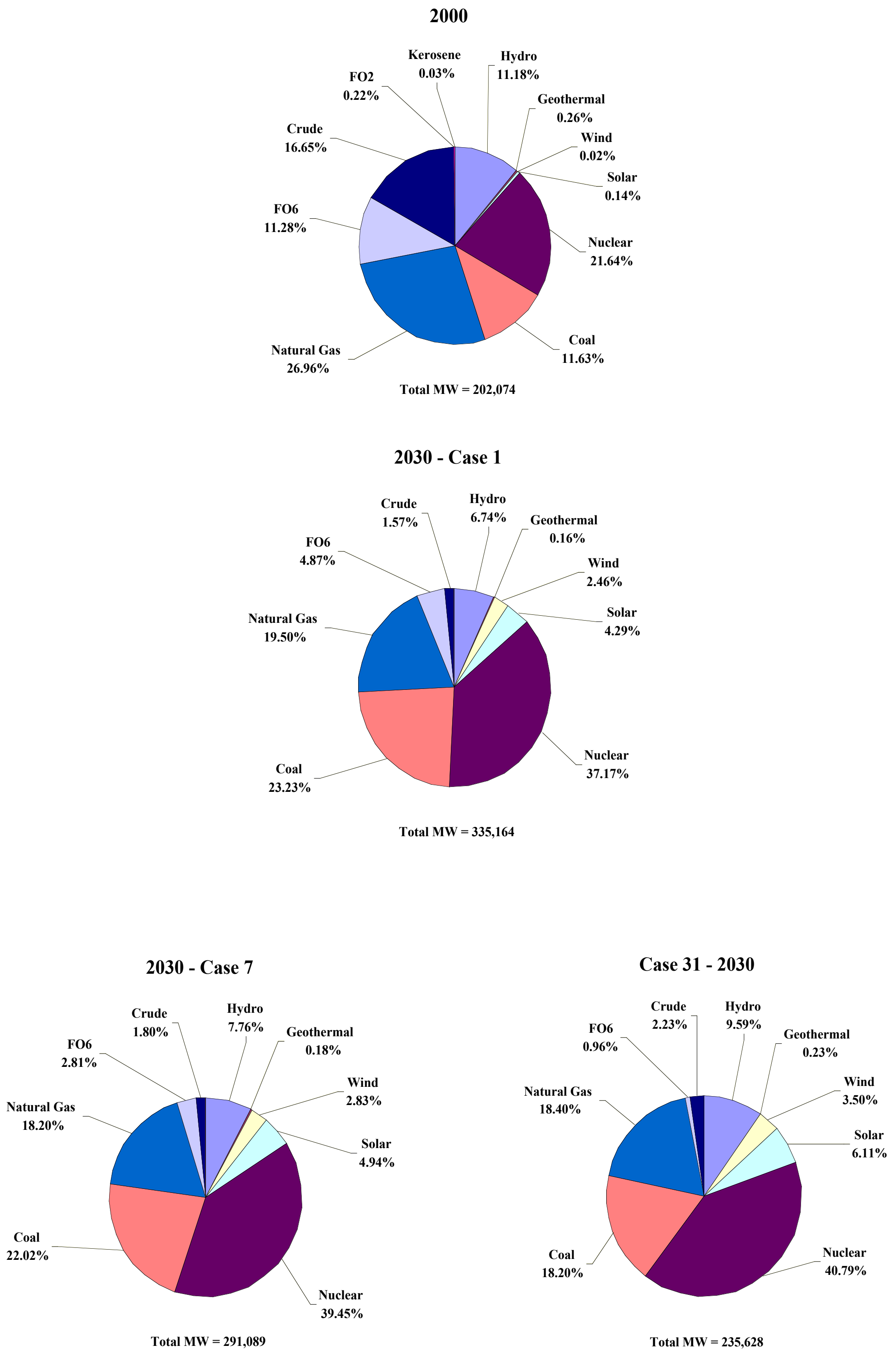
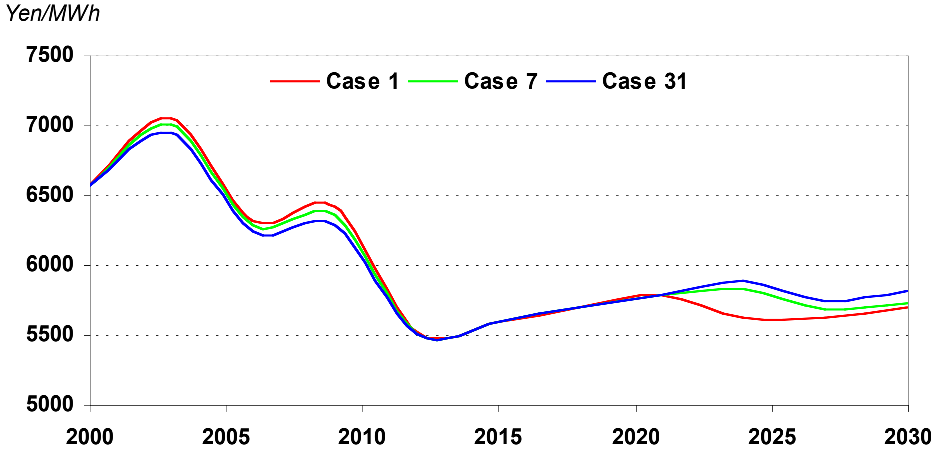
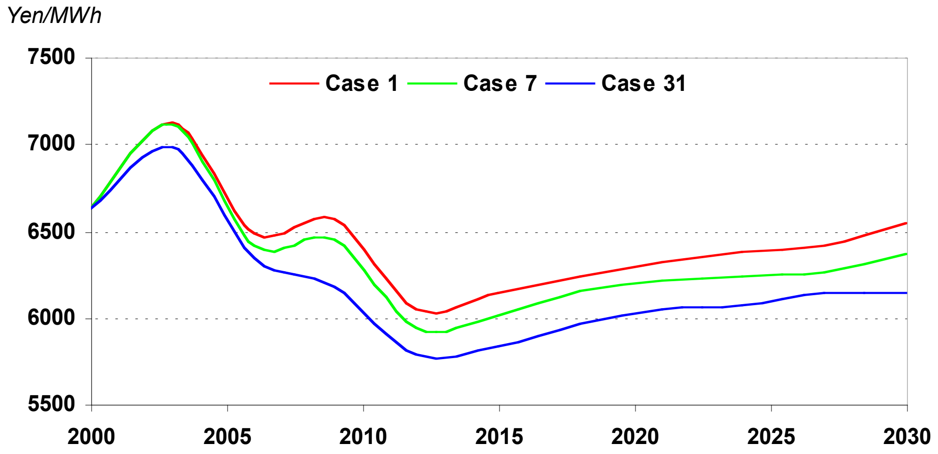


Figure 12a – Off-peak, Average, and On-peak Price by Case

Off-peak (T-50%) Marginal Cost of Generation



Average Marginal Cost of Generation



Peak (T-95%) Marginal Cost of Generation

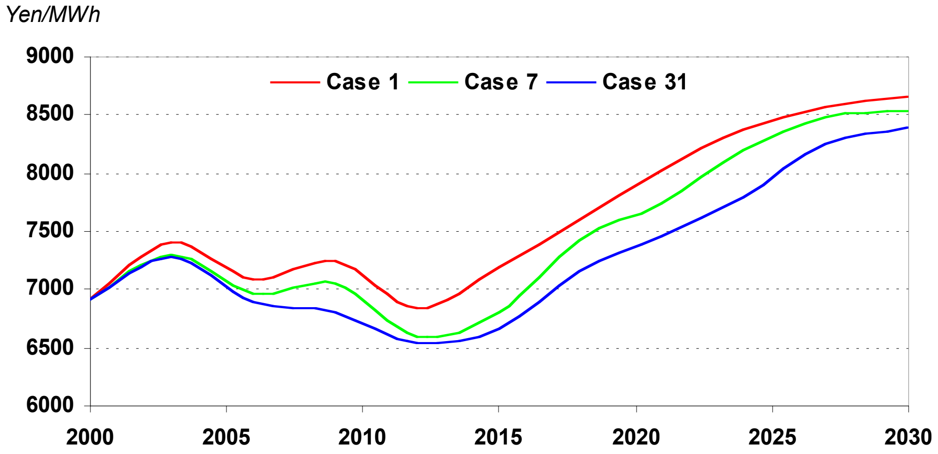
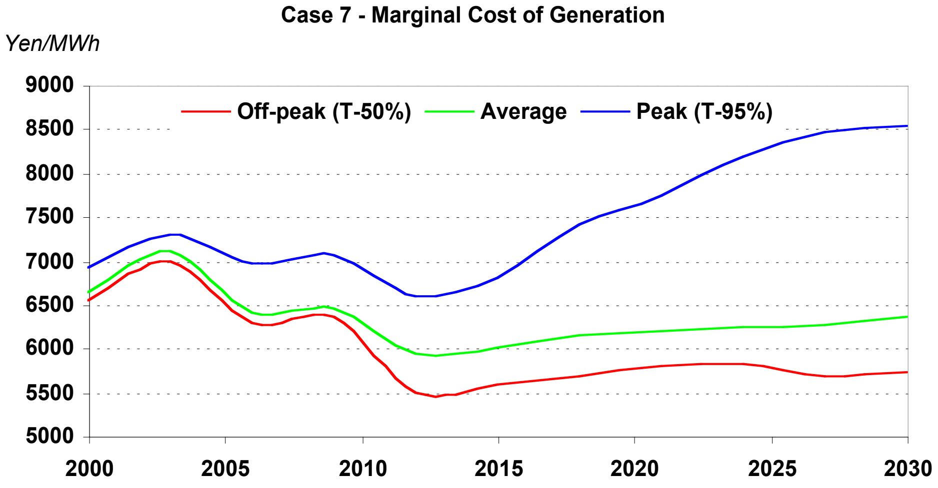


Figure 12b – Off-peak, Average, and On-peak Price within Case 7



In each of the cases, the shares of both nuclear and coal-fired generation in total installed MW increase. Although the installed MW of natural gas-fired generation increases slightly, its share declines. The shares of crude and petroleum products also decline. Although there is some construction of heavy oil-fired generation to meet peaking requirements, these types of facilities do not generally compete with nuclear, coal, and natural gas during non-peak periods. Note also that prices are generally highest in Case 1, with the exception of off-peak periods (T-50%). There are several reasons for this outcome. Under the Case 1 scenario, strong demand growth encourages increased construction of coal and nuclear facilities. These low operating cost plants are the marginal units only during off-peak periods. Under Case 1, peak demand also tends to grow relative to off-peak demand. To meet the additional surge in peak demand, there is also greater construction of natural gas and oil-fired generation units, which have higher operating costs than coal and nuclear units. Moreover, to meet these high peaking needs, older units, which are not yet retired and have even higher operating costs, are also dispatched more frequently.

An important caveat with regard to these results is that environmental restrictions may hinder the expansion of coal-fired generation. At the margin, this would favor nuclear and natural gas. However, caution must be exercised when making this claim. Specifically, the Japanese government has encouraged firms to reduce their heavy dependence on oil, but over-reliance on any fuel, including natural gas, could be just as detrimental for energy security as over-reliance on oil. On the one hand, natural gas is imported in the form of LNG, the competition for which is expected to grow dramatically in the coming decades. On the other hand, recent reductions in liquefaction, shipping and regasification costs have expanded the number of possible sources of LNG supply for Japan and other countries.

Future developments in the market for LNG could dramatically alter the results herein reported. The market for natural gas is likely to experience substantial change over the next few decades. Competition for LNG supplies will accelerate in the coming years, as emerging economies such as China, India and Mexico import increasing quantities of natural gas. Moreover, the historical analysis of fuel prices showed that natural gas prices were very closely linked to oil prices, making LNG a poor choice for insuring against oil price movements. As natural gas plays an ever larger role in world energy use, oil and gas prices may become even more closely linked, perhaps differing only on the basis of heat content. However, these are other issues that are left for future investigation.

IV. Energy Prices and the Japanese Macroeconomy

The macroeconomic disruption caused by the oil shocks of the 1970's is testimony to the potential welfare costs of over-reliance on any one fuel. The potential for incurring high costs from a disruption may be especially large when fuel must be imported from a limited number of sources. The literature relating energy price shocks to macroeconomic performance is long. Since the 1970's, the negative correlation between energy prices and macroeconomic performance in industrialized oil-importing nations has been well-documented. Hamilton (1983), Mork et al (1994), Lee et al (1995), Ferderer (1996), and Medlock et al (2004) are just a few of the many authors who have investigated the issue.

For this study, we examined the relationship between energy prices (specifically, oil price, natural gas price, and electricity price) and GDP in Japan using a vector autoregressive (VAR) framework. As noted above, oil prices appear to be the fundamental determinant of the prices of all of the energy inputs, including, LNG, coal and indirectly, uranium. Oil also has played, and continues to play, a prominent role in the Japanese economy. Indeed, after accounting for the changing share of oil in total energy use, we find that the oil price has a significant negative impact on Japanese macroeconomic activity. Specifically, we find that the price of oil has a significant negative relationship to GDP that declines as the share of oil in total primary energy use declines. Moreover, bivariate Granger causality tests (described further below) indicate that the share-weighted price of oil Granger causes GDP in Japan.

In conducting this analysis, we found it important to account for the share of each fuel in total energy use. The share of oil in total energy use can be taken as a measure of the importance of oil prices for overall energy prices. In fact, the share of oil in total primary energy in Japan declined from over 75% in the early 1970's to 53% in 2000. Failing to account for the declining share of oil in total primary energy could lead to a negative bias in the estimated impact of oil prices on the macroeconomy.

To begin, we estimated the following system of equations:

$$\begin{pmatrix} GDP_t \\ P_t^{Elec} \\ \theta_t^{LNG} P_t^{LNG} \\ \theta_t^{Oil} P_t^{Oil} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{pmatrix} + \begin{pmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & \phi_{42} & \phi_{43} & \phi_{44} \end{pmatrix} \begin{pmatrix} GDP_{t-1} \\ P_{t-1}^{Elec} \\ \theta_{t-1}^{LNG} P_{t-1}^{LNG} \\ \theta_{t-1}^{Oil} P_{t-1}^{Oil} \end{pmatrix} + \varepsilon$$

where each of the variables is measured in natural logs. Prior to estimation, however, each of the variables in the system was tested for stationarity. We found that the oil and LNG prices were stationary once allowing for a structural break in the data in 1986. The series for electricity prices and GDP were both also found not to contain evidence of unit roots. Since each of the series exhibited no unit roots, we proceeded with the estimation in level form (that is, without first differencing or allowing for a co-integrating relationship).[8] The estimated coefficients ϕ_{ii} are summarized as follows.

$$\begin{pmatrix} 0.826 & -0.023 & 0.018 & -0.042 \\ -0.027 & 0.571 & -0.020 & 0.064 \\ 0.510 & 0.827 & 0.358 & 0.207 \\ -1.457 & -1.263 & -0.617 & 0.648 \end{pmatrix}$$

(For more detailed results refer to Appendix Table 2.)

The estimated coefficients ϕ_{ii} give the elasticity of each variable with respect to the others. In particular, the coefficient $\phi_{14} = -0.042$ indicates that a one percent change in the share-weighted price of oil will induce a 0.042% drop in GDP. Also of note is the relatively large negative impact of GDP on the share-weighted oil price. If we interpret

---

[8] If the series had exhibited unit roots, not controlling for those non-stationarities would have lead to inappropriate test statistics and erroneous inferences.

this as a genuine structural relationship, it may indicate that oil is an inferior fuel and that GDP growth primarily stimulates the demand for energy sources, such as electricity, that are less intensive in oil. Alternatively, the correlation may be "spurious" in the sense that the share of oil in total energy supply has been declining steadily in Japan since 1973 while at the same time there has been positive growth in GDP. The relationship also may be the result of omitted variables in the system and suggest some caution in interpreting the remaining results. We did guard against this possibility, however, by allowing for real interest rates, CPI, exchange rates, fuel price (as an alternative to share-weighted fuel price), and US GDP, as alternative explanatory factors but none of these variables significantly alter the results.[9]

Since we want to use the model to measure the effect of energy price fluctuations on the rest of the economy, we also tested for causal relationships among variables. This is done by testing the significance of zero restrictions on each of the variables in each of the equations in the above system. The results are as follows (where $X \rightarrow Y$ is read, "variable *X* Granger causes variable *Y*."):

$$\begin{aligned}
&\theta^{Oil} P^{Oil} \rightarrow GDP \\
&\theta^{Oil} P^{Oil} \rightarrow \theta^{LNG} P^{LNG} \\
&\theta^{Oil} P^{Oil} \rightarrow P^{Elec} \\
&GDP \rightarrow \theta^{Oil} P^{Oil}
\end{aligned}$$

Note in particular that the results imply a bidirectional causal relationship between GDP and the share-weighted oil price. Additionally, we find that the share-weighted oil price

---

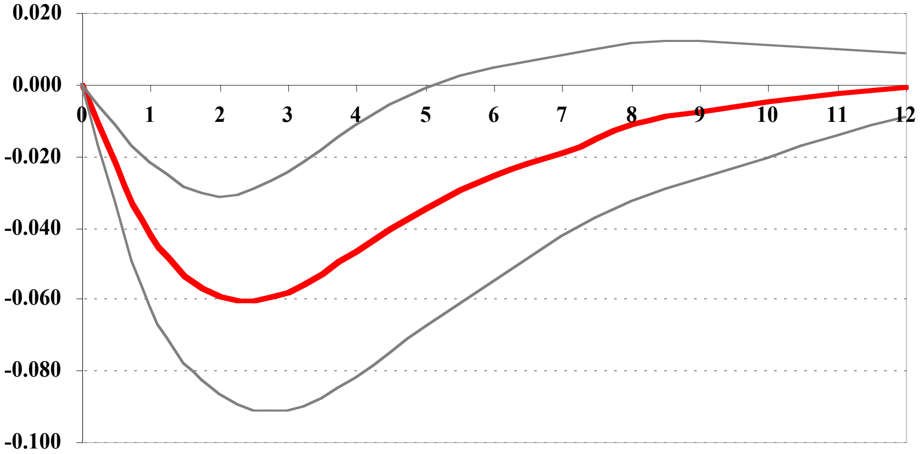
[9] A limitation of this analysis is that it uses annual data. The resulting small sample size limits the amount of information one can extract from the data. We experimented with estimating other types of statistical models, including a simultaneous equations system. The results were on the whole less satisfactory than the ones we have reported here. The issue could be investigated in greater depth using quarterly data.

Granger causes both the share-weighted natural gas price and the price of electricity without any causation running in the opposite direction.

Impulse response functions were also generated in order to determine the full impact of a perturbation in a particular variable in the system on the other variables. Reported in Figure 13 is the impulse response function for a one standard deviation shock to the share-weighted oil price variable with respect to GDP (the red line in the figure, with the gray lines giving one standard error bounds on the estimated effect). Noting the statistical significance of the estimated coefficients (see Appendix Table 2) and the results of the Granger causality tests, we conclude that the share-weighted price of oil is the primary driver of GDP (other than lagged realizations of GDP) in the estimated system. As is evident from the graph, the impact of an oil price shock is negative, it is statistically significant, and its effect takes about 12 years to fully decay. However, the result is statistically significantly different from zero for only the first 5 years.

Figure 13 – Impulse response function

Impulse variable: Share-weighted Oil Price, Response variable: GDP

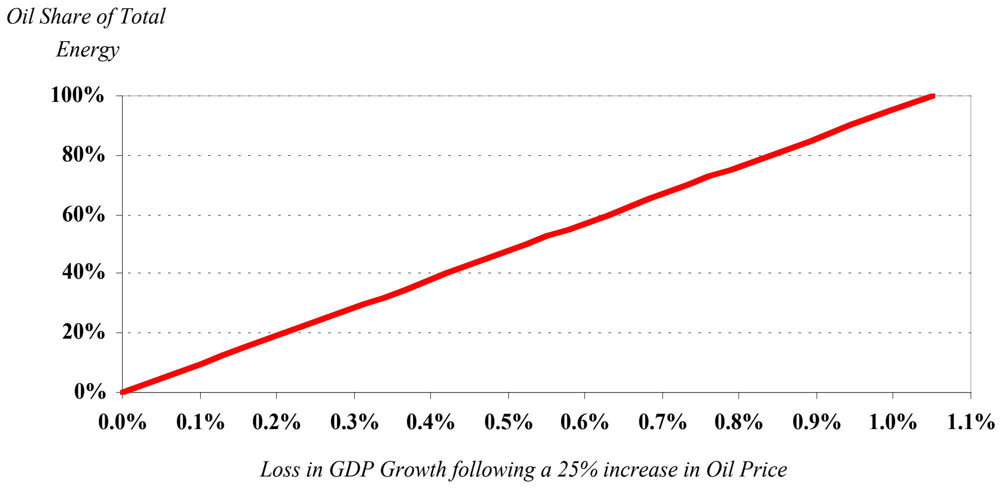


The results of this exercise are used along with the model of the power sector to analyze the effect on GDP of a change in oil prices. In order to understand how other factors may alter this effect, we repeat the exercise under a range of different scenarios. This enables us to quantify the energy security value of installed nuclear capacity in terms of GDP. Specifically, if we take the share of oil as given, and perturb the price of oil, the immediate impact of the oil price change is given as

$$\%\Delta GDP = \left(-0.042 \cdot \Theta^{Oil}\right)\%\Delta P^{Oil} .$$

Note in particular that the effect on GDP is a function of the share of oil in total energy. The effect of a one time 25% increase in the price of oil is illustrated in Figure 14. To understand the longer term repercussions of an increase in oil prices, we must use the impulse response function, which shows how the negative effect at first builds and then dies away over time.

Figure 14 – "Portfolio Effect" of a 25% increase in Oil Price on GDP



V. Scenario Analysis

The study examined, in detail, 42 different scenarios. (Again, see the Appendix Table 1 for a description of the different cases.) While it is reasonable to examine alternatives to these 42 scenarios by averaging results, such exercises should be done with caution. Any significant deviations in the assumptions would affect the underlying capacity investment decisions, which are non-linear functions of the model inputs. For the purpose of illustration, in this section we will examine some of the broader implications of altering the policy with regard to installed nuclear capacity. It is a matter of judgment as to which scenario is "most likely" to approximate future history. The purpose of presenting the model in a way that makes it easy for a user to choose different scenarios is that we are aware of the divergence in expert opinion regarding future trends to population growth, economic growth and so forth over the next twenty-five years. Our discussion will concentrate on the Medium GDP Growth/High Population Growth cases (Cases 7-12 and 38). The differences between cases 7 through 12 all involve different policy stances toward the development of nuclear power in Japan. Case 38 examines a fictional, theoretical world where we assume that Japan had never invested in nuclear power. This is of interest since it also shows what the realistic alternatives to nuclear power would have been in the past (in a situation where the other exogenous variables are known) and thus provides another indication of what the alternatives to nuclear power are likely to be in the future. Figures 15 through 17 summarize the results of all these scenarios.

Some general conclusions follow from the results. First, prices (Figure 17) are, on average, lowest when there are no constraints on the construction of new capacity.

This reflects a very general result in economics. A constraint typically only makes matters worse or has no effect. If a constraint actually improves the outcome, it would be irrelevant since the decision maker would choose to obey it in any case. Strictly speaking, the general result in this case applies to costs and not prices, and prices reflect not just marginal generating costs but also decisions about adding new capacity. Nevertheless, the outcome is not very surprising. Different types of generation capacity are best suited to meet particular loads. For example, lower capital cost facilities are preferred when generating for peak demand periods. This is because the peaks are intermittent, and the facilities operating at that time have limited opportunity to generate a sufficient return to capital. Likewise, nuclear and coal-fired generation facilities will not generally be constructed to meet peaking services. Rather, they are preferred baseload providers because they have comparatively low variable costs and the long hours of operation enable more opportunity to capture a margin between prices and operating costs that can be used to defray the large up-front capital costs. This explains why peak electricity prices are so high in case 12 (not illustrated), where public policy forces all *new* capacity to be nuclear. The peaks are not long enough to cover the capital costs of additional nuclear capacity when those units only operate short periods of time (notwithstanding engineering/technical considerations which would preclude such a scenario[10]). Hence, peak electricity prices achieve higher levels than in scenarios that do not impose such constraints. In summary, there is an optimal mix of installed megawatts of each type to meet a particular time profile of demand, and deviating from this optimal mix raises costs.

---

[10] In practice, nuclear plants cannot be ramped up and down at short notice. Therefore, to accommodate such a large share of supply from nuclear plants additional pumped storage capacity would be required to shift demand from peak to off-peak periods.

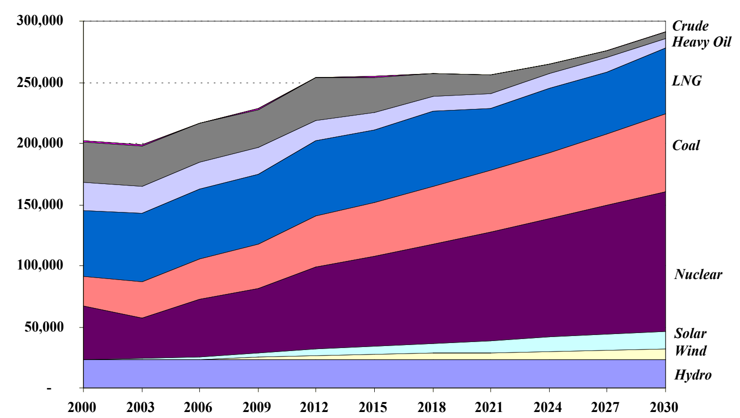
A second general conclusion that follows from examination of various scenario results is that coal-fired generation is the next best alternative in terms of cost effectiveness to nuclear power, should nuclear capacity expansion be inhibited. Coal prices are the lowest on a BTU equivalent basis and the least volatile of the remaining fuels, and, as such, coal is preferred for baseload requirements. Natural gas, in particular high efficiency combined-cycle, would be next in line as a potential alternative in terms of cost. Coal is expected to provide lower prices than LNG given the potentially volatile nature of oil prices, to which LNG is closely related, and the higher forecasted cost of LNG in the longer term as world demand rises.

A potentially interesting future study would be to examine alternatives to the EIA price forecasts, but that is beyond the scope of this study. In particular, it may be useful to look at the implications of flat-to-falling real prices of primary fuels.

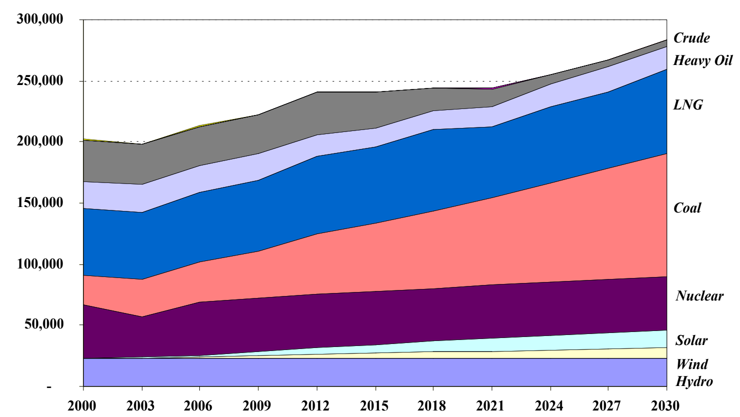
The general pattern of electricity prices associated with each scenario is of interest. As mentioned above, the lowest average price occurs when the fewest impediments to entry exist. Interestingly, the largest swing from off-peak to on-peak prices is demonstrated in the Case 12 (Only Nuclear). As mentioned above, this is tied to the fact that on-peak prices do not last long enough for investment in nuclear capacity to be profitable.

Figure 15 – Installed Capacity by Fuel Type

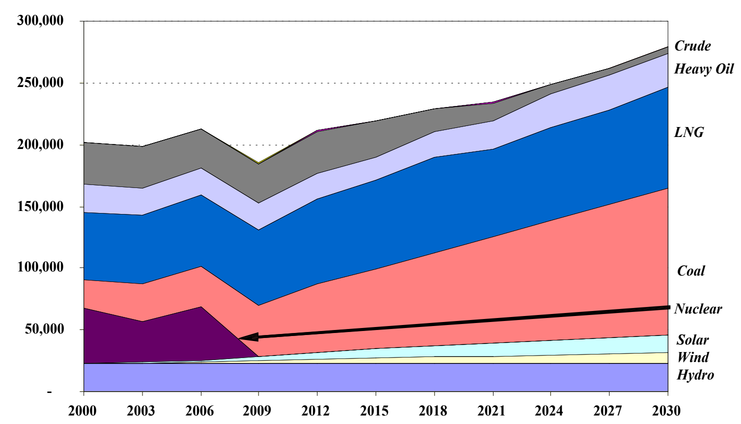
Installed MW by Fuel Type, Case 7



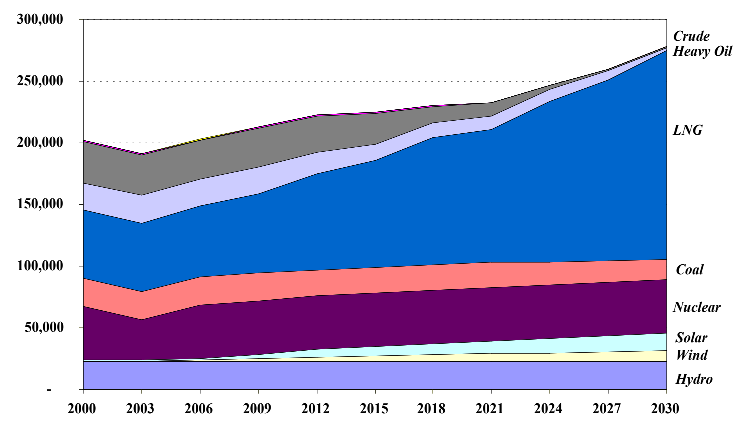
Installed MW by Fuel Type, Case 8



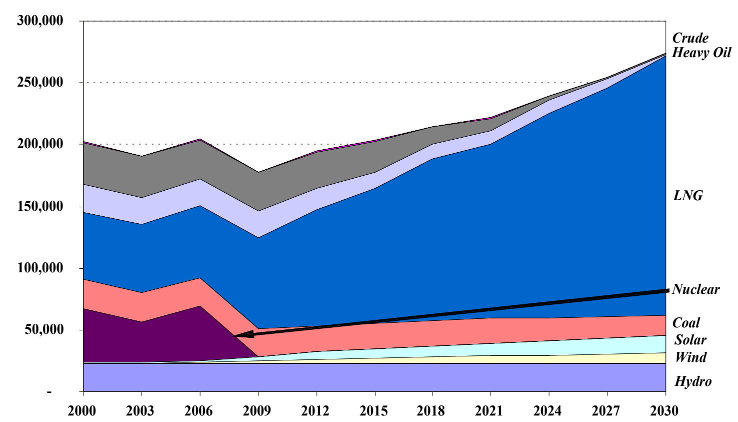
Installed MW by Fuel Type, Case 9



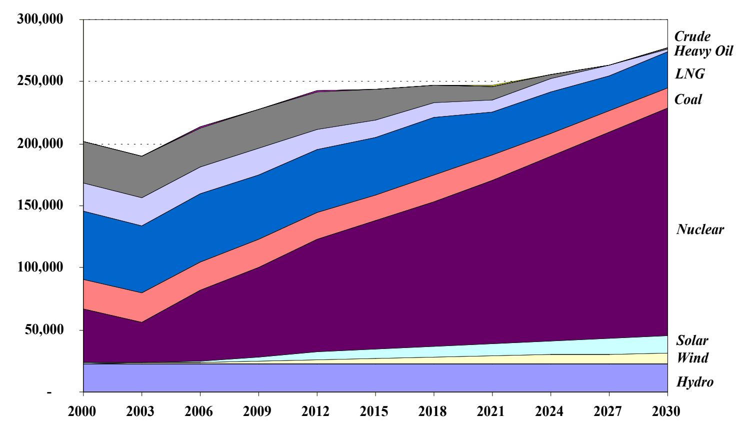
Installed MW by Fuel Type, Case 10



Installed MW by Fuel Type, Case 11



Installed MW by Fuel Type, Case 12



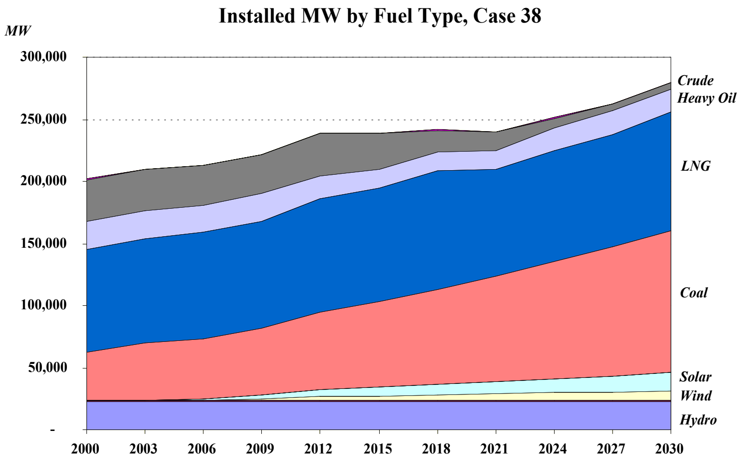
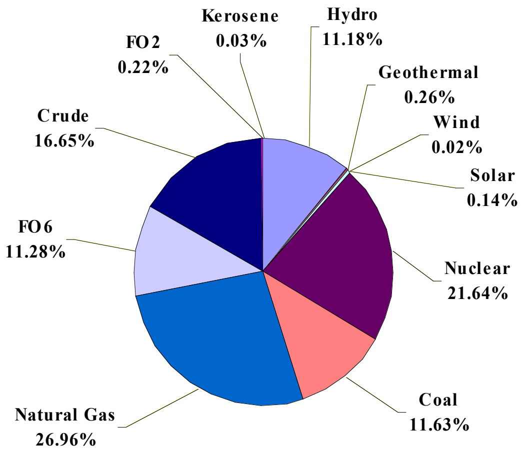


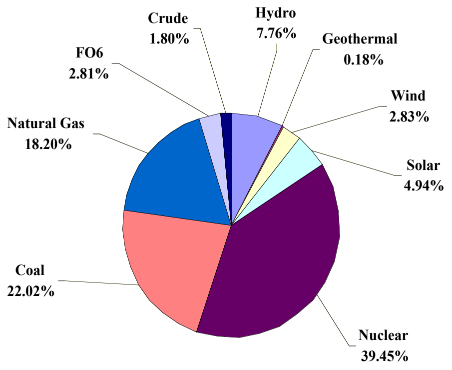
Figure 16 – Share of Generation Capacity by Fuel Type, 2000 and 2030 (by Case)

2000



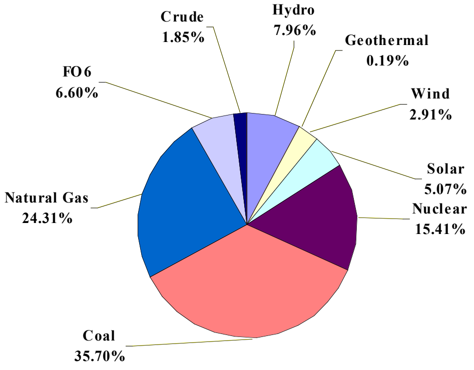
Total MW = 202,074

2030 - Case 7



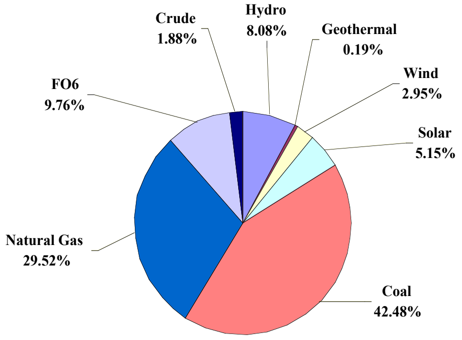
Total MW = 291,089

2030 - Case 8



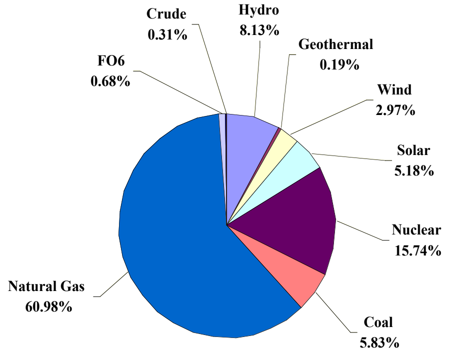
Total MW = 283,788

2030 - Case 9



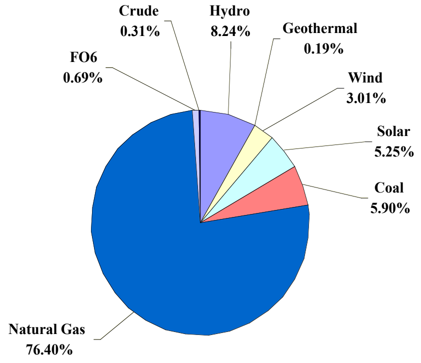
Total MW = 279,531

2030-Case 10



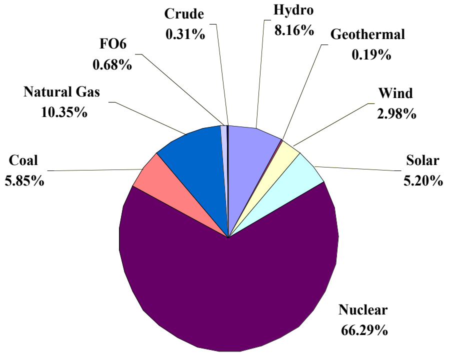
Total MW = 277,800

2030 - Case 11

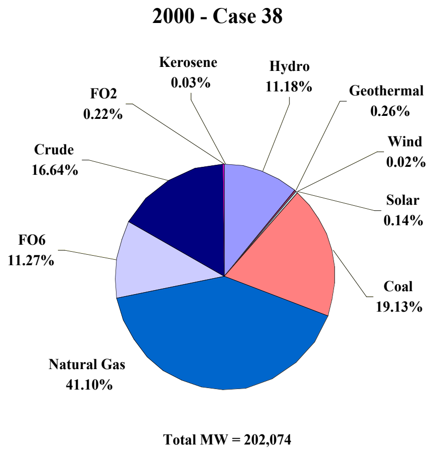


Total MW = 274,105

2030 - Case 12



Total MW = 276,834



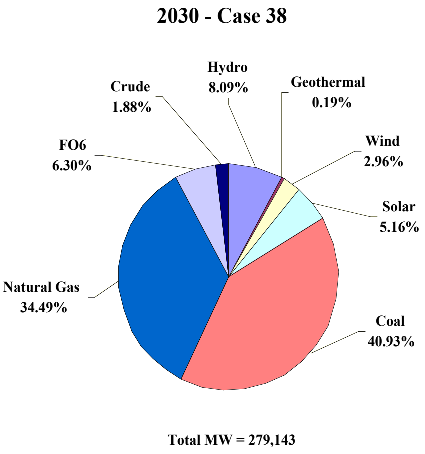
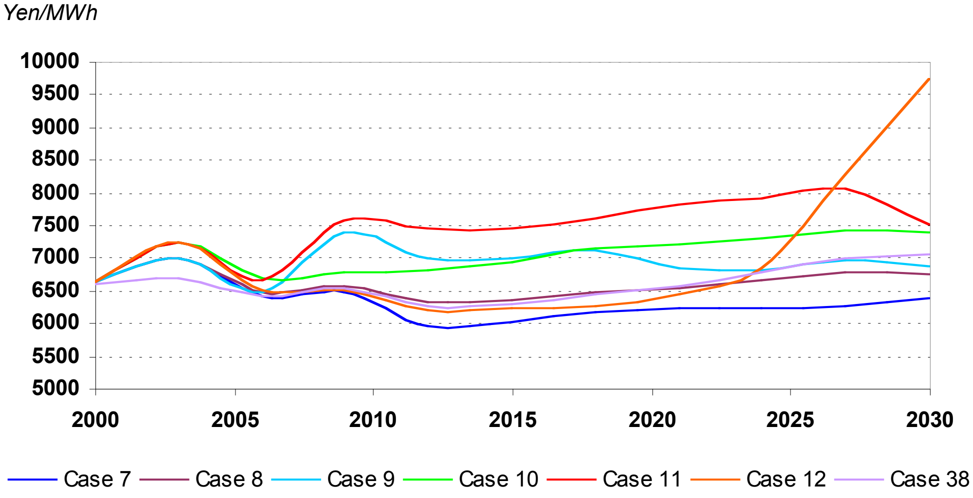


Figure 17 – Average Price for Select Cases



VI. Calculating Security Value

The calculation of the energy security value of nuclear capacity is complex and requires analysis of multiple scenarios and numerous steps. First, the power market in Japan must be simulated under different conditions and levels of nuclear power saturation --with and without oil price shocks-- so that those cases may be compared. Although this can be performed for many different combinations of cases, two case scenarios allow for an explicit comparison from which it is possible to draw a baseline conclusion. The approach taken here is to first simulate the Japanese power market using Case 7 and Case 38 assuming an oil price shock occurs in 2006. The shock is assumed to raise oil prices by 25%, and is a one-time, unanticipated event. Because it is unanticipated, it does not affect investment decisions away from the original path. Although this approach does not explicitly model oil price volatility, so long as each shock is unanticipated one can think of more volatile prices as implying a sequence of one-off unanticipated shocks of the type we examine. We then extend this analysis, for the same two cases, assuming oil prices are randomly perturbed about the long run mean, as illustrated in Figure 6 above.

The second step requires us to calculate the discounted present value of the GDP savings resulting from allowing for nuclear capacity in the presence of a 25% increase in oil prices. For this purpose, we use the estimated impulse response function giving the effect on GDP of the oil share-weighted oil price and which is illustrated in Figure 13. In doing this, it is important to note that changing the policy assumption with regard to nuclear power will alter the share of oil in total energy use in the Japanese economy. We use, as a benchmark for the "baseline" Case 7, the projected oil share as posited by the US EIA for Japan. In the comparison case, Case 38, we need to adjust the current oil share since it would undoubtedly be higher if Japan had never invested in nuclear capacity. To do this, we allow the model to determine the most efficient construction of power plants from the allowable types (coal, oil, natural gas) to replace the nuclear MW removed from the supply stack.

Since the oil share is determined not only in the power generation sector, but also by other sectors, we must make some assumptions regarding oil use in the rest of the economy. For our purposes, we take the other energy-consuming sectors as given, using projections for oil share by sector from the International Energy Agency, and allow the model to determine the share of oil used in electricity generation. This is then coupled with the forecasts for the other sectors to determine the future oil share in total primary energy, which, in turn, is used to determine the impact of changes in oil prices. For example, if we compare the MW constructed in Case 38 versus Case 7, we see that the oil share in electricity generation in 2030 is 4.61% in Case 7 and 8.18% in Case 38. Thus, as a point of reference, we might infer that the difference in share amounts to an increase in oil share of 3.57% if nuclear capacity is not an option. In Case 38, the oil share in the overall Japanese economy declines from 55.6% in 2000 to 45.5% in 2030, while in Case 7 the oil share in Japan declines from 53.4% in 2000 to 42.8% in 2030.

The deviation from baseline GDP is calculated using the impulse response function, and the GDP growth rate is altered as a result of the one-time oil shock (see Figure 18). While the differences appear negligible, the effect of a 25% shock to the price of oil on GDP growth is about 0.02% higher in Case 38 than in Case 7 in year 1. Considering Japanese GDP in 2000 was about 540,000 billion Yen, Case 38 yields an additional loss of 200 billion Yen immediately following the recession (or $1.8 billion). After compounding this over time, the quantity of lost GDP is significant. In Figure 18, we see the typical pattern of recession, or depressed growth, in the immediate year following the oil price shock. The recession is followed by expansion, or accelerated growth, that is typical of a recovery. The recovery puts Japan back on its assumed long run average annual rate of growth, which describes potential GDP. It is important to note, particularly for this exercise, that although the GDP growth rate returns to its long run value, the absolute level of GDP is generally lower.

Figure 18 – GDP growth rate comparison

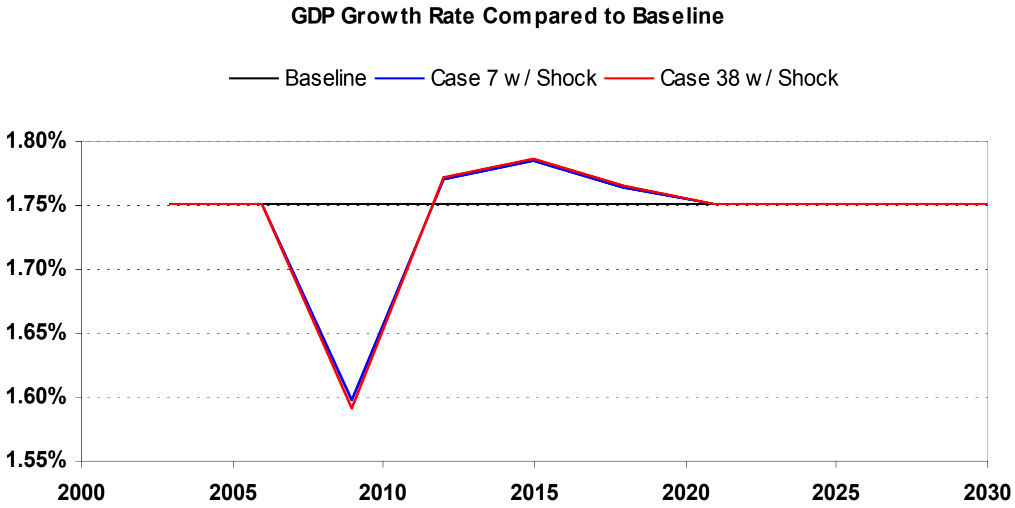
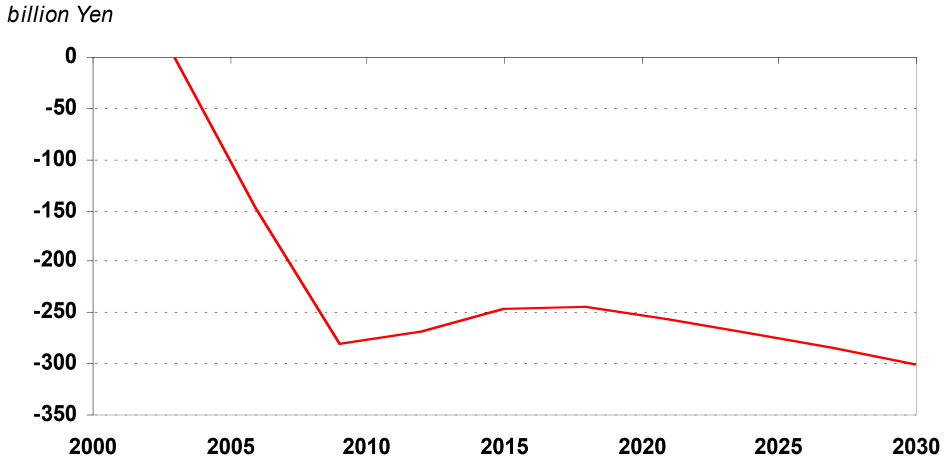


Figure 19 depicts the difference in GDP that results from an oil price shock in the two cases. It is precisely this measure with which we are concerned. In particular, we want to calculate the discounted present value of the area between the curve and zero. It is this difference that we can directly attribute to the absence of nuclear capacity, as all other variables have remained the same. We can then calculate the per megawatt value of nuclear capacity by comparing the discounted present value of savings in the present to installed megawatts.

Figure 19 – ΔGDP (Case 38 - Case 7) following an Oil Price Shock



The results of this exercise are given in Table 6. The discounted present value of nuclear capacity (ESV) is calculated as

$$ESV = \sum_{t=t_0}^{T} \beta^{t-t_0} \left(GDP_t^{Case38} - GDP_t^{Case7} \right)$$

where β is assumed to be 7.2%, T is equal to 12 years, and the GDP measures are understood to be post-oil price shock. The discount rate is chosen to match the assumed weighted average cost of capital for a nuclear facility. We find this measure of ESV to be about 15.7% of the per MW cost of construction for a nuclear facility.

Table 6 – Energy Security Value of Nuclear Capacity in the event of a 25% Shock to Oil Price in 2006

Summary Table		
Discounted PV of difference in GDP loss	**1,998**	*billion Yen*
MW Nuclear Case 7	**47,560**	
MW Nuclear Case 38	**0**	
Energy Security Value of Nuclear Capacity		**42,003,946** ***Yen/MW***

		382,132	***$/MW***
% of per MW Capital Cost for Nuclear Capacity		**15.70%**	
Average Reduction of Electricity Price			
due to Nuclear capacity	**6.55%**		
Annual Savings (Average) from Nuclear capacity		**3,539,923**	***Yen/MW***
		32,205	***$/MW***
% of per MW Capital Cost for Nuclear Capacity		**1.32%**	
Note:			
in Japan installed nuclear capacity = $2438/kW			
in US installed nuclear capacity = $1700/kW			

Another approach to measuring the energy security value of nuclear power, which is given in Table 6, is to calculate the change in electricity prices following an oil price shock when nuclear capacity is available and when it is not. Comparing Case 7 to Case 38 reveals prices to be roughly 6.5% lower, on average, when nuclear capacity is available. On a per megawatt basis, this amounts to about 1.32% of the cost of nuclear power.

To extend this analysis, we also consider cases in which oil prices are allowed to fluctuate over time in the manner consistent with Figure 6. We consider three alternative oil price scenarios, each of which is illustrated in Figure 20 against the EIA Baseline oil price projection. In each of the cases (OPS 1, OPS 2, OPS 3), volatility in the price of oil yields intermittent spikes, which will have varying effects on GDP growth rates. Each case was chosen so that the oil price spikes occur in different time periods and with different severity. Thus, the impacts will be different for the Japanese economy (see Figure 21), as will the calculated energy security value of nuclear power.

Figure 20 – Alternative Oil Price Scenarios

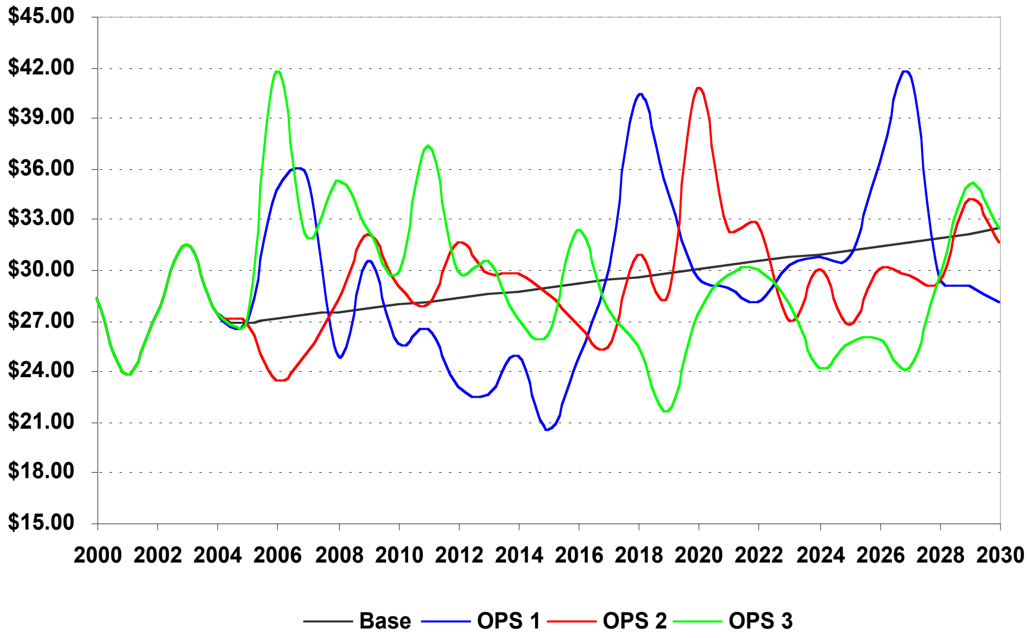


Figure 21 – GDP effects of Different Oil Price Scenarios for Case 7

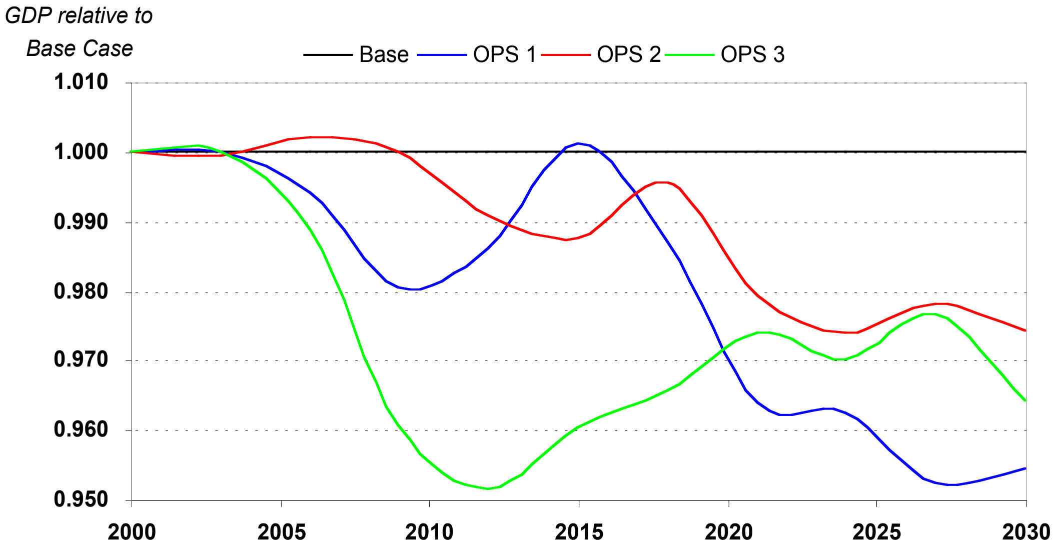
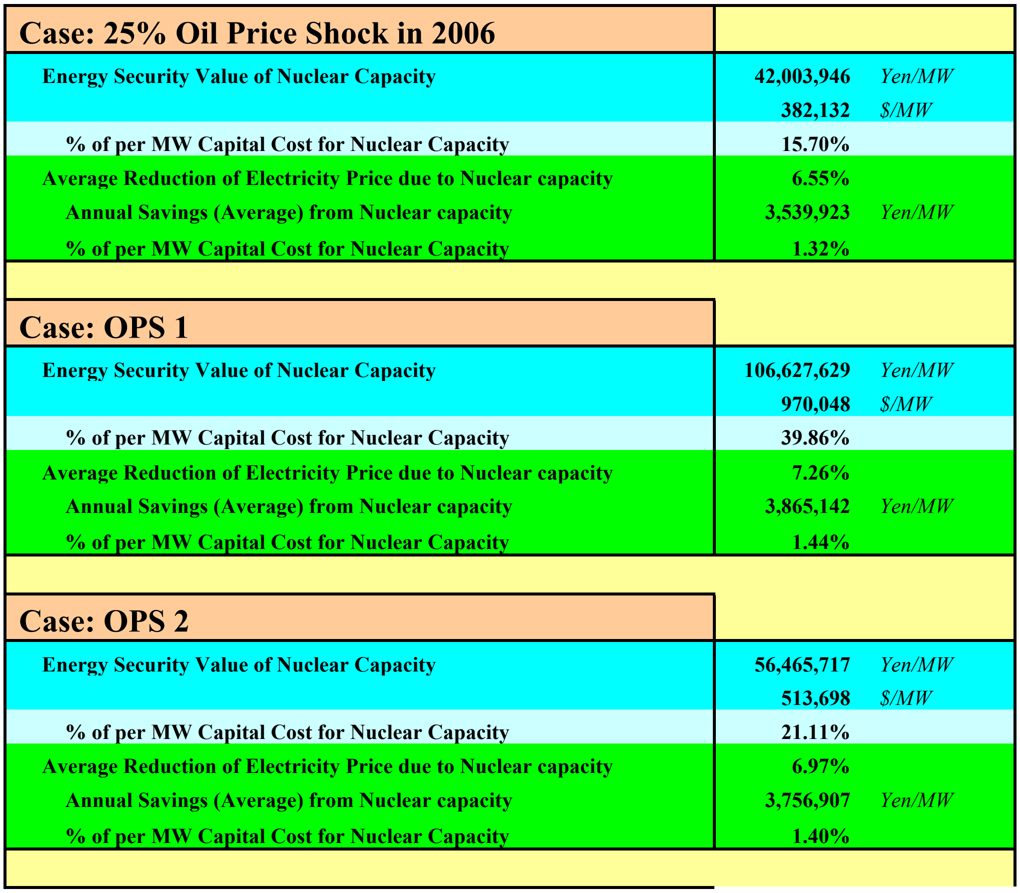


Table 7 reports the calculated energy security values of nuclear power for each of the three fluctuating oil price scenarios as well as, for the purpose of comparison, the case of the single oil price shock from Table 6. We see that the energy security value of nuclear power is calculated to be greatest in Oil Price Scenario 3 (OPS 3). This is largely due to the fact that effects of future shocks are discounted in the present. In OPS 3 prices reach $42/bbl in 2006 and average above $35/bbl through 2012, which are the highest near term prices among the scenarios considered here. OPS 3 is followed, in terms of magnitude, by OPS 1 and OPS 2. The case of a single oil price shock over the thirty year period is the case in which the smallest energy security value is placed on nuclear power.

Table 7 – Summary of ESV under different Oil Price Scenarios



Case: 25% Oil Price Shock in 2006		
Energy Security Value of Nuclear Capacity	**42,003,946**	*Yen/MW*
	382,132	*$/MW*
% of per MW Capital Cost for Nuclear Capacity	**15.70%**	
Average Reduction of Electricity Price due to Nuclear capacity	**6.55%**	
Annual Savings (Average) from Nuclear capacity	**3,539,923**	*Yen/MW*
% of per MW Capital Cost for Nuclear Capacity	**1.32%**	
Case: OPS 1		
Energy Security Value of Nuclear Capacity	**106,627,629**	*Yen/MW*
	970,048	*$/MW*
% of per MW Capital Cost for Nuclear Capacity	**39.86%**	
Average Reduction of Electricity Price due to Nuclear capacity	**7.26%**	
Annual Savings (Average) from Nuclear capacity	**3,865,142**	*Yen/MW*
% of per MW Capital Cost for Nuclear Capacity	**1.44%**	
Case: OPS 2		
Energy Security Value of Nuclear Capacity	**56,465,717**	*Yen/MW*
	513,698	*$/MW*
% of per MW Capital Cost for Nuclear Capacity	**21.11%**	
Average Reduction of Electricity Price due to Nuclear capacity	**6.97%**	
Annual Savings (Average) from Nuclear capacity	**3,756,907**	*Yen/MW*
% of per MW Capital Cost for Nuclear Capacity	**1.40%**	

Case: OPS 3		
Energy Security Value of Nuclear Capacity	**154,597,209**	*Yen/MW*
	1,406,452	*$/MW*
% of per MW Capital Cost for Nuclear Capacity	**57.79%**	
Average Reduction of Electricity Price due to Nuclear capacity	**6.96%**	
Annual Savings (Average) from Nuclear capacity	**3,499,419**	*Yen/MW*
% of per MW Capital Cost for Nuclear Capacity	**1.31%**	

One conclusion that is readily drawn from the results presented in Table 7 is that the energy security value of nuclear power largely depends on the path of future oil prices. While we have placed no probability bounds on the outcomes considered here, it is possible to see that nuclear power plays a potentially large role in promoting energy security under any scenario that provides for major fluctuations in oil prices. Thus, on these grounds, it is not surprising that Japan's electric generation capacity has shifted so dramatically away from oil, and nuclear power has been the primary alternative. It is important to note, however, that while the energy security benefits are potentially large, we have made no effort in this study to examine the full range of potential costs of moving to a "nuclear society".

We have also shown that there exists an optimal mix of generation capacity, as evidenced by the comparison of cases 7-12 and 38 above. The optimal policy is one of diversity, and in fact, results in the lowest long term electricity prices. Moreover, given the recent shutdown of several nuclear reactors in Japan, diversity in fuel source for power generation has indeed served to mitigate the price impacts of shutting down nuclear capacity.

VII. Findings and Conclusion

The purpose of this study was to assess the role that nuclear power plays in enhancing Japan's national security. The project entailed a year-long research and economic modeling program designed to quantify the contribution that nuclear power makes to Japan's overall economic health and energy security. The research addressed not only nuclear power's current contribution to Japan's energy security but also examined the country's future fuel choices to quantify some of the economic costs and benefits of expanding nuclear power's share of Japan's electricity sector fuel mix in the coming years. The study focused solely on issues related to energy security and the national economy, and did not attempt to model or quantify any safety, waste-disposal, or social issues related to the use of nuclear power.

The model quantified the energy security value of nuclear power generation in Japan, giving consideration to a number of issues including:

1. the magnitude and probability of sudden cost increases or supply shortages of imported oil and gas
2. the damage that can come to the Japanese economy from such price increases or supply disruptions, including loss of GDP
3. the economic and security risks that would follow from a partial or total elimination of nuclear power from Japan's energy mix
4. the dollar value and security benefits provided to Japanese society by the existence of nuclear power
5. the relative value and costs of expanding nuclear power's share of Japan's electricity system against other fuel sources.

Specifically, the study was primarily concerned with the savings, in terms of macroeconomic output that would otherwise be forgone in the event of an oil market disruption, associated with relying more on nuclear capacity.

The study results demonstrate that using a mix of fuels to generate electricity provides a clear benefit to the public good. This benefit comes not only from lowering overall electricity costs to Japanese consumers but also from protecting the national economy from the negative economic effects of a major international energy disruption, such as the oil crises of the 1970s. The implication of this conclusion is that because there is a social, public goods benefit to the use of multiple fuels, governments have a basis to justify intervention to promote fuel diversity. Individual firms will not necessarily take these broader national energy security and GDP effects of fuel choices into account in selecting new capacity but rather will select new capacity on the basis of the cheapest, most efficient fuel for their narrow, immediate commercial goals.

The study, however, does indicate certain limitations are necessary in consideration of government intervention in electricity fuel markets. A key implication of the findings is that elimination of, or conversely, promotion of government subsidies for certain fuels will incur real costs and therefore these costs must be weighed against the calculated benefits for promoting a particular fuel for national security or environmental reasons. In the case of promoting nuclear power, the overall energy security contribution and benefit to the national economy must be judged against other consequences outside the scope of this study. Moreover, the study results also indicate that there is a certain level of nuclear capacity that is cost-minimizing, and that movement in either direction of too much nuclear capacity or too little nuclear capacity will raise the overall costs of electricity generation in Japan.

Diversity of fuel sources increases flexibility to keep overall costs low during sudden or prolonged disruptions or demand spikes. Comparison of various scenarios performed through the modeling runs demonstrated that heavy reliance on one or two fuel types can raise the costs of a major disruption. Having alternative choices to replace lost fuel supplies helps minimize the impact of a large supply disruption. It also helps keep costs low in the face of more normal day-to-day fluctuations in fuel prices. Our research highlights this conclusion by demonstrating that electricity prices are, on average, lowest when there are no constraints to construction of new capacity. That is because particular types of generation capacity are best suited to meet certain types of loads.

Finally, the results suggest that coal is the closest substitute for nuclear power in economic terms. Since coal comes from different sources than oil and gas, a greater use of coal could also contribute generally to security benefits, though environmental factors must be considered against this security implication. While the utilization of clean coal technology can help avoid problems of SO_X and NO_X, a potential issue is that the clean coal process does not eliminate CO_2 emissions. Still, the results of this study suggest that the Japanese government is correct in its pursuit of clean coal research and development activities, and may want to consider augmenting its support in this area given the other issues surrounding the use and extension of atomic power. From a corporate perspective, our results suggest that it would be wise for Japanese power generation firms to keep abreast of developments in clean coal generation technologies.

According to our analysis, nuclear power helps provide stable fuel costs on a day-to-day basis and protect overall national economic performance during times of disruption or crisis. We examined three different oil price shock scenarios with variabilities inside the bounds of historical experience. We found the security value of nuclear power under these scenarios to range from about 21% to about 58% of the capital cost of construction of a nuclear power plant in Japan.

References

Advisory Committee for Natural Resources and Energy, New and Renewable Energy Sub-Committee. “2010 nendo shin energy donyu mitoshi (mokuhyo case [shisanchi]) no kangaekata (The view of the renewable energy introduction prospect in the 2010FY as a target case (trial calculation value).” Material no. 2-2 for no. 2 Sub-Committee (February 2001), http://www.meti.go.jp/report/committee/index.html

Agency for Natural Resources and Energy, Electricity and Gas Industry Department. *Denryoku Jyukyu no Gaiyo (Outline of Electricity supply and demand) (annual).*Tokyo: Chuwa Insatsu, 1971-2002.

Cabinet Office, Economic and Social Research Institute. “GDE by prefectures.” http://www.esri.cao.go.jp/jp/sna/kenmin/h12/0319kenmin1.xls

Energy Information Administration. *Country Analysis Briefs – Japan.* (www.eia.doe.gov).

Energy Information Administration. *International Energy Outlook, 2003*. (www.eia.doe.gov).

Experts Committee on Taxation for Global Warming, Joint Committee between Total Policy and Global Environment, The Central Environment Council. “Ondanka Taisaku Zeisei no Gutaitekina Seido no An, -Kokumin niyoru Kento・Giron notameno Teian- (The proposal of the concrete system of a taxation system for global warming measure -The proposal for the examination and the argument-).” Material 1 for no. 14 Expert Committee (August 2003), http://www.env.go.jp/council/16pol-ear/y161-14/mat01.pdf

Federation of Electric Power Companies of Japan (FEPC), Statistics study groups. *Denki Jigyo Binran (Hand Book of Electric Power Industry)*. Tokyo: Japan Electric Association, 2002.

Ferderer, J. Peter. “Oil Price Volatility and the Macroeconomy.” *Journal of Macroeconomics*. (Winter 1996): 1-26.

Hamilton, James D. “Oil and the Macroeconomy Since World War II”. *Journal of Political Economy*. Vol.91 No. 2 (1983): 228-248.

Institute of Energy and Economics, Japan (IEEJ). *EDMC/Energy Keizai Tokei Yoran (Handbook of Energy and Economic Statistics in Japan)*. Tokyo: Energy Conservation Center, Japan, 2002.

International Energy Agency (IEA). *Energy Policies of IEA Countries – Japan 2003*. Paris: OECD/ IEA, 2003.

International Energy Agency (IEA). *Power Generation Investment - 2003*. Paris: OECD/ IEA, 2003.

International Energy Agency (IEA). *World Energy Investment Outlook -2003 / Insights*. Paris: OECD/ IEA, 2003.

IOR energy. “Energy Conversion Factor.” http://www.ior.com.au/ecflist.html

Lee, Kiseok , Shawn Ni, and Ronald Ratti. "Oil shocks and the Macroeconomy: The Role of Price Variability." *The Energy Journal*. Vol 16 No.4 (1995): 39-56.

Medlock, Kenneth B, Robin Sickles, Weiyu Gao. "The Effects of Oil Price Changes on Productivity and Technical Change", Rice University Working Paper, (2004).

Ministry of Environment. "Jigyosha karano Onshitsu Kouka gas Haishutsu Santei Houhou guideline [Shian ver. 1.4] (The calculation method guideline of greenhouse gas emission from enterprises [Draft ver. 1.4])." (July 2003), http://www.env.go.jp/earth/ondanka/santeiho/guide/pdf1_4/mat_01.pdf

Mork, Knut, Hans T. Mysen and Oystein Olsen. "Macroeconomic Responses to Oil Price Increases and Decreases in Seven OECD Countries." *The Energy Journal*, No.4 (1994).

Nagata, Yutaka. Hoshino, Yuko. Hattori, Tsuneaki. Wakabayashi, Masayo. Sakurai, Norihisa. and Ohkawara, Toru. "Economic Analysis of Phasing out Nuclear Power Generation." Socio-economic Research Center Report No. Y01016 (2002)

National Institute of Population and Social Security Research. "Man and Women, Population forecast." Http://www.ipss.go.jp/Japanese/newest02/p_age2.xls

New Energy and Industrial Technology Development Organization (NEDO). "Ohgata Furyoku Hatsuden no Todofuken betsu Senzai Kanosei (The potential of large-sized wind power classified by all prefectures)." https://www.nedo.go.jp/nedata/14fy/03/b/0003b004-8.htm

New Energy Foundation (NEF). "Nendo betsu・Todofuken betsu Taiyo Denchi Shutsu Nyuryoku Bunpu (The solar cell output distribution classified by - prefectures by year concerning Solar power project)." http://www.solar.nef.or.jp/josei/h15kw_bunpu.htm

Organization for Economic Cooperation and Development (OECD). "Results from the OECD Report on International Projections of Electricity Generating Costs." http://www.iea.org/pubs/studies/files/procog/summ.pdf

Sekitsu. *1999 nen ban Sekiyu Kakaku Tokei Hyo (Petroleum Price Statistic, 1999).* Tokyo: Sekitsu, 1999.

Ux Consulting Company, LLC. "Historical Ux Month-end Spot Prices." http://www.uxc.com/review/uxc_prices_mth-end.html

Data sources (General)

Energy data is obtained from Agency for Natural Resources and Energy. http://www.enecho.meti.go.jp

GDP data is obtained from Cabinet Office, Economic and Social Research Institute. http://www.esri.cao.go.jp/jp/sna/toukei.html

Petroleum products price data is obtained from Petroleum Association of Japan. http://www.paj.gr.jp/html/statis/index.html

Population data is obtained fromMinistry of Public Management, Home Affairs, Posts and Telecommunications, Statistics Bureau. http://www.stat.go.jp/data/jinsui/wagakuni/index.htm

Tax data is obtained from Ministry of Finance (http://www.mof.go.jp/) and Ministry of Public Management, Home Affairs, Posts and Telecommunications, Statistics Bureau (http://soumu.go.jp/).

Temperature data is obtained from Japan Meteorological Agency. http://www.data.kishou.go.jp/

Data source (Electric Power Company)

Chubu Electric Power Company
http://www.chuden.co.jp/

Chugoku Electric Power Company
http://www.energia.co.jp/

Electric Power Development Company (J-Power)
http://www.jpower.co.jp/index2.html

Federation of Electric Power Companies of Japan (FEPC)
http://www.fepc.or.jp/index-h.html

Hokkaido Electric Power Company
http://www.hepco.co.jp/index.html

Hokuriku Electric Power Company
http://www.rikuden.co.jp/

Japan Atomic Power Company
http://www.japc.co.jp/index.htm

Kansai Electric Power Company
http://www.kepco.co.jp/

Kyushu Electric Power Company
http://www.kyuden.co.jp/

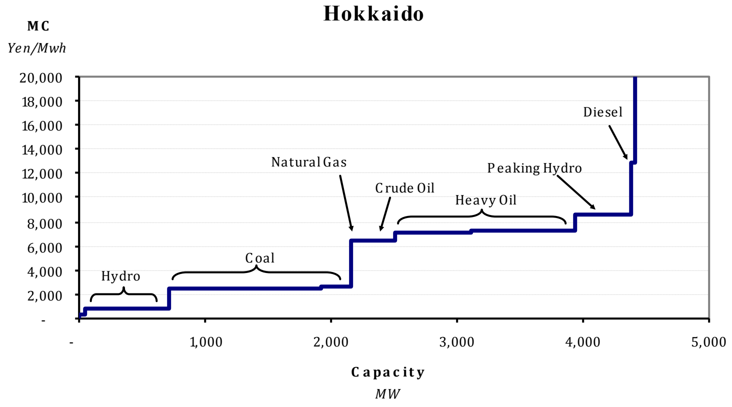
Okinawa Electric Power Company
http://www.okiden.co.jp/

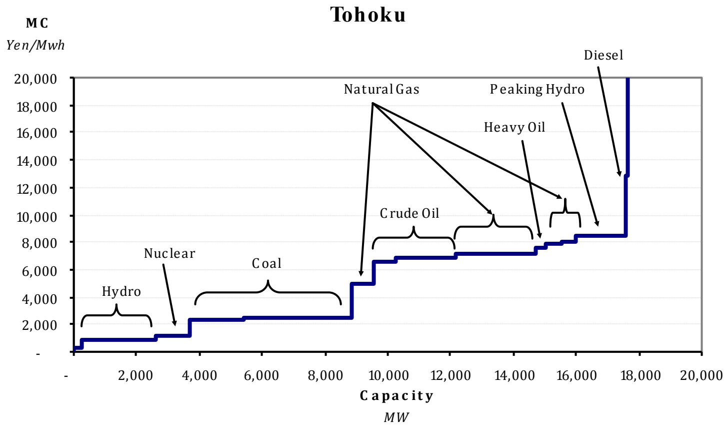
Shikoku Electric Power Company
http://www.yonden.co.jp/

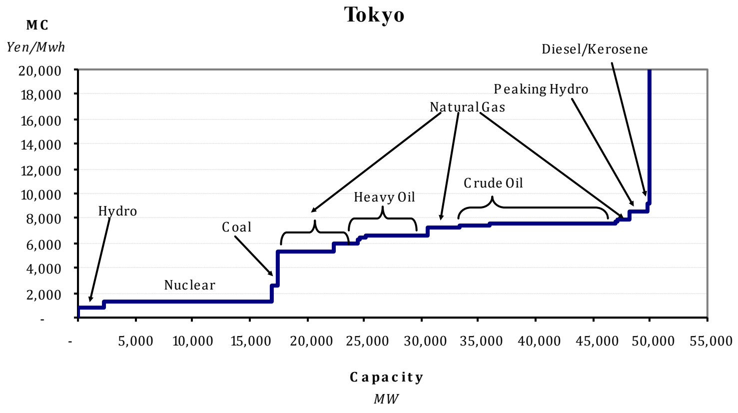
Tohoku Electric Power Company
http://www.tohoku-epco.co.jp/index.htm

Tokyo Electric Power Company
http://www.tepco.co.jp/

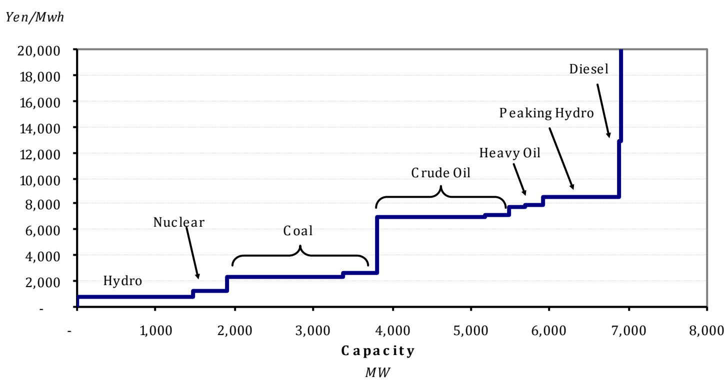
Appendix Figure 1 – Supply Stacks by Fuel and Utility Area, 2000



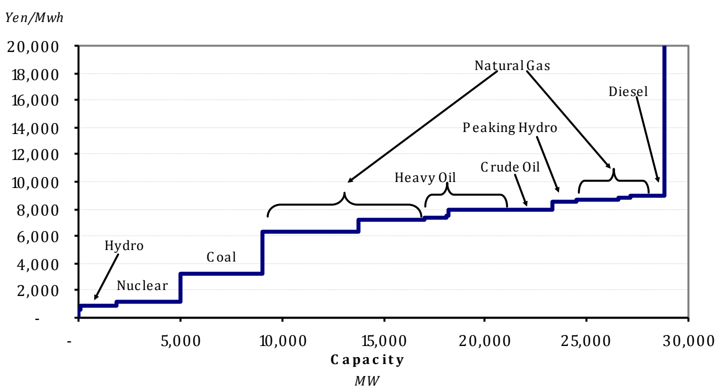




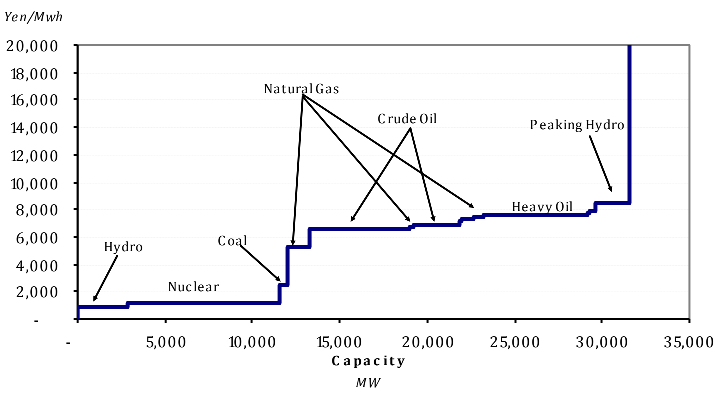
Hokuriku

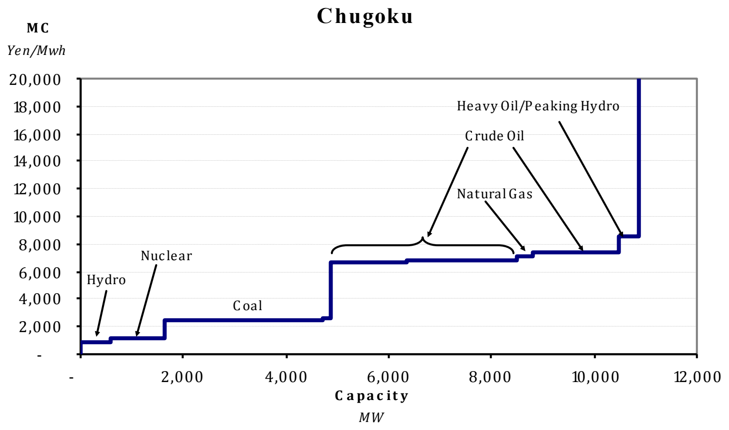


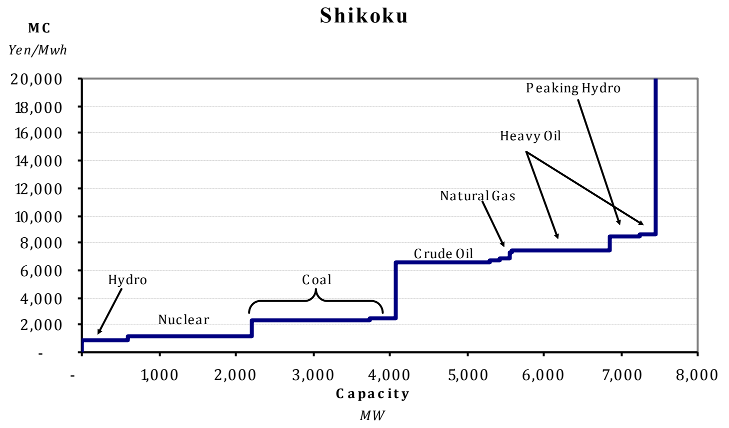
Chubu

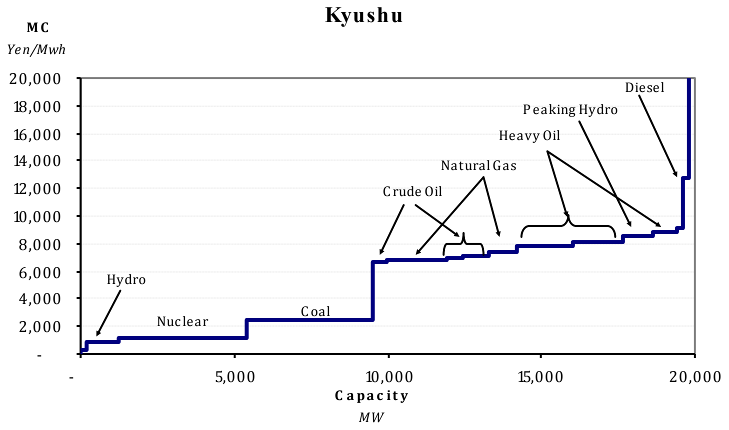


Kansai




Chugoku
MC
Yen/Mwh
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
Hydro
Nuclear
Coal
Natural Gas
Crude Oil
Heavy Oil/Peaking Hydro
-
2,000
4,000
6,000
8,000
10,000
12,000
Capacity
MW


Shikoku
MC
Yen/Mwh
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
Hydro
Nuclear
Coal
Crude Oil
Natural Gas
Heavy Oil
Peaking Hydro
-
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
Capacity
MW


Kyushu
MC
Yen/Mwh
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
Hydro
Nuclear
Coal
Crude Oil
Natural Gas
Heavy Oil
Peaking Hydro
Diesel
-
5,000
10,000
15,000
20,000
Capacity
MW

Appendix Table 1 – Scenario Description

	High Population			Low Population		
Plan + Economics (Baseline Scenarios)	***Case 1*** High GDP	***Case 7*** Medium GDP	***Case 13*** Low GDP	***Case 19*** High GDP	***Case 25*** Medium GDP	***Case 31*** Low GDP
No New Nuclear constructed	***Case 2*** High GDP	***Case 8*** Medium GDP	***Case 14*** Low GDP	***Case 20*** High GDP	***Case 26*** Medium GDP	***Case 32*** Low GDP
All Nuclear Retired in 2009	***Case 3*** High GDP	***Case 9*** Medium GDP	***Case 15*** Low GDP	***Case 21*** High GDP	***Case 27*** Medium GDP	***Case 33*** Low GDP
No New Nuclear constructed/Only LNG constructed	***Case 4*** High GDP	***Case 10*** Medium GDP	***Case 16*** Low GDP	***Case 22*** High GDP	***Case 28*** Medium GDP	***Case 34*** Low GDP
All Nuclear Retired in 2009/Only LNG constructed	***Case 5*** High GDP	***Case 11*** Medium GDP	***Case 17*** Low GDP	***Case 23*** High GDP	***Case 29*** Medium GDP	***Case 35*** Low GDP
Only Nuclear constructed	***Case 6*** High GDP	***Case 12*** Medium GDP	***Case 18*** Low GDP	***Case 24*** High GDP	***Case 30*** Medium GDP	***Case 36*** Low GDP
Never Nuclear	***Case 37*** High GDP	***Case 38*** Medium GDP	***Case 39*** Low GDP	***Case 40*** High GDP	***Case 41*** Medium GDP	***Case 42*** Low GDP

Appendix Table 2 – Vector Autoregression Results

Left-hand side variable	$ln(GDP_t)$					
	parameter estimate	**standard error**	**z**	**prob>z**	**95% Confidence Interval**	
Constant	6.127	1.757	3.490	0.000	2.684	9.570
$ln(GDP_{t-1})$	0.826	0.043	19.080	0.000	0.742	0.911
$ln(P_{elec,t-1})$	-0.023	0.096	-0.240	0.812	-0.210	0.165
$ln(Q_{NG,t-1}*P_{NG,t-1})$	0.018	0.034	0.530	0.599	-0.049	0.085
$ln(Q_{Oil,t-1}*P_{Oil,t-1})$	-0.042	0.010	-4.080	0.000	-0.062	-0.022
				R^2	**RMSE**	**$\chi 2$**
				0.996	0.013	4526.268

Left-hand side variable	$ln(P_{elec,t})$					
	parameter estimate	**standard error**	**z**	**prob>z**	**95% Confidence Interval**	
Constant	2.670	2.837	0.940	0.347	-2.890	8.230
$ln(GDP_{t-1})$	-0.027	0.070	-0.390	0.697	-0.164	0.110
$ln(P_{elec,t-1})$	0.571	0.154	3.700	0.000	0.268	0.874
$ln(Q_{NG,t-1}*P_{NG,t-1})$	-0.020	0.055	-0.370	0.712	-0.128	0.087
$ln(Q_{Oil,t-1}*P_{Oil,t-1})$	0.064	0.017	3.840	0.000	0.031	0.096
				R^2	**RMSE**	**$\chi 2$**
				0.948	0.021	361.998

Left-hand side variable	$ln(\Theta_{NG,t}*P_{NG,t})$					
	parameter estimate	**standard error**	**z**	**prob>z**	**95% Confidence Interval**	
Constant	-20.326	11.542	-1.760	0.078	-42.947	2.296
$ln(GDP_{t-1})$	0.510	0.285	1.790	0.073	-0.047	1.068
$ln(P_{elec,t-1})$	0.827	0.628	1.320	0.188	-0.404	2.059
$ln(Q_{NG,t-1}*P_{NG,t-1})$	0.358	0.224	1.600	0.109	-0.080	0.797
$ln(Q_{Oil,t-1}*P_{Oil,t-1})$	0.207	0.067	3.080	0.002	0.075	0.339
				R^2	**RMSE**	**$\chi 2$**
				0.784	0.086	72.563

Left-hand side variable	$ln(\Theta_{Oil,t}*P_{Oil,t})$					
	parameter estimate	**standard error**	**z**	**prob>z**	**95% Confidence Interval**	
Constant	58.190	31.168	1.87	0.062	-2.899	119.278
$ln(GDP_{t-1})$	-1.457	0.768	-1.90	0.058	-2.964	0.049
$ln(P_{elec,t-1})$	-1.263	1.696	-0.74	0.457	-4.588	2.062
$ln(Q_{NG,t-1}*P_{NG,t-1})$	-0.617	0.604	-1.02	0.307	-1.801	0.566
$ln(Q_{Oil,t-1}*P_{Oil,t-1})$	0.648	0.182	3.56	0.000	0.291	1.004
				R^2	**RMSE**	**$\chi 2$**
				0.867	0.233	130.626