Considering Nuclear Accident in Energy Modeling Analysis

Ryoichi Komiyama

Abstract After Fukushima nuclear accident, alternative energy sources show a dramatic growth such as natural gas, petroleum and solar photovoltaic to compensate the loss of nuclear energy supply in Japan, and in the latest national energy policy, the government plans to promote renewable energy at a scale larger than the one aimed in the previous policy. Hence, the Fukushima accident can be regarded as the tipping point for the country to pursue alternative energy and environmental policy adjusting into the social circumstance after the Fukushima. So far, energy model has been developed to discuss long-term energy scenario in a consistent way and to analyze the effectiveness of energy policy. However, the most of the model developed until now does not explicitly consider the impact of nuclear accident on the long-term pathway of energy portfolio, in spite of the fact that the Fukushima accident is actually observed to dramatically change the situation of energy demand and supply in Japan. This manuscript aims to overview the transition of energy supply and demand in Japan after the Fukushima and to discuss the possibility of considering nuclear accident in energy modeling analysis by applying stochastic dynamic programming.

Keywords Nuclear energy · Nuclear accident · Energy mix · Energy modeling · Stochastic dynamic programming

1 Introduction

Energy supply serves as a basis to maintain socio-economic activity. For Japan which highly relies on the import of energy resource from other countries, the reinforcement of energy security is considered as an important challenge to be tackled with. In the global energy market, Japan is one of the big energy consumers

R. Komiyama (✉)
Resilience Engineering Research Center, The University of Tokyo, Tokyo, Japan
e-mail: komiyama@n.t.u-tokyo.ac.jp

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and importers, becoming fifth in primary energy consumption, third in both petroleum imports and consumption, and first in liquified natural gas (LNG) imports. In addition, petroleum holds the largest fraction in the primary energy supply mix (44%), followed by coal (27%) and natural gas (22%), and the ratio of fossil fuels in total energy supply amounts to 93% in 2013 [1]. Moreover, the Japanese energy self-sufficiency ratio shows a considerably lower level, since the energy supply in Japan depends on imports of almost all fossil fuels; the Japanese energy self-sufficiency ratio is only 7% in 2013 [1], which exhibits a level below that in other developed countries. In addition, Japan is heavily dependent on the Middle East for about 80% of its domestic crude oil supply. Thus, nuclear power has traditionally played an essential role to ensure domestic energy supply in Japan where the situation of energy balance is considerably vulnerable as explained.

However, the impact of Fukushima nuclear accident, caused by Great East Japan Earthquake in Japan, is quite influential on the Japanese energy mix and socio-economy, and has caused intensive discussion for rethinking energy policy thereafter which strongly supported nuclear energy. Elaborate political and technical effort has been dedicated to replace the loss of nuclear power supply, an important base-load technology contributing to energy security and environmental sustainability before the Fukushima. Actually, after the Fukushima accident, alternative energy sources compensating nuclear have shown a dramatic increase such as natural gas, petroleum and solar photovoltaic (PV) as well as electricity conservation. Therefore, the severe nuclear accident is considered to be one of driving force which might change the pathway of the country's energy mix, and the Fukushima can be understood as the tipping point for the country to pursue energy, environmental and nuclear policy adjusting into the socio-economic circumstance after the Fukushima.

Until now, a lot of academic effort has been dedicated to the development of energy system model which allows us to yield long-term energy scenario in a consistent way and to analyze the effectiveness of energy and environmental political instrument such as carbon tax, regulation or subsidization. However, the majority of existing analysis does not explicitly assess the impact of disruptive nuclear accident and its successive shutdown on the long-term pathway of energy portfolio, although the accident is actually observed to dramatically alter the situation of energy balance in Japan.

The objective of this chapter is to overview the transition of energy supply and demand in Japan after the Fukushima, and, based on that, to discuss the possibility of considering nuclear accident as contingency risk in energy modeling analysis by applying the methodology of risk analysis such as stochastic dynamic programming. The chapter is organized as follows: Sect. 2 describes the energy balance situation in Japan before and after the Fukushima accident; Sect. 3 discusses the possible methodology to consider a nuclear accident in energy model and Sect. 4 depicts the concluding remark.

2 Impact of Fukushima Nuclear Accident on Japanese Energy Market

The Great East Japan Earthquake and following tsunami attack caused serious damage to nuclear power plants together with other critical energy infrastructures such as thermal power plants, oil refineries, and LNG import terminals in the broad area of eastern Japan. Particularly the significant damage was put on the power sector. Due to the sudden loss of 27 GW of power generation capacity in Japan where the total capacity is 231 GW, power supply shortage became a profound problem shortly after the earthquake. To resolve the power shortage, enormous efforts were concentrated on incrementing the power generation capacity by restarting aging and idle petroleum-fired power plant, while mandatory power saving was implemented to cope with insufficient power supply. In order to cover the electricity supply loss caused by the earthquake, urgent measures were conducted to maximize the utilization of natural gas (LNG)-fired and petroleum-fired power plants, including the aging idled power plants. In the demand side, rolling blackouts were implemented from March to April in Tokyo/Kanto area in 2011, and then the government ordered compulsory curtailment in power usage from July, 2011 to treat the peak power load in summer for the first time since the oil crisis in 1970s. Due to those measures, no critical unplanned blackouts were implemented during the summer period immediately after the Fukushima accident. However, thereafter, all of 50 nuclear power reactors shut down in Japan due to their regulatory inspection. After the Fukushima, there has remained strong concerns over the safety of nuclear power plant in the public, and the local authority which holds nuclear power plants in their sites does not easily provide an official permissions for those restarts. At last, on August 11, 2015, Sendai nuclear power reactor in Kyushu Electric Power Company restarted its operation, which is the first case of the restart since 2013. However, the nuclear shutdown has still influenced the power supply mix in Japan.

2.1 Trend of Energy Mix After Fukushima

After Fukushima, national concerted efforts to maximize the usage of thermal power generation as well as electricity saving have contributed to prevent the occurrence of power shortage. LNG-fired power plants and petroleum-fired power plants, which serves regularly as middle-peak power generator, operate so as to compensate the loss of nuclear power which is responsible for base load in power load profile. It should be also noted that power utility companies attempt to newly build thermal power capacity as well as to bring very aging power plants back on line.

The Fukushima nuclear accident triggered the shutdown of the country's entire nuclear power plants, which accounted for 30 percent of the country's electricity

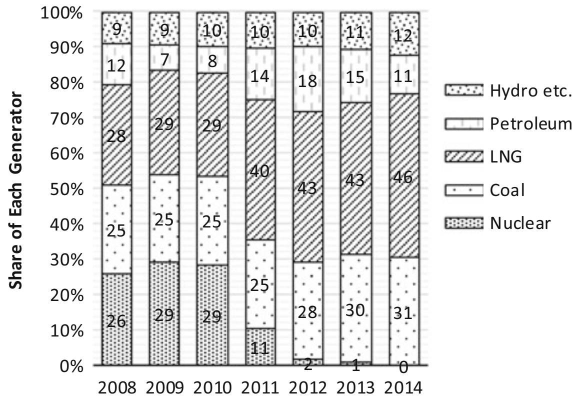


Fig. 1 Annual power generation mix in Japan [2, 3]

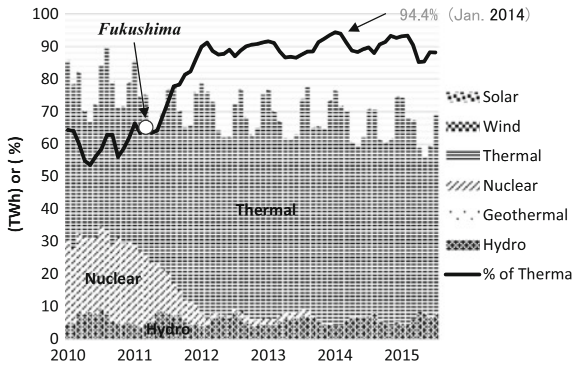


Fig. 2 Monthly power generation mix in Japan [3]

supply before the Fukushima (Fig. 1) [2, 3]. Due to the declined utilization of nuclear power since the Fukushima accident, the fraction of fossil fuel over total power generation reached at the highest level (94.4% in January 2014) in the last three decades (Fig. 2) [3].

Substantial increase in LNG and petroleum is attributed to power generation to offset the decline in nuclear power generation after the accident. In particular, a radical shift to LNG occurred to compensate the loss of nuclear. Currently, LNG-fired power accounts for almost half of the power generation mix in Japan (Fig. 1) and LNG becomes an essential fuel in the Japanese energy supply portfolio. Actually, Japan's LNG imports increased from 70.5 million tons (MT) in FY 2010 to 83.2 MT in FY 2011, 86.9 MT in FY 2012, 87.7 MT in FY 2013 and 89.1 MT in FY 2014 [1]. Growing LNG consumption has caused an increase in import payments for LNG (Fig. 3) [4, 5], electricity supply cost, dependence on Middle East for LNG supply (Fig. 4) and CO_2 emissions, and has provided a decline in the country's energy self-sufficiency. Figure 3 shows Japan's annual imports of LNG. Japan's import payments for LNG in 2014 were a record high at 7.9 trillion yen,

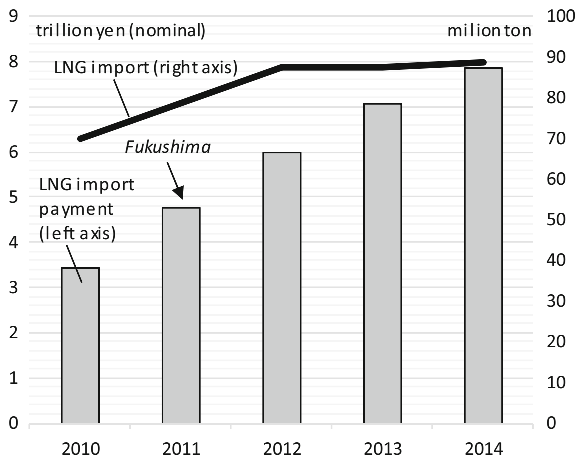


Fig. 3 Annual payment for LNG import in Japan [4, 5]

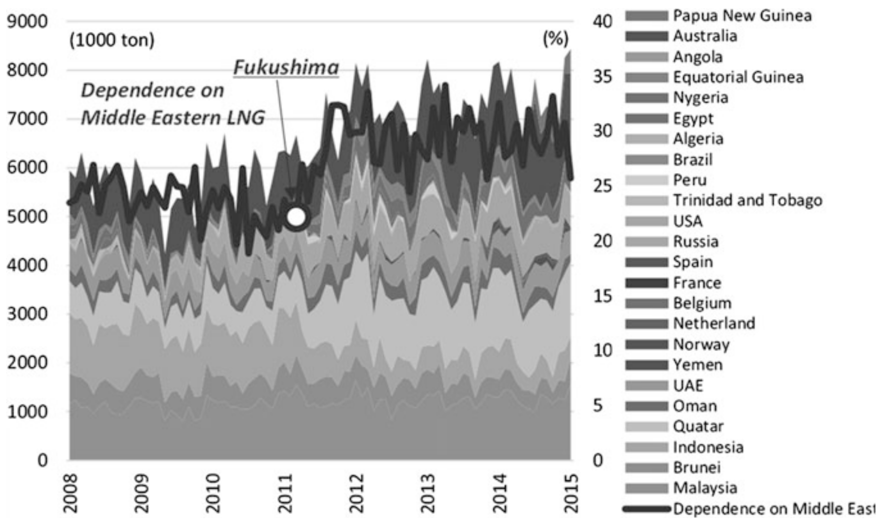


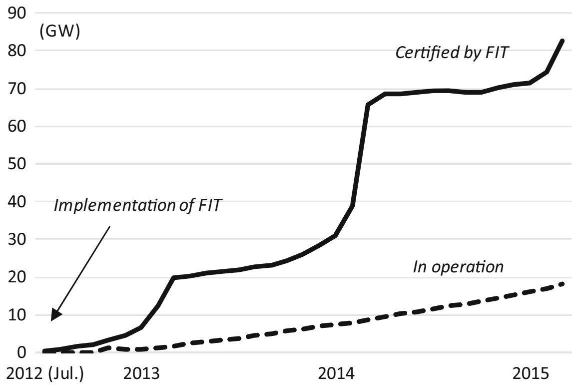
Fig. 4 Monthly LNG import by country in Japan [5]

more than doubling from FY 2010. By this soaring LNG import, the balance of payment turned to negative in fiscal year 2011 for the first time since 1980 [4].

Meanwhile, coal holds an important advantage of being economically competitive cost, although it has an environmental disadvantage of its higher intensity of CO_2 emissions. Thus, coal-fired plant plays an important role for an economical power supply as base load power generator. As nuclear power plants in Japan remain shut down since the Fukushima nuclear accident, Japanese utility companies actually began planning the new operation of coal-fired power plants in order to enhance the capability of economical power supply, influenced by the soaring import payment for LNG. For example, Tokyo, Kansai, Chubu, Kyushu and Tohoku electric power companies plan to add 1.0 GW [6], 1.2 GW [7], 1.0 GW [8], 1.2 GW [9] and 0.6 GW [10] of coal-fired power plant in their power generation mix respectively. Including those plans, total 13 GW of newly building plan of coal-fired is under consideration. Japan needs to place coal as an important energy resource in order to secure the economical competitiveness of power supply and to effectively purchase other fuel through the employment of coal as a bargaining power in negotiation. Additionally, to suppress its external environmental impact, Japan is expected to develop clean coal technologies such as IGCC (integrated coal gasification combined cycle) and CCS (carbon capture and storage).

As explained so far, fossil fuel serves as main alternative energy substituting nuclear energy after Fukushima. However, expectation has been currently concentrated on renewable energy sources such as solar photovoltaic and wind power systems, since those are domestic and carbon-free energy sources that will contribute to create advanced electricity business. In addition, renewables are socially preferable options due to its reliance on natural sources of energy as distributed power sources. Since July 1, 2012, the Japanese government started to implement a Feed-in Tariff (FIT) system for renewable electricity, aiming at the promotion of renewable energy in the country's energy mix. Particularly after the implementation of FIT in 2012 by the government, the cumulative installed PV capacity rapidly increased from 6.6 GW in 2012 to 23.3 GW in 2014 (Fig. 5) [11]. Moreover, PV capacity, which is certified to be built for the future and now under consideration, amounts to 68.9 GW as of October 2014 against 231 GW of total utility capacity in Japan (Fig. 5) [11], suggesting that the effects of FIT have been very powerful, although the power generation cost of PV is still more expensive (Fig. 6) [12]. However, a set of FIT tariff is difficult in terms of integrating renewables in an optimal way as implied by the experiences of other countries such as Germany and Spain. If the FIT tariff is set to be profitable for PV owners, PV investment rapidly expands well beyond the managerial capability of power grid, and increasing

Fig. 5 Installed solar PV capacity (certified by FIT & in operation) in Japan [11]



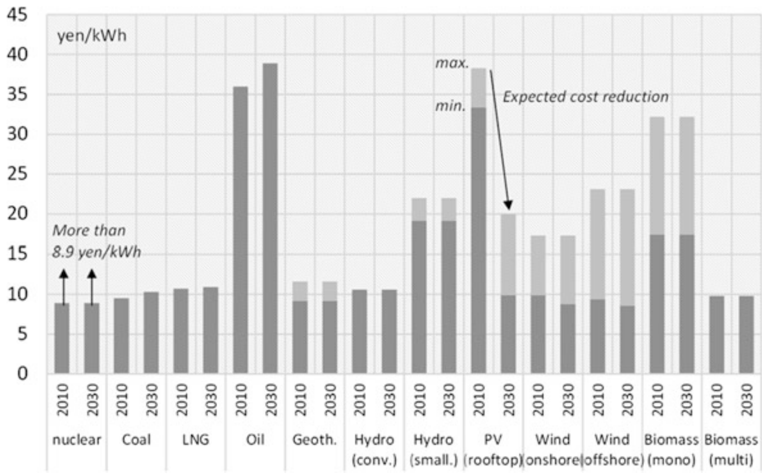


Fig. 6 Assessment of power generation cost in Japan [12]

electricity price through a surcharge by FIT puts a financial burden on end-users. It should be carefully considered that the massive integration of renewables poses a lot of challenges in technical and financial aspects, derived from their output intermittency and higher generation costs. Technical efforts are required to stabilize the power supply system through flexible resources such as rechargeable battery, back-up generators and demand response, and massive investments to enhance power grid capability will be indispensable. Meanwhile, if the tariff is set at a lower level, the installation of renewable power will not be successfully promoted. Paying cautious attention on the status of electricity market such as electricity price, it is important to promote renewable energy and improve the grid capability for the sustainable development of energy supply.

Increased dependence on fossil fuel supply and the associated growing import payments for the fossil fuels have eventually resulted in higher power generation cost and soaring electricity retail price. The increase in import payments for fossil fuel for power generation is projected to still cause an increase in average unit costs by 3.0 yen/kWh in FY 2015 from their FY 2010 levels [13]. Higher power generation cost has serious economic impact, causing more than 30% escalation in electricity bill for the average household in Tokyo after the Fukushima [14]. Actually, Kansai Electric Power Company, around half of which power generation mix is derived from nuclear energy, submitted applications for approval to the government about a 10.23% increase in power rates for the customers from FY2015. In those surroundings, rising electricity bills will pose a serious challenge for Japanese economy. Particularly for Japanese manufacturing sectors which come up against challenges in their international competitiveness, a further energy cost escalation is considered to be economically harmful. Since electricity price in Japan

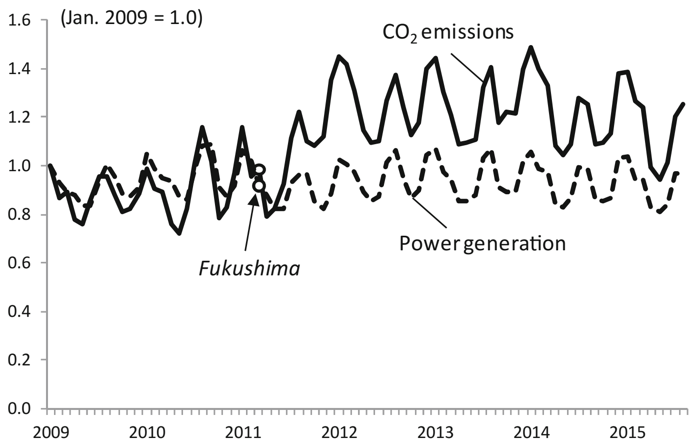


Fig. 7 Monthly CO_2 emissions and power generation in Japan (estimated from [3])

is relatively expensive in the context of an international comparison, its further increase can be understood as an additional financial burden.

CO_2 emissions will increase as well, because of increased usage of fossil fuel to replace the loss of nuclear power after Fukushima. The utility power companies accounted for 439 million tons of CO_2 for the year 2011 (after Fukushima), up 17 percent from 374 million tons in the year 2010 (before the Fukushima) (Fig. 7). Kansai Electric Power Company, which relies most on nuclear power, produced 65.7 million tons, a 40 percent increase in CO_2 emissions. Japan's total CO_2 emissions increased from 1.124 billion tons (6.1% higher than that in FY 1990) in FY 2010 to 1.173 billion tons (11% higher) in FY 2011, 1.208 billion tons (14% higher) in FY 2012 and 1.224 billion tons (16% higher) in FY 2013. Growing CO_2 emissions due to higher fossil fuel usage has imposed new challenges for Japan to strategically consider post-Kyoto climate change policy. As discussed so far, it is important to note that Japan currently faces multiple difficulties concerning energy security and environmental conservation together with sustainable economic growth.

2.2 Energy Policy Overview in Japan Before and After Fukushima

Before Fukushima, the Japanese government, in its Strategic Energy Plan officially approved in June 2010 [15], assigned the target of increasing the energy self-sufficiency ratio from the present level of 38 to 70% by 2030 and of mitigating CO_2 emissions by 30% compared with the 1990 level. For achieving those targets, an important measure was to expand the contribution of nuclear power supply in future energy mix. The Energy Plan assumes that carbon-free energy sources, that is, nuclear and renewable, account for 70% in power generation mix in 2030. The fraction of nuclear power itself amounts to more than 50% in the mix as indigenous and emission-free sources. The Japanese government planned to build additional 14 reactors, thereby boosting the installed nuclear capacity from 49 GW in 2010 to 68 GW by 2030, while maintaining all the existing plants. In addition, the government aimed to raise the capacity factor of nuclear power plants to average 90%. However, the Fukushima accident required a rethink of this Plan in terms of nuclear energy development.

The changing circumstances after Fukushima necessitate the fundamental review of the energy policy which was formulated before Fukushima. The new Strategic Energy Plan of Japan [16], the first national energy policy after Fukushima, was officially approved in April 2014, and the new governmental energy outlook to 2030 was presented in July 2015 [17]. The plan and the outlook discuss the normative view of desired energy mix to 2030 by reviewing the properties of nuclear power and other alternative energy sources, and proposes the optimal power generation mix to satisfy the requirement of energy demand and supply in terms of 3Es: energy security, environmental conservation and economic efficiency. The plan places nuclear power as an important base load power generator which satisfies all of the agenda in 3Es. The new energy outlook of Japan assumes the appropriate fraction of total electric power generation in 2030: 20–22% for nuclear, 27% for liquefied natural gas (LNG)-fired thermal, 26% for coal-fired thermal, 3% for oil-fired thermal, and 22–24% for renewables (Fig. 8). The plan describes that nuclear has advantage in economic efficiency based on its higher density of power output and in environmental compatibility as carbon-free source. Meanwhile, the plan describes that the enhancement of nuclear safety has higher priority than the assurance of 3Es and the dependence on nuclear in the energy supply portfolio should be decreased. It is therefore indispensable that nuclear operations strictly comply with the new safety standards, regarded as the world's most stringent code by the Nuclear Regulation Authority (NRA). According to the basic direction in the

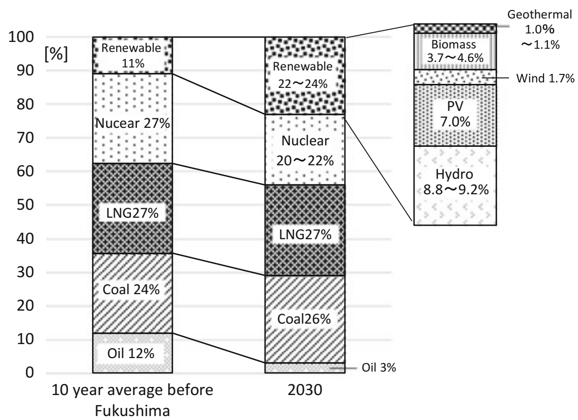


Fig. 8 Power generation mix of Japan to 2030 [17]

plan, the new outlook sets the desired fraction of nuclear in 2030 as 20–22%, a level below that in the plan before Fukushima (more than 50%). Regarding the appropriate fraction of nuclear (20–22%), the possibility of supplying power at that designated ratio by nuclear needs to be cautiously discussed. Because the existing capacity of nuclear power plants will decline by half to 2030, if the regulation of 40-year operational lifetime is assigned on all the existing plants [17]. However, the 20–22% nuclear fraction could be realized if a 20-year lifetime extension is endorsed by NRA through the additional investment to comply with the new safety standards. Other challenge for maintaining nuclear at the fraction is electricity market reform in Japan to 2020 where new investment for nuclear becomes difficult because nuclear faces competition to other alternative power resources. The new outlook describes that the desired fraction of nuclear energy could play an indispensable role to satisfy the requirement of 3Es in Japan, although multiple challenges remain to maintain the status of nuclear in the future power supply portfolio.

The plan also suggests to maximize the ratio of renewables at a level higher than the one pursued in the previous plan. In the new outlook, renewables will account for 22–24% of total power generation in 2030 (Fig. 8). A special consideration was conducted concerning the cost of purchasing renewable energy under the FIT system which was introduced in 2012. FIT has played a crucial role to increase the installation of renewable energy in Japan, while the financial burden of purchasing renewable energy at a specific rate from 10 to 20 years is regarded as one of the challenge in energy policy of Japan like Germany. The new outlook forecasts that annual purchasing cost of renewable will increase from 0.5 trillion yen in 2013 to 3.7–4.0 trillion yen in 2030. However, the outlook estimates that total electricity costs in 2030 will decrease by 3–5% from 9.7 trillion yen in 2013, since renewables, nuclear and energy efficiency reduce the consumption of fossil fuels, even if the purchasing cost for renewables will grow significantly.

In addition, the fraction of energy source in total primary energy supply in 2030 is estimated as well in the new outlook: oil 32% (40% in 2010, before Fukushima), coal 25% (22%), natural gas 19% (19%), nuclear 10–11% (11%), and 13–14% for renewables (7%) (Fig. 9). The energy self-sufficiency in Japan will increase to around 24% by 2030, and the dependence ratio on fossil fuels show a significant decline from 81% in 2010 to 76% in 2030.

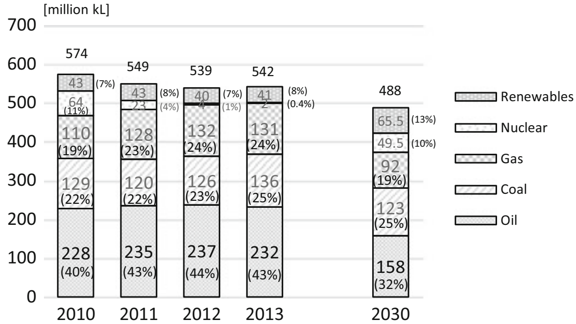


Fig. 9 Primary energy mix in Japan to 2030 [17]

The new outlook describes the vision to satisfy the 3E targets. However, keeping the nuclear fraction at 20–22% and expanding renewable energy in power grid are considered to be big challenges, and political supports, technical advancement and gaining the public understanding are indispensable.

3 Attempt for Energy Modeling Considering Nuclear Accident

After the Fukushima nuclear accident, Japan recognizes itself as the country where the energy planning considering the risk of nuclear disruption is required to enhance the country's energy security, experiencing the unprecedented increase in fossil fuels imports to guarantee the loss of nuclear energy as explained so far. The previous section introduces the official energy outlook of Japan to 2030. However, generally speaking, those kinds of long-term projection do not consider the possible disruptive events such as nuclear accidents and the subsequent suspension of all nuclear power plants which causes the increase in power supply cost by massive fuel import and deep electricity saving. Moreover, the huge cost of decontaminating radioactive material needs to be considered in the case of nuclear accidents, based on the Fukushima experience. In addition, after Fukushima, the government started feed-in-tariff to promote renewable energy which has pushed up electricity price and the Japanese power generation mix has shown the radical change. Thus, if the nuclear accident is explicitly considered which possibly assigns severe socio-economic burden, the long-term outlook of the country's energy mix will take the alternative pathway such that the deployment of nuclear energy is suppressed and the alternative sources are more introduced against the nuclear accident.

Based on the author's existing literature [18], this section attempts to discuss a potential methodology of considering the nuclear accident in energy modeling analysis. The literature [18] regards nuclear accidents as phenomena to cause a shutdown of nuclear power supply and tries to specify the optimal operation of fuel stockpiles, corresponding to SPR (strategic petroleum reserve) in the U.S., as control variables, considering the possible occurrence of a nuclear accident. Other than nuclear accident, in the analysis, the closures of Hormuz Straits and Straits of Malacca are explicitly considered as the extreme events, which cause the increase in energy supply cost. The literature [18] attempts to formulate the mathematical optimization which minimizes the country's total energy system cost, adopting stochastic dynamic programming, taking into account nuclear power shutdown. As an estimation period, the literature assumes a short-term such as nearly one year where the minimum unit of the estimation period is each day of the year, and eventually energy supply capacity is assumed to be fixed variable. Through the calculation, the optimal charge and discharge strategy of fuel stockpile is endogenously determined under the risk of the nuclear power supply disruption.

Firstly, fuel price volatility can be modeled as stochastic process. The daily time profile of the fuel import price in the study is assumed to have a certain cyclic pattern in average. In the model, the fluctuating change of the fuel import price P_t is expressed with Winner process dZ_t. As the specific stochastic process, the mean reverting process was assumed where price recurs to the average price for the long term. The stochastic process of fuel price is shown as follows.

$$dlogP_t = \frac{dP_t}{P_t} = \alpha(log\theta_t - logP_t)dt + \sigma dZ_t \tag{1}$$

$$log\theta_t = \frac{1}{\alpha}\frac{\partial logF(0,t)}{\partial t} + logF(0,t) + \frac{\sigma^2}{4\alpha}\left(1 - e^{-2\alpha t}\right) - \frac{1}{2\alpha}\sigma^2 \tag{2}$$

where P_t: fuel price at t [yen/specific unit], θ_t: equilibrium fuel price at t [yen/specific unit], α: reversion rate, σ: volatility, dZ_t: winner process, F: future price.

The expected total energy system cost (the total cost that is necessary from t to the expiration of an analytical period) in the state of $\boldsymbol{s}$ and $\boldsymbol{i}$ at t is defined as $V_i(\boldsymbol{P_t}, \boldsymbol{s}, t)$. By stochastic dynamic programming, $V_i(\boldsymbol{P_t}, \boldsymbol{s}, t)$ becomes the minimum of the sum of the expected total energy system cost after the time of $t + dt$, $\sum_j \Pr(i \rightarrow j) \cdot E\left[V_j(\boldsymbol{P_t} + d\boldsymbol{P_t}, \boldsymbol{s} + d\boldsymbol{s}, t + dt)\right]$ and the total energy system cost in each unit of time, $TC(\boldsymbol{P_t}, Av(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})dt$, as follows.

$$\begin{aligned} V_i(\boldsymbol{P_t}, \boldsymbol{s}, t) = \min_{\boldsymbol{u}} \Big\{ & TC(\boldsymbol{P_t}, Av(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})dt + Stk(\boldsymbol{P_t}, \boldsymbol{u}, \boldsymbol{s})dt \\ & + e^{-rdt} \sum_j \Pr(i \rightarrow j) \cdot E\left[V_j(\boldsymbol{P_t} + d\boldsymbol{P_t}, \boldsymbol{s} + d\boldsymbol{s}, t + dt)\right] \Big\} \end{aligned} \tag{3}$$

where i, j: state of fuel supply and nuclear, t: time step, $V_i(\boldsymbol{P_t}, \boldsymbol{s}, t)$: discounted total energy system cost, $\boldsymbol{u}$: daily change of fuel stockpiles, $\boldsymbol{s}$: stockpiles of crude oil and LNG, $\boldsymbol{Im}_i$: Import of crude oil and LNG, $Av(\boldsymbol{u}, \boldsymbol{Im_i})$: oil and LNG available in a day, $\boldsymbol{F}$: power generation capacity, dt: differential of time(=1 day), $Stk(\boldsymbol{P_t}, \boldsymbol{u}, \boldsymbol{s})$: daily O&M cost of fuel stockpile, r: discount rate, $\Pr(\cdot)$: State transition probability, $TC(\boldsymbol{P}_t, \boldsymbol{Av}(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})$: daily total system cost.

Through the computational simulation of the above Eq. (3), the optimal operation of crude oil or LNG stockpile can be theoretically identified under the risk of nuclear supply disruption assumed in certain probability $\Pr(\cdot)$ (state transition probability). Thus, the author so far analyzes the short-term impact of nuclear supply disruption on the operation of fuel stockpile, because the energy supply capacity is assumed to be fixed variable. The analysis reveals that the arrangement of adequate scale of energy stockpile such as LNG significantly decreases the expected cost of the country's energy supply against those extreme events. However, this is not the analysis regarding the long-term impact of disruptive events on the desirable pathway of power generation mix. As a future challenge to be considered, the author attempts to conduct the evaluation of the optimal installed capacity of fuel stockpiles and individual power generator in a long-term perspective.

4 Conclusions

The Fukushima nuclear accident has necessitated the fundamental review of Japan's energy supply portfolio and is a turning point for the country to rethink energy, environmental and nuclear policy acclimating to the socio-economic situation after Fukushima. For developing effective long-term energy policy, it is important to have a firm vision optimizing the country's energy mix, considering contingency risk such as nuclear severe accident which has actually and dramatically changed the country's energy balances. This chapter reviews the transition of energy balance in Japan after Fukushima and discusses the potential energy modeling approach to consider nuclear accident by applying stochastic dynamic programming.

To revise appropriately the long-term energy policy, various uncertainties need to be considered, and the discussion over long-term energy planning should be closely rooted in consistent and quantitative analysis based on certain mathematical tool. In this context, the simulation tool such as stochastic dynamic programming is expected to provide insight for developing effective energy policies. Actually, however, constructing the optimal energy portfolio is not merely a discussion about identifying the optimal combination of energy source. For the adequate formulation of energy policy against various risks, comprehensive argument should be conducted in various viewpoints such as sustainable economic growth, energy resource diplomacy and national technical competitiveness.

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