# CHAPTER 12

# Substitute of Nuclear Energy Supply-A Strategic Policy Decision for Asia[1]

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*Asian energy policy makers are now in the cross road of defining the future direction of the region's long term energy scenario which can strike a balance between economic development, energy supply security and climate change mitigation due to the Fukushima nuclear accident in Japan. Though there are certain drawbacks and constraints on mainstream utilization of renewable energy at a large scale, renewable energy seems much clearer for Asian countries, especially for the developing countries considering the risks and damage associated with the nuclear energy. This study demonstrates feasibility of no-nuclear energy supply scenarios as well as potential benefits of renewable energy based future energy supply path from the perspectives of electricity supply cost and total cost of energy supply to the market. This study shows the possibility for Japan, India and China to satisfy future energy demands without nuclear energy. Further, this study demonstrates potential benefits of focusing more on renewable energy development than other fossil fuel based energy resources for having a sustainable, affordable and reliable energy supply in these countries. Renewable energy's expensiveness should not be a constraint for its development and promotion in the regional market.*

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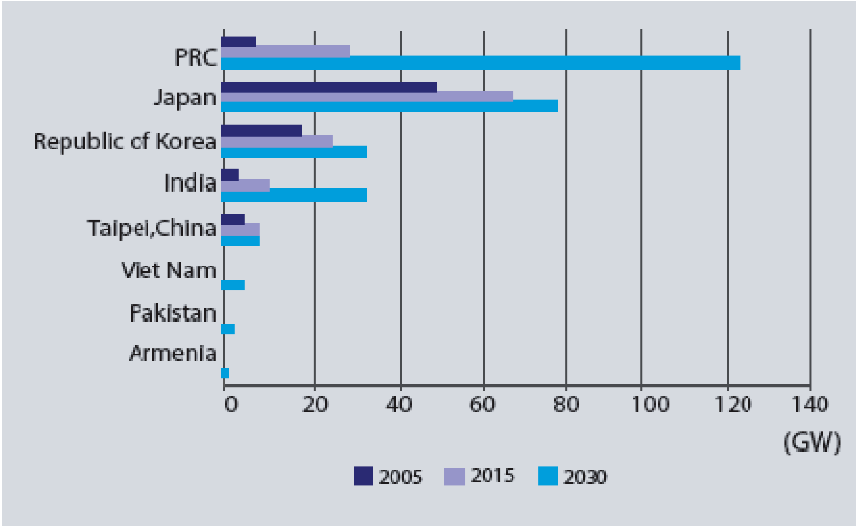
[1] The base model and its Reference case are developed and maintained by KanORS/KanLo. See www.KanORS-EMR.org/DCM/TIAM_World for details. It is also recognized here the valuable contribution of Dr. Amit Kanudia in terms of setting the technical details of the model and its calibration. We are also thankful to our IGES colleagues Dr. Takeshi Kuramochi and Ms. Takako Wakiyama for providing us Japanese renewable energy data and also for providing several technical comments on the findings.

## 1. Background

Asian energy supply is in a critical juncture now in the context of triple goals of the region: economic development, poverty eradication to achieve the millennium development objectives, and environmental protection with reduced emissions. Asia is now the growth hot spot with its expected GDP growth rate at around 6-7% per annum and energy demand growth rate at 4-5% per annum (ADB, 2009). In spite of relatively rich reserves of coal, natural gas and crude oils, the energy system of this region as a whole is dependent on fossil fuel imports from the world market, particularly from politically vulnerable Middle East countries. This situation is undesirable from the energy security perspective. Emissions risk is another concern for Asian countries. Although only the Annex-I countries like Japan under the Kyoto target are currently constrained by GHG emissions internationally, more and more non-Annex-I countries such as China, India and Indonesia start serious consideration in setting emission reduction targets. This emission constraint further casts doubt in sustainability of the current imported fossil fuel dependent energy scenarios in Asia.

Against this background, nuclear energy has been envisaged as an important energy supply source in the region with its multipurpose benefits including lower cost, less pollution and reduced import dependence. As a matter of fact, major Asian countries like Japan, Korea, China, and India have pursued the nuclear energy development programs to increase the share of nuclear power supply in the national energy mix. Japan has already implemented nuclear energy program with certain pioneering technologies while China, India and other countries are in the process of developing the program with various multilateral and bilateral technology transfer processes. As shown in Figure 1, by the year 2030 the total installed capacity of nuclear power generation in these regions is expected to be around 250 GW from 70GW at 2005 level.

**Figure 1. Existing and Planned Nuclear Power Plant Capacity**




*Source:* ADB, APEC 2009

However, the Fukushima Daiichi nuclear accident in March 2011 compelled to critically review this rosy picture of nuclear technology. The most critical lesson from the Fukushima Daiichi accident is the fact that potential scale of damages from nuclear power accidents is essentially unforeseeable and immeasurable. The damages not only cross over the national boundaries but also affect generation together. The German government led by Chancellor Merkel immediately takes this lesson very seriously. Merkel administration convened the Ethics Committee in addition to the existing Nuclear Safety Commission (RSK) for the consultation on the nuclear and future energy issues, and based on the conclusion of the Ethics Committee it was decided to completely phase out nuclear power in Germany by 2021[2] So far, there is not much repercussion after the Fukushima accident among Asian countries (except for Japan) in terms of their nuclear energy program, but the debate has been raised in many cases to reconsider the option with additional dimensions of civilian safety and damage cost liability sharing among the stakeholders. Whatever be the outcome of these debates, the

[2] One of the major recommendation of the Ethics Committee was "Technologies of which risk is immeasurable and uncontrollable are negative assets to the future generations". Source: Ethics Commission for a Safe Energy Supply (2011) "Germany's Energy Transition: A Collective Endeavour for the Future" (http://ecojesuit.com/wp-content/uploads/2011/06/The_Phase_Out_of_Nuclear_Energy_is_Ethically_Demanded.pdf)

policy makers are now facing tremendous challenges to envisage a balanced energy supply outlook for the countries amidst nuclear energy uncertainties and to seriously reconsider future energy scenarios with taking the lessons from Fukushima Daiichi accident.

In this regard it is important that Asia is endowed significant amount of renewable energy resources which are mostly untapped so far due to financial and technological barriers. It has been estimated that the total renewable energy supply potential in major Asian countries is largely many fold of the existing total electrical power generation in the countries as shown in Table 1.

**Table 1. Renewable Energy Generation Potential in Asia**

| Countries | Total RE potential (Gwh) | Actual RE Generation in 2005 (Gwh) | Total Electricity Generation, 2005 (Gwh) |
|---|---|---|---|
| Brunei | 154 | 0 | 2,707 |
| Indonesia | 421,684 | 6,229 | 112,730 |
| Malaysia | 58,094 | 0 | 89,247 |
| Philippines | 327,996 | 12,692 | 63,166 |
| Thailand | 34,312 | 2,018 | 131,839 |
| Viet Nam | 165,946 | 1,232 | 53,798 |
| China | 529,373 | 5,942 | 1,846,836 |
| Japan | 1,132,265 | 15,907 | 1,054,596 |
| Korea | 18,718 | 0 | 368,022 |
| Total | 2,688,541 | 44,020 | 3,722,940 |

*Source:* Romero et.al 2010

## 2. Research Goal and Objectives

Taking the lessons from Fukushima Daiichi nuclear accident seriously, it seems wise to diversify the scope of future alternative energy scenarios including no-nuclear scenarios. This study aims to demonstrate feasibility of no-nuclear energy scenarios in the future as part of such efforts. This study assumes two alternative assumptions about major substitutes of nuclear power, i.e. conventional fossil fuels and renewable energies. As mentioned in the previous section, Asia has so far utilized only a fraction of renewable potential, and huge untapped resources are lying idle in the region. Therefore, our scenario setting also tries to demonstrate that renewable energy is an economically viable solution which can satisfy the dual targets of emissions reduction and energy security via energy import control at a reasonable economic cost.

Towards the above goal, this study estimates the impacts of the two alternative scenarios to phase out nuclear energy supply in Japan, China and India by indigenous renewable energy, by energy efficiency improvement and by rigorous energy conservation along with use of advanced technologies in energy generation and reducing emissions.

The impacts are assessed based on the following indicators associated with the cost of supply, environmental impacts, and energy security implications:

Nationwide CO2 emissions

Total energy system cost

Electricity supply cost in the country

Electricity supply mix

## 3. Methodological Approach

The TIMES Integrated Assessment Model (TIAM-WORLD) is a technology-rich model that integrates the entire energy/emission system of the World, divided in 16 regions, including the extraction, transformation, trade, and consumption of a large number of energy forms. India, along with Japan and China are represented as individual regions in this model. The model contains explicit descriptions of more than 1500 technologies and several hundreds of commodities in each region. TIMES' economic paradigm is the computation of a inter-temporal partial equilibrium on energy and emission markets based on the maximization of total surplus, defined as the sum of suppliers and consumers surpluses. The detailed technological representation of the energy system of TIAM-World allows the computation of energy flows, prices, technology uses, net greenhouse gas emissions and concentrations.

### 3.1. Scenario Assumptions

The TIAM model in the study used the energy service demand projections based on the projections of various demand drivers like GDP, per capita GDP, population, number of households, sectoral growth rate etc. The following Table 2 shows the basic assumptions for various energy demand drivers mentioned above and used in this model[3].

**Table 2. Macroeconomic Drives Used for Service Demand Projection Unit 2050 (CAGR[4])**

| Macroeconomic Drivers (Annual Growth Rate ) | Japan | China | India |
|---|---|---|---|
| GDP | 0.50% | 4% | 4% |
| GDPP (GDP per capita) | 0.68% | 3% | 3% |
| GDPPHOU (GDP per household) | 0.23% | 3% | 3% |
| HOU ( No. of household) | 0.25% | 1% | 1% |
| PAGR (Agr growth rate) | -0.01% | 4% | 4% |
| PCHEM (Chem sector growth rate) | 0.36% | 4% | 4% |
| PISNF (Iron & Steel sector growth rate) | 0.43% | 4% | 4% |
| POP (Population growth rate) | -0.14% | 0.3% | 0.7% |

*Sources:* Authors' estimation based on IMF Projection of World Economic Outlook 2010.

In energy systems analysis, final energy demand variation gets reflected in the system's supply side and vice versa. As a matter of partial equilibrium model, the TIAM model endogenously determines the prices of energy that flows through a particular energy process based on the given costs of that particular energy production, supply and other activities. Thus primary energy prices are important in this model which finally determines the demand and supply equilibrium. The basic assumptions are shows in the figure below:

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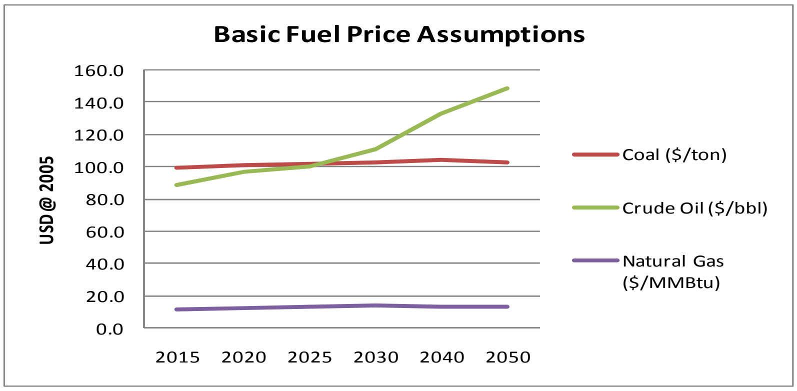
[3] This study assumes pessimistic economic growth of the world viewing the current economic condition and considering the uncertainty of long term high growth prospect especially for China and India.
[4] CAGR is the compounded annual growth rate which is taken over the period of 2005 and 2060.

**Figure 2. Primary Fuel Prices**




*Sources:* Model determined fuel price projection using production data from IEA.

The costs of technologies are also very important for this study as they determine the final technological intervention in the system. The following table shows the reference case cost comparison between different renewables mainly solar and wind. Here the 2050 cost projection is assumed to be affected by the learning a curve experience where the cost decreases by around 3% every next year of the previous year [Ct = Ct-1* 0.97] for Japan. For China and India the costs are reducing at the rate of 2% per annum for solar technologies and 1% for wind technologies.

**Table 3. Reference Case Technology Investment Cost Comparison**

Unit: USD/KW

| RE Technology | JAPAN | | CHINA | | INDIA | |
|---|---|---|---|---|---|---|
| | 2005 | 2050 | 2005 | 2050 | 2005 | 2050 |
| Solar PV_Grid | 6900 | 1750 | 5300 | 1340 | 5300 | 1340 |
| Solar PV_Off-Grid | 8000 | 2000 | 6300 | 1570 | 6300 | 1570 |
| Wind On-shore_Grid | 4000 | 1000 | 1100 | 1000 | 1100 | 1000 |
| Wind Off-shore_Grid | 8000 | 2000 | 2700 | 1700 | 2700 | 1700 |
| Wind On-shore_Off-Grid | 5000 | 1250 | 1300 | 1200 | 1300 | 1200 |

*Source:* Data has been drawn from the TIMES Integrated Assessment Model (Version 4.3.3) base data which are primarily collected from IEA and other external sources including MoEJ for Japan.

### 3.2. Scenarios

Scenarios have been created to follow the research objective of demonstrating the benefits and costs of renewable energy dependent path over the fossil fuel dependent path under the nuclear energy phase out condition by 2050. The fundamental assumption of this study is nuclear phase out by 2050 from all these case study countries.

1. **Reference Energy Scenario (REF)**: This is the business as usual scenario. This scenario assumes continuation of pre disaster energy supply policy. However, this scenario inherently emphasizes nuclear energy supply in the mix. For Japan it is expected to be reaching around 40% of total electricity by 2050 and for India and China, nuclear energy supplies are expected to be reaching around 20-25% of total electricity supply in the market under this reference scenario. This scenario also assumes no fundamental technology changes which can affect the energy systems as a whole.
2. **Fossil Fuel Dependent Scenario (FF Dependent)** : This is fossil fuel dependent scenario with gradual phase out of nuclear energy supply in the total electricity supply mix by 2050. This scenario assumes that Japan, China and India will gradually phase out its nuclear energy supply completely by 2050 with replacement of fossil fuels. The share of nuclear power in total electricity generation is assumed decreasing from 30% in 2009 to 0% in 2050 for Japan and for China and India it is assumed decreasing from their respective current level to 0% by 2050. This scenario also assumes that the renewable energy supply is maximum up to 10% of total electricity supply in the system by 2050. This scenario assumes energy efficiency improvement of between 5-10% and energy conservation of around 15% across the sectors of the economy and energy utilizing activities and processes. Energy efficiency improvement is assumed taking place in the energy conversion processes where primary energy is getting converted to usable energy (oil refinery and power plants) and in all other energy utilizing processes in the system. For the energy conversion processes we have used the maximum limit of 5% improvement which is at the higher side of the world average of 3 to 6% by 2030.
3. **Renewable Energy Dependent Scenario (RE Dependent)**: This is renewable energy dependent scenario with gradual phase out of nuclear energy. This scenario also assumes energy efficiency improvement of between 5-10% and energy conservation of around 15% across the sectors of the economy and energy utilizing activities and processes. In addition to the assumption of gradual phase out of nuclear energy in the Fossil Fuel Scenario, this scenario assumes to have certain

market policies in place like FIT and/or mandatory minimum RE supply to achieve target level of minimum renewable energy share of 40% (15% from wind and 25% from solar) by 2050 with gradual escalation. The following table (Table 5) shows the assumption of solar and wind energy penetration ratio in the total electricity supply mix until 2050. As different countries have different levels of renewable energy potential and capacities to produce electricity and also different levels of total electricity demands, we used the percentage reduction target rather than absolute target. This approach helps us to avoid the computation problem of magnitude difference for same variables in different countries.

**Table 4. Solar and Wind Energy Penetration Ratios**

| Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Wind ( on-shore & off-shore ) | 5% | 10% | 12% | 15% |
| Solar (PV/CSP) | 10% | 15% | 20% | 25% |

Geothermal energy is assumed to be restricted in all cases of electricity supply especially in Japan (maximum up to 10% by 2050) based on the assumption of continuation of the current regulatory restrictions which hinder its development in Japan. Moreover, biofuel utilization (biodiesel and bio-ethanol) in the transport sector is also assumed maximum of 5% by 2050 in all cases. This assumption is based on the understanding of the global decline in biofuel production and its availability in the international market for trade.

### 3.3. Simulation Setting

We compare two nuclear phase-out scenarios (REN and SFF-LR) under the same amount of emission reduction. First we estimated the amount of emission reduction under REN scenario, and use this amount as the benchmark emission reduction level. Table 5 below shows the benchmarking emissions reduction compared to the reference case for each country and for each milestone year.

Then this benchmark emission reduction level is given to the model as constraint for the fossil fuel dependent scenario.

**Table 5. Benchmarking $CO_2$ Emissions Reduction for Each Country**

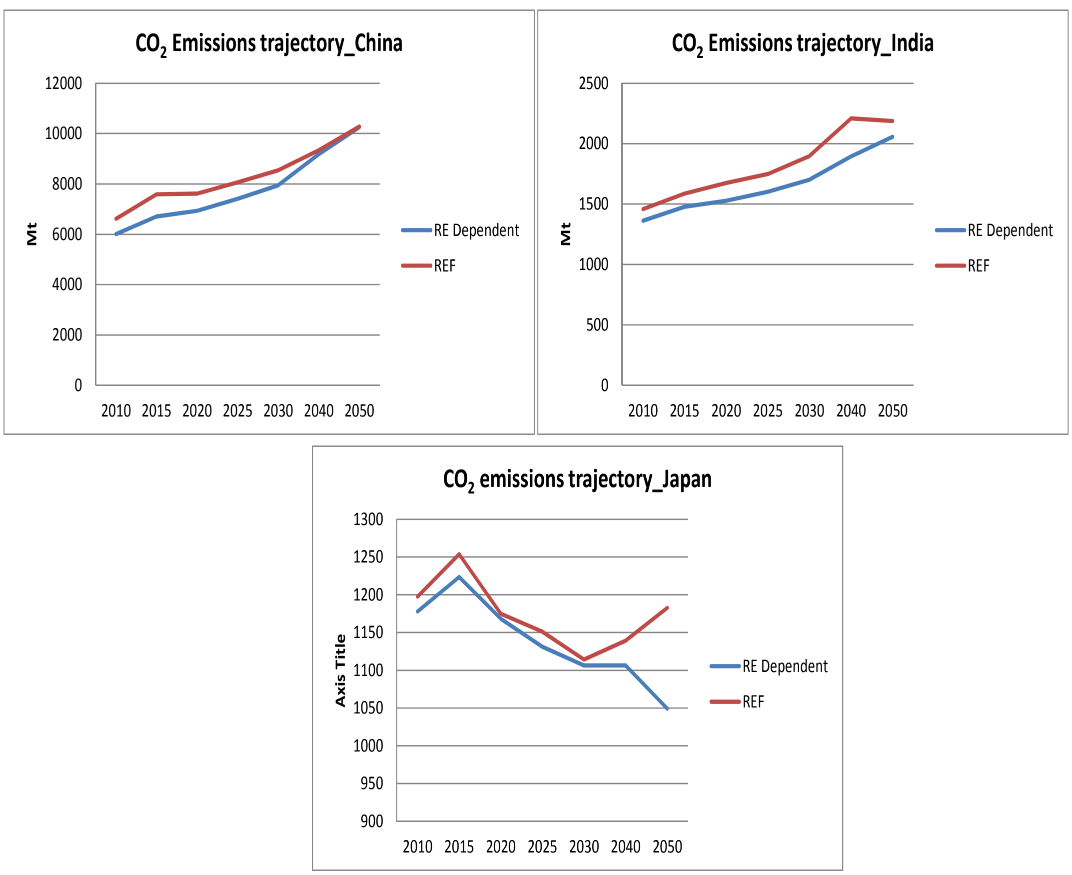
| Country | 2020 | 2030 | 2050 |
|---|---|---|---|
| China | -9% | -7% | -0.4% |
| India | -9% | -10% | -6% |
| Japan | -1% | -1% | -11% |

## 4. Results and Discussion

### 4.1. CO2 Emissions Pathway for Renewable Energy Dependent Scenario

Figure 3 below shows the total CO2 emissions trajectory for Japan, China and India under the reference and renewable energy dependent scenarios.

**Figure 3. Cumulative $CO_2$ Emissions Trajectory for Japan, China and India**



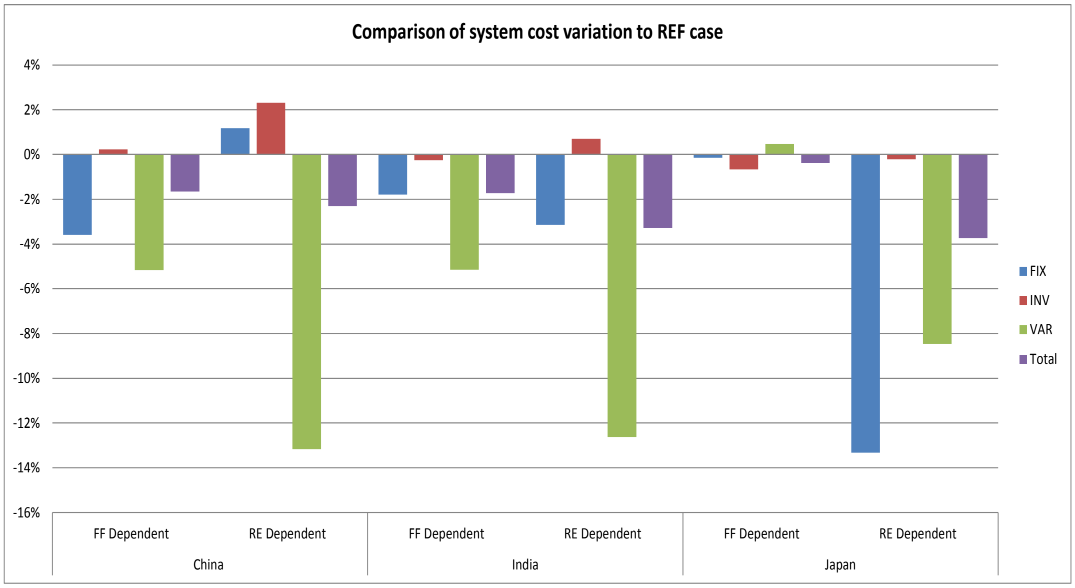
The renewable energy dependent path can contribute to the maximum of 11% total national CO2 emissions reduction from the electricity sector compared to the reference case by the year 2050 and by 17% compared to the base year 2005 in Japan. For China and India, CO2 emissions are increasing at a rapid rate until 2050 under the reference case scenario. By 2050 the CO2 emissions could be doubled in China (102% increase) and around 1.7 times for India (76% increase). Nevertheless, renewable energy dependent path can restrain this massive growth in emissions to some extent. In this study, CO2 emissions reduction is benchmarked for the fossil fuel dependent scenario for level playing comparison of the two scenarios under the condition of no-nuclear supply by 2050.

### 4.2. Impact on total system costs

The system cost is the net present value of the total annualized cost of energy supply and consumption in the system discounted at 5% rate over the period of time between 2005 and 2050. The total cost includes fixed cost, new investment costs and variable costs. The fixed cost is the overhead expenditures of the energy production units like power plants which mainly cover all sorts of rents, wages and salaries and interest payments for debts. Investment cost is for new construction of energy extraction, production and consumption facilities which is the major cost to the system. The variable costs include the fuel costs along with operation and maintenance costs which are linked to the level of production of each unit of energy.

The total system cost impact comparison demonstrates that renewable energy dependent path is in general economically better off for all the countries like Japan, China and India compared to the fossil fuel dependent path (See Figure 4) under the condition of certain level of CO2 emissions reduction. As a consequence, the countries can ripe the benefit of reduced energy use and its corresponding effect on import reduction. Being the net energy importers, Japan, China and India can get the benefits of such energy import reduction. This result further corroborates the importance of renewable energy for the long term sustainable energy planning for Asia.

**Figure 4. System Cost Variation to REF Case Under Different Scenarios**




### 4.3. Impact on Electricity Price

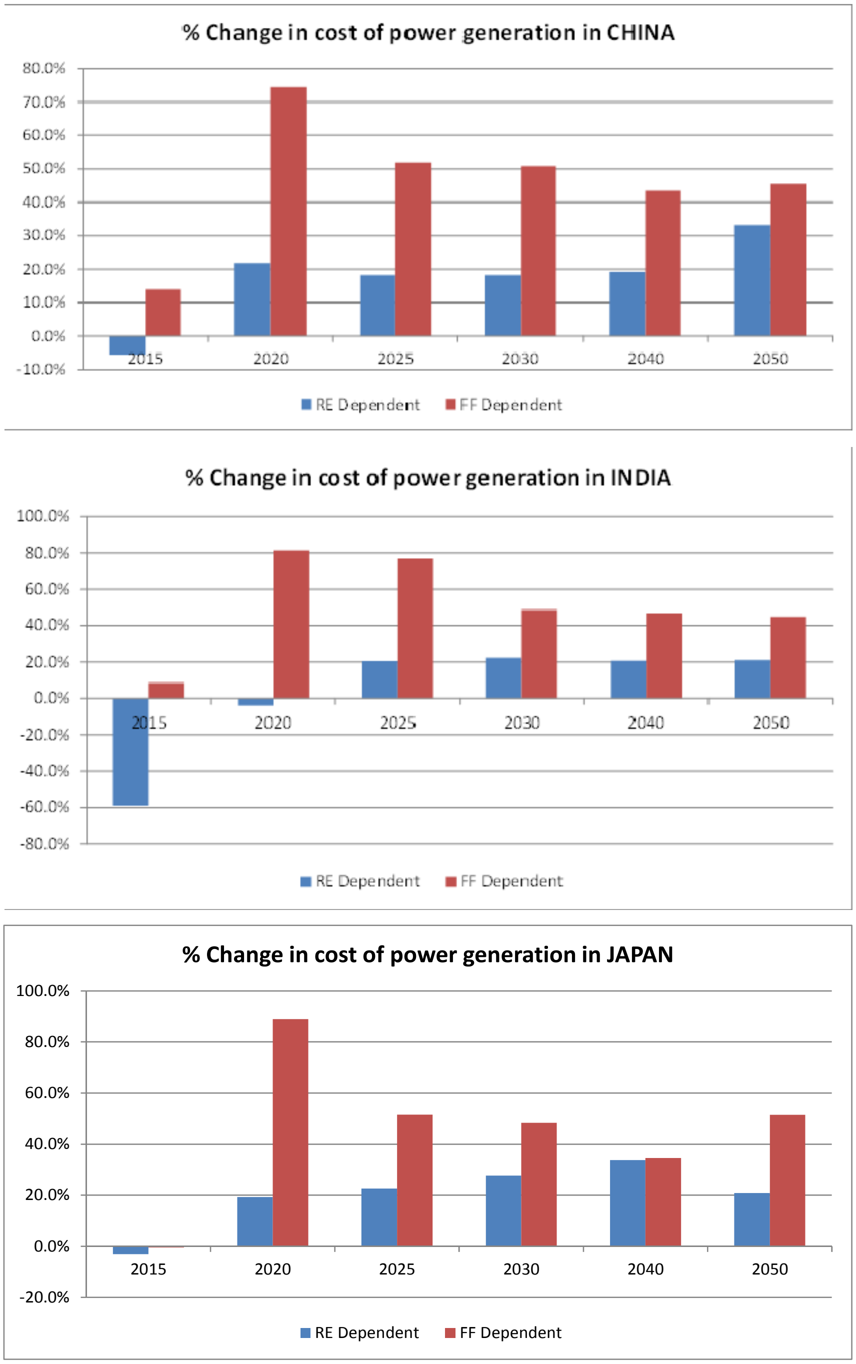
For investigating the consumer prices of electricity, we estimate the variation in cost of production of electricity in the power plants. This cost is the marginal cost of per unit of electricity generation. For the sake of simple understanding we took the mean of these marginal prices for all six different time slices[5] of the year. Figure 5 shows changes in electricity generation cost under different scenarios in each country.

The results show that under both nuclear phase-out scenarios, electricity price is expected to be higher than the reference case but the price differences are gradually reducing towards the end of the simulation time. This decline is observed mainly due to the reduced investment costs and other overhead cost reduction happening due to full depreciation of the power plants capital investment costs, full paid up of debts and liabilities etc. Nevertheless, 2020 to 2030 is expected to be the costliest time period for the consumers in terms of electricity price escalation. The results also show that fossil

[5] Time slices are lined to the seasonal electricity load patterns in Japan and divided into six categories like summer day, summer night, winter day, winter night etc. The marginal cost of generation of electricity in a perfect competitive market condition varies between each time slice due to different supply mix shows the mean of all the marginal costs over a year to demonstrate the trend of overall cost variation of the electricity generation.

fuel dependent path generates electricity at the higher cost compared to the renewable energy dependent path.

**Figure 5. Changes in Electricity Generation Cost Under Different Scenarios**



### 4.4. Impact on Electricity Supply Mix

Figure 6(a) and 6(b) show the electricity supply portfolio in the countries until 2050 under the reference case and under two dependency path scenarios. These supply mixes are endogenously determined under the given constraints of no nuclear supply, energy efficiency improvement and conservation of certain level, minimum renewable energy supply etc. These supply mixes indicate how the RE and FF dependent paths under certain CO2 emissions reduction constraint can influence countries' long terms energy scenarios compared to the reference case.

This result indicates that in the fossil fuel scenario, coal will be the single largest fuel sources for power generation in China and India while for Japan, coal and natural gas together are the major sources of power generation.

**Figure 6(a). Reference Case Electricity Supply Mix for The Countries**

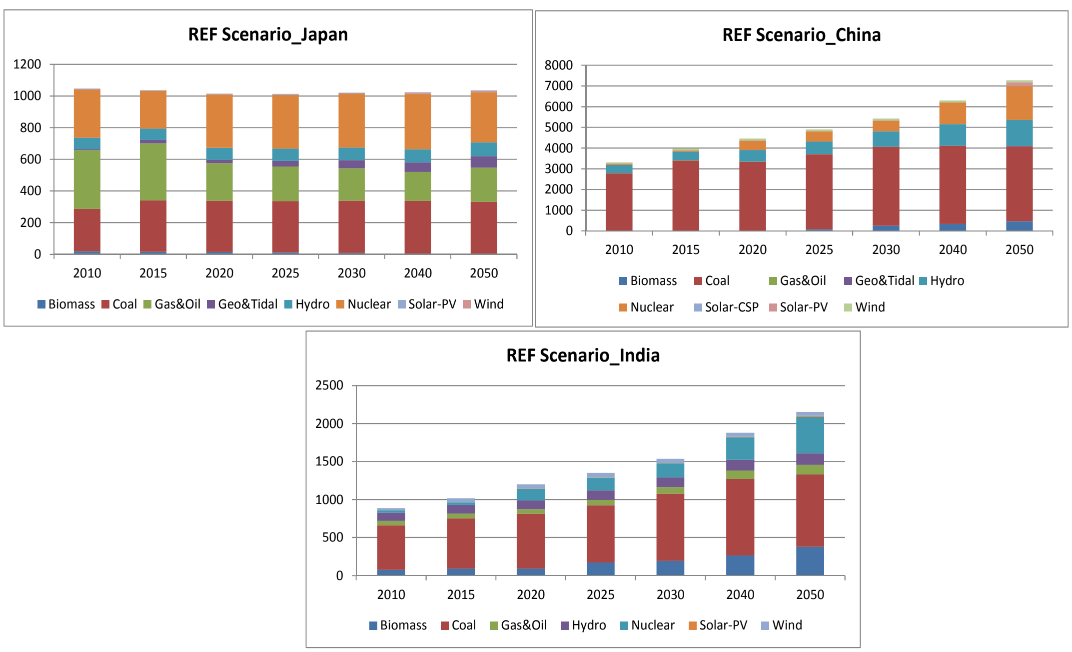
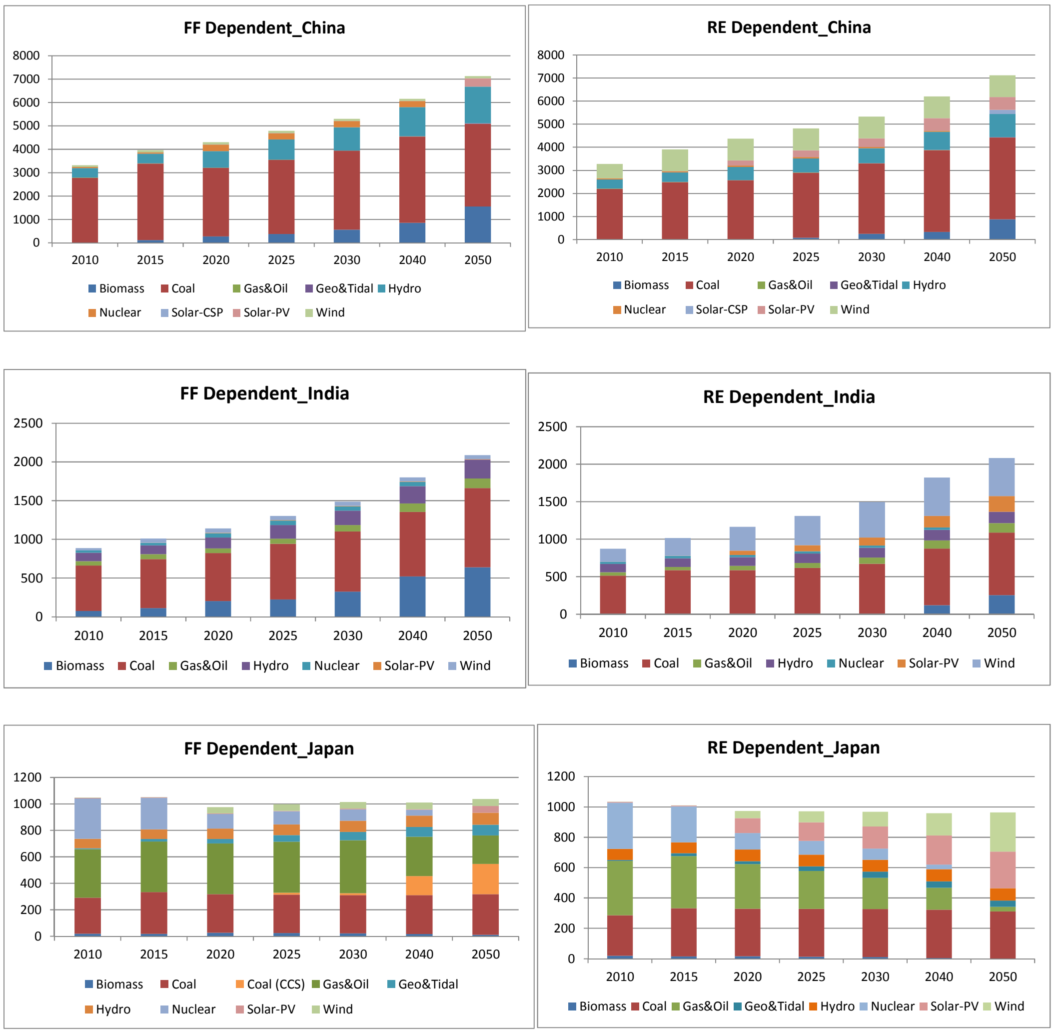


**Figure 6(b). Electricity Supply Mix for The Countries Under Different Scenarios**




Under the fossil fuel dependent path, CCS technology is required to achieve the same level of emissions reduction as the renewable energy dependent path. It is observed that this advanced technology is becoming an option after 2030 and rapidly increasing in the share. This further indicates that Japan has to make trade-off between the advance technologies like CCS which are yet to be commercially available and solar and wind technologies which are already commercially available. In Japan, the fossil fuel dependent path may lead the country more towards investment uncertainties with newer technologies.

In China, solar CSP technology is expected to be coming up in the market during the later stage of the time horizon when other technologies are utilized fully. Another important aspect of nuclear phase-out scenario for China and India is lesser utilization of hydro power in the supply mix for the renewable energy scenario compared to the fossil fuel dependent scenario. Similarly biomass based energy generation is reduced under renewable energy dependent compared to the fossil fuel dependent path in China and India both.

## 5. Discussions

Compared to the renewable energy dependent path, the fossil fuel dependent path appears costly in the long run in Japan, China and India when given the same level of emissions reduction. Benefits of renewable energy are multifarious and observed in terms of total system cost and electricity generation cost.

In Japan, the renewable energy dependent path could be even clearer provided the indigenous geothermal potential is allowed to be harnessed significantly. So far its utilization is restricted under the legal protection of forest conservation. But given the nature of geothermal energy which is primarily suitable for base load power supply, Japan may need to consider appropriate utilization of this resource especially under the nuclear phase out planning. Geothermal energy can partly address the technical problem of intermittency of renewable energy and grid instability indeed.

Electricity price is expected to increase under both the nuclear phase-out scenarios in all three countries, but the renewable energy dependent path will have lesser increase than the fossil fuel dependent path. This also indicates reduction of imported energy use (variable cost) in the renewable energy dependent path. The myth of renewable energy utilization i.e. higher cost implication to the consumers seems doubtful. It may be relevant to raise priority of renewable energy with other objectives like better environment, risk free energy supply and sustainable future of the country.

Coal is expected to be dominating the supply under nuclear phase-out scenarios at least until 2050 in the three countries. There is a trade-off observed here between the advanced technology like CCS and renewable energy in Japan. The risk of investment can play a crucial role in this context. Investment risk in CCS needs to be evaluated against risks in renewable technologies like solar and wind under long term nuclear phase-out energy scenario analysis.

## 6. Recommendations and Way Forward

Based on the above findings, this study recommends that Asia needs to focus more towards its indigenous energy resources like renewable energy rather than looking for something which is not of its own like nuclear energy and or fossil fuel based technologies, to have sustainable future with reasonable economic development which can support basic human needs for all. It is recommended to develop and promote indigenous renewable energy resources for the developing countries in Asia to the maximum possible level with all technical and financial support from developed countries like Japan. Nuclear energy may be expected to solve the problem of higher cost of energy, environmental pollution and maintaining certain economic growth rate assuming no accidental threat, but it will ultimately make the region dependent on other countries for nuclear fuel supply, technology support, maintenance of power plants, and even for decommission of power plants. This is political problem to be seriously considered, in addition to the nature of risks associated with nuclear technology revealed by the Fukushima nuclear plant accident.

To significantly increase the share of renewable energy in energy mix, there are technical challenges to ensure grid supply stability. This issue cannot be covered by the employed methodology of this study. Additional work and more advanced modeling technique need to be used to address this issue. Furthermore, the model does not pose much importance on the demand sector of energy in this study, which is an important component of the energy system analysis and assumed a general range of demand elasticity to its own price between 10 to 20% across the demand sectors. Sector specific demand elasticities are more appropriate in this case. In addition to that, the study also lacks in sensitivity analysis of price changes of various primary energies which could be of further interest of the readers.

## References


ADB/APEC. 2009. *Energy Outlook for Asia and the Pacific* 2009. Manila: Asian Development Bank.

IEA, 2010. *World Energy Outlook 2010*, Paris, France: International Energy Agency.

IMF.2010. *World Economic Outlook 2010*. Washington DC. International Monitory Fund.

Loulou, R., 2007. ETSAP-TIAM: the TIMES integrated assessment model. part II: mathematical formulation. *Computational Management Science*, 5(1-2), pp.41-66. Available at: http://www.springerlink.com/index/10.1007/s10287-007-0045-0.

Loulou, R. & Labriet, M., 2007. ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. *Computational Management Science*, 5(1-2), pp.7-40. Available at: http://www.springerlink.com/index/10.1007/s10287-007-0046-z.

MIT Energy Club, 2011. *Units & Conversions Fact Sheet*, Cambridge, MA, USA. Available at: http://web.mit.edu/mit_energy.

MoE, Japan. 2011. *Study of Potential for the Introduction of Renewable Energy (FY2010*). Climate Change Policy Division. Ministry of Environment Japan. Tokyo.

Romero, J. Elder, M. and Bhattacharya, A. 2010. *Strengthening ASEAN+3 Renewable Energy Strategies.* International Energy Journal (11). p. 173-180.