www.serd.ait.ac.th/reric

Security of Supply Concerns and Environmental Impacts of Electricity Capacity Expansion in Thailand

Thanawat Nakawiro* [1] and Subhes C. Bhattacharyya*

Abstract – *To meet its growing electricity demand Thailand needs an extensive expansion of its electricity capacity in the foreseeable future. The country faces twin challenges in this respect: a) Continued dependence on gas for power generation adversely affects the security of electricity supply by deteriorating fuel diversity and raising vulnerability to the Thai economy; and b) A diversification to other fossil fuels could in turn impose additional environmental degradation. Therefore, the objective of this paper is to explore an acceptable solution balancing these two concerns. The paper employs the electricity capacity expansion planning approach and simulates alternative capacity expansion paths for Thailand between 2011 and 2025. The analysis contains four scenarios, each of which is also subjected to two fuel price assumptions. It was found from the simulation results that natural gas is likely to remain the major fuel for electricity generation during the planning horizon and consequently the impact from gas dependence to security of supply will continue in the near future. An addition of new coal-fired power plants could improve security of supply but its environmental impact remains a crucial concern. Nuclear power could offer the least cost solution for electricity generation while appreciably reducing environmental emissions but a large scale penetration of this technology within the planning horizon is unlikely.*

Keywords – Electricity capacity expansion, Thailand, natural gas dependence, vulnerability.

1. INTRODUCTION

Nowadays, electricity capacity expansion becomes more complicated due to numerous uncertainties in prices and costs of utility business, particularly when the current trend of globally volatile fuel cost raises risks associated with investments and operations of electric utility significantly [1]. Meanwhile, the security of electricity supply has emerged as another important concern for capacity expansion.

In Thailand, natural gas has been the main fuel for power generation for decades and in 2004, 74% of gas supply in the country was consumed for power generation and 70% of electricity came from gas based technologies [2]. However, a high share of gas in power generation could affect the security of electricity supply in terms of fuel diversification [3]-[5] and recently there is evidence that the Thai economy has been vulnerable from high gas dependence in power generation [6]. Continued reliance on natural gas could therefore deteriorate the security of supply. Similarly, diversification to coal is only possible with imported coal as the low-grade lignite deposits of the country may not allow much further capacity expansion and strong public opposition remains an influential hurdle for the prospect of new coal-fired power plant. Concurrently, the similar barrier could adversely affect potential of nuclear power generation in Thailand, as well.

In addition, environmental impacts of electricity generation become another crucial issue of electricity planning, particularly in the light of global warming concern. This has required electric utilities to enhance power generation from cleaner technologies. Although high share of natural gas makes the Thai electricity sector to be comparatively clean, maintaining such an environmental friendliness in the future could be difficult as the gas resources of the country are limited. Thus, the concerns for security of supply can be in conflict with that of the environment protection.

The objective of this paper is to assess security of electricity supply and the environmental concerns for future electricity capacity expansion of Thailand. Thus, fuel diversity in electricity generation is examined. In addition, four scenarios of electricity capacity expansion in Thailand, namely the base case, the Integrated Gasification Combined Cycle (IGCC) case, the nuclear case, and the no new coal or nuclear alternative case, are performed. In addition, these four scenarios are analysed under two different assumptions of fuel prices, namely baseline and high fuel prices, where the latter investigates the effect of continued high fuel prices for power generation in Thailand due to high oil prices in the international markets.

The organisation of this paper is as follows. After this introductory section, the analytical framework is presented in Section 2, followed by the presentation of simulation results in Section 3. Alternative scenarios are then compared in Section 4. Finally, concluding remarks are presented in section 5.

2. ANALYTICAL FRAMEWORK

Essentially, this section provides background information on impact of electricity capacity expansion to security of electricity supply in Thailand, namely analysis on fuel diversity in electricity generation and analytical framework for simulation of electricity capacity planning.

*****Centre for Energy Petroleum and Mineral Law and Policy (CEPMLP), University of Dundee, DD1 4HN, Scotland, UK.

[1]Corresponding author;
Tel: + 44 79 20763949, Fax: + 44 1382 385584.
E-mail: t.nakawiro@dundee.ac.uk; nakawiro@yahoo.com.

a. Fuel Diversity in Electricity Generation

The generic idea of fuel diversity, although being interpreted into various dimension depending upon area of study [7] [8], relates to balancing a variety of dissimilar things [9]. Meanwhile, diversity concept could also be captured through the proverb “don’t put all your eggs in one basket” [10]. In general, a highly diverse system is likely to respond external changes robustly. In energy supply, high diversity could help mitigate adverse consequences from several external changes, such as unstable supply in global energy market, change in environmental constraint, price volatility or supply shortage of a particular fuel source [9]. Therefore, fuel diversity in electricity supply would enhance the robustness of electricity generating system to shortage as well as price spike of a single fuel or generation technology, and accordingly, fuel diversity has been considered as one of the crucial concerns in electricity supply planning [11].

To measure fuel diversity in electricity generation in Thailand, Shannon-Weiner Index (SWI) [10] is calculated according to Equation 1.

$$\sum_{i=1}^{I} - p_i \ln\left(p_i\right) \qquad (1)$$

where p_i is the proportion of generation represented by type of i^{th} type of fuel. Based on fuel mix of four scenarios, Shannon-Weiner index is calculated to measure fuel diversity.

The SWI of the Thai system is presented in Figure 1. This figure shows that SWI is decreasing whenever gas share to fuel mix increases. This can be observed from between 1986 and 1988, when SWI decreased from 1.30 to 1.13 as gas share to fuel mix increased from 40% to 57%. Between 1989 and 1995, SWI was improved significantly as shares of other fuels to fuel mix increased. The SWI between 1996 and 2000 decreased drastically from 1.40 to 1.04 due to a rising share of natural gas to fuel mix. Therefore, electricity supply in Thailand between 2001 and 2006 was likely to be concentrated as SWI fell below 1.0, due to a considerable increase in natural gas share to fuel mix in power generation. However, SWI between 2004 and 2007 was recovered as gas share to fuel mix was decreasing due to a constraint in gas pipeline capacity.

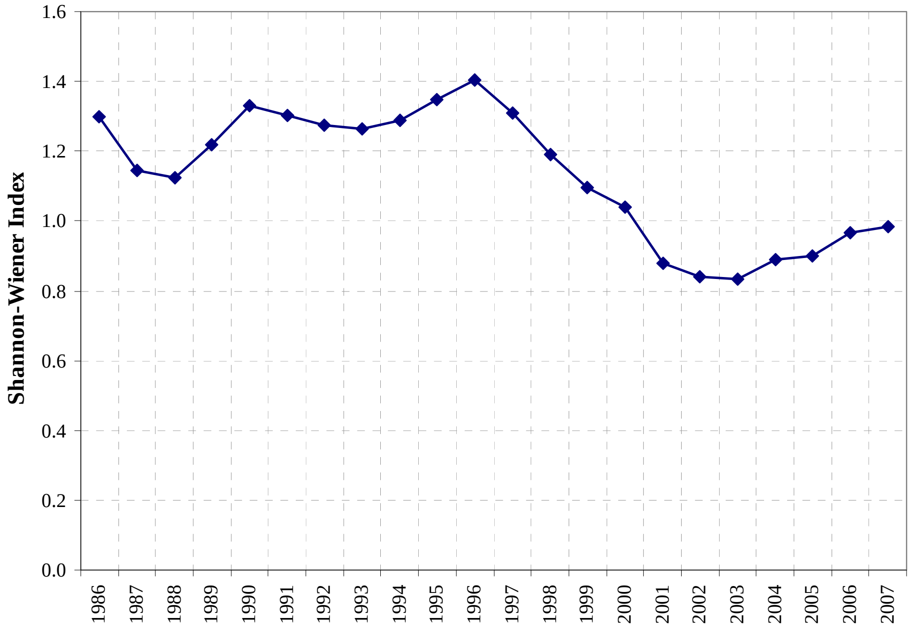

Fig. 1 SWI for fuel diversity in power generation in Thailand, 1986 – 2007.

b. Electricity Capacity Expansion Planning

Principle

In this research, the analysis on electricity capacity expansion planning follows a traditional supply-oriented method only. The basic objective of this planning is to determine the optimal mix of generation technologies that meets anticipated electricity demand while fulfilling all specified constraints [12].

Analytical Tool

The Wien Automatic System Planning version IV (WASP-IV) package is used in this study. The evaluation in this programme is to minimise the discounted costs of electricity generation, which fundamentally comprise capital investment, fuel cost, operation and maintenance cost, and cost of energy-not-served (ENS), which is defined as “the expected amount of energy not supplied per year owing to deficiencies in generating capacities and/or shortage in energy supplies” [13].

Assumptions and Data

1. Planning horizon

The planning horizon is the period between 2011 and 2025. The electricity capacity expansion planning up to 2010 is excluded from the study as all candidate plants for that period have already been committed in the 2007 Power Development Plan (PDP) [14].

2. Electricity demand forecast

The demand forecast carried out by the Thailand Load Forecast Subcommittee (TLFS) [15] was retained for the period up to 2021. Meanwhile, the demand from 2022 to 2025 is assumed to continue increasing at the growth rate and load pattern, represented by Load Factor (LF), as those of 2021. During the planning horizon, electricity demand in Thailand is expected to grow on average 5.62% per year.

3. System requirement

To ensure reliable electricity supply in the future, it is assumed, based on standard practice [16], that at least 15% of reserve margin is always kept and the loss of load probability (LOLP) is less than 1 day per year.

4. Candidate power plants

Each simulation considers three different types of conventional fossil-based technologies, namely gas combined cycle power plant, coal-fired thermal power plant, and open cycle gas turbine using diesel oil. In addition, conventional coal-fired candidate power plant is replaced by Integrated Gasification Combined Cycle (IGCC) candidate power plant in the IGCC case. Nuclear candidate power plant is also added into the simulation of nuclear case but it is assumed that the first nuclear candidate power plant will be available from 2020 due to six years lead time required for power plant construction and additional seven years required for promoting public acceptance as well as preparing legislations to support nuclear power project in Thailand [12]. Table 1 summarises the main characteristics of these candidate power plants [14].

5. Fuel price

Two different sets of fuel price assumption, namely baseline and high fuel prices, are considered in the simulation of each scenario. The assumption of baseline fuel prices follows that of the PDP 2007 [17], which is based on a price of crude oil at 55 USD/barrel and currency exchange rate at 38 Baht/USD.

To reflect high oil price situation affecting prices of gas and oil supplies for power sector in Thailand, the price of crude oil in the high fuel price scenarios is assumed to increase from 55 USD/barrel in the baseline to 73 USD/ barrel. The adjustment of this crude oil price is in line with the high price cases as used in the studies carried out by the U.S. Department of Energy (DOE) [18].

As the domestic gas price in Thailand is linked to fuel oil price in the international market, the fuel oil price in international markets is calculated for oil prices corresponding to $73 per barrel. Similarly, the prices of fuel oil and diesel supplies for power generation in Thailand are re-calculated to reflect the new assumption of high crude oil price as well. Table 2 summarises baseline and high fuel price assumption, respectively.

Table 1. Characteristics of candidate power plants.

	Combined Cycle (CC)	Thermal (TH)	Gas Turbine (GT)	Integrated Gasification Combined Cycle (IGCC)	Nuclear (NUC)
Fuel	Natural Gas	Imported Coal	Diesel Oil	Imported Coal	Imported Uranium
Capacity (MW)	700	700	220	500	1,000
Heat rate (BTU/kWh)	7,000	9,260	10,995	7,346	9,208
Force Outage Rate	6%	7%	10%	6%	10%
Maintenance (days/year)	28	42	14	28	42
FOM ($/kW-month)	1.49	2.12	0.87	1.27	2.5
VOM ($/MWh)	0.6	1.04	0.4	0.73	0.5
Capital Cost ($/kW)	545.6	941.9	377.3	1,420	1,020
1^{st} candidate to be available from	2011	2013	2011	2013	2020

Table 2. Assumption of fuel prices.

Fuel Type	Baseline Price, (USD/M.BTU)	High Price, (USD/M.BTU)
Natural Gas		
- Domestic	6.63	8.30
- Import	6.63	8.30
Lignite	1.55	1.55
Imported Coal	2.41	2.41
Fuel Oil	8.82	11.73
Diesel Oil	16.63	22.01
Nuclear	0.74	0.74

6. Gas limit

Given that Thailand has limited indigenous gas reserves [19], limited gas supply is expected to affect electricity capacity expansion plan in long-term. In the simulation, gas limit is not directly taken into account. However, if the results show that the gas demand from the power sector exceeds 2,800 standard million cubic feet per day (MMSCFD), which is the expected gas supply availability for power generation during the planning horizon [20], [21], gas import is considered.

7. Restricted number of coal-fired candidate plants

In PDP 2007, the least cost scenario of electric capacity planning is obtained from additional 30x700 MW coal-fired power plants [17]. However, in PDP2007 this number was restricted to 4x700 MW based on the potential of adding new coal fired power plants at EGAT' s existing sites only.

In this study, the above constraint is relaxed to 14x700 MW coal plants. Although a strong public opposition to coal-fired power projects remains an influential hurdle for electric capacity expansion in Thailand, according to EGAT' s feasibility study on the capacity of transmission network [17], there are six more potential locations that can accommodate additional electricity capacities. Three of them are close to shorelines and these locations may have the potentials to support 10x700 MW of new power projects based on imported coal.

3. RESULTS

a. The Base Case

Objective

The objective of the base case is to reflect an electricity capacity expansion following the current trend of electricity planning in Thailand where generating system mainly relies on fossil fuels. Therefore, three candidate power plants, namely gas-fired combined cycle, coal-fired thermal and diesel-based gas turbine power plants, are included.

Configuration

The simulation results suggest that by 2025, Thailand would require 45,220 MW of additional electric capacities if fuel prices follow their baseline assumptions. The optimal mix of these new capacities comprises 44x700 MW of gas combined cycle, 14x700 MW of coal-fired thermal and 21x220 MW of diesel-based gas turbine power plants.

In the high fuel price case, the addition capacity requirement changes slightly to 45,180 MW comprising of 43x700 MW of gas-fired combine cycle, 14x700 MW of coal-fired thermal, and 22x220 MW of diesel-based gas turbine power plants. Even though diesel price remains relatively more expensive than that of natural gas, the number of additional gas turbines running based on diesel oil is slightly increase in the high fuel price case as the size of each gas turbine is significantly smaller than that of gas-fired combined cycle. Therefore, WASP suggests replacing gas-fired combined cycle power plant by a diesel-based gas turbine to serve peak load power generation so that the total cost of electricity generation can be minimised in the high fuel price case.

Energy Mix

Based on the configurations of these new capacities, energy mix of expansion plan is then calculated and the results are presented in Figures 2 and 3 for baseline and high fuel prices, respectively.

From Figures 2 and 3, natural gas will remain the main fuel for power generation in Thailand in the foreseeable future. More than 50 percent of electricity generated in each year will come from gas-based technologies. High price situation does not significantly alter electricity generation plan as the demand-side feedback is not included and the restriction of coal effectively limits coal-based electricity generation.

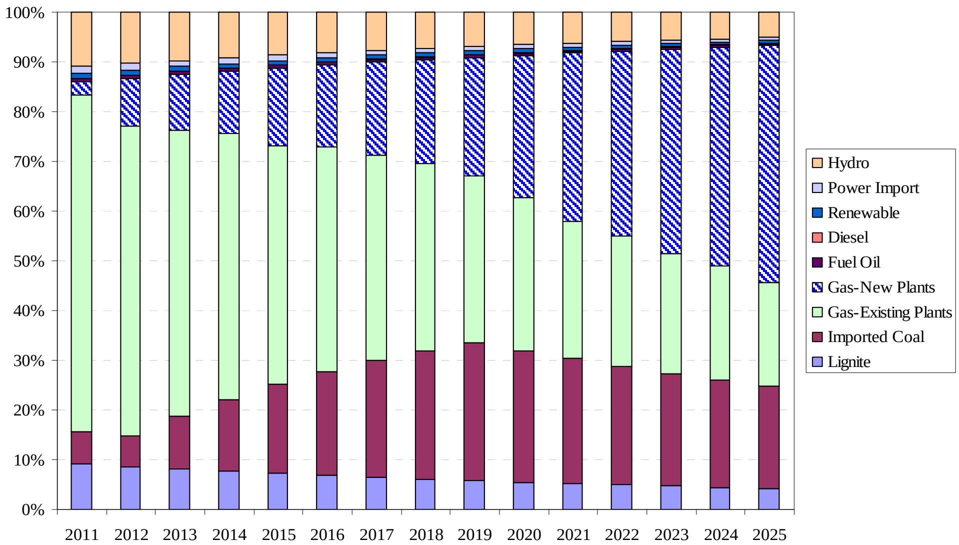

Fig. 2. Energy mix of the base case with baseline fuel prices.

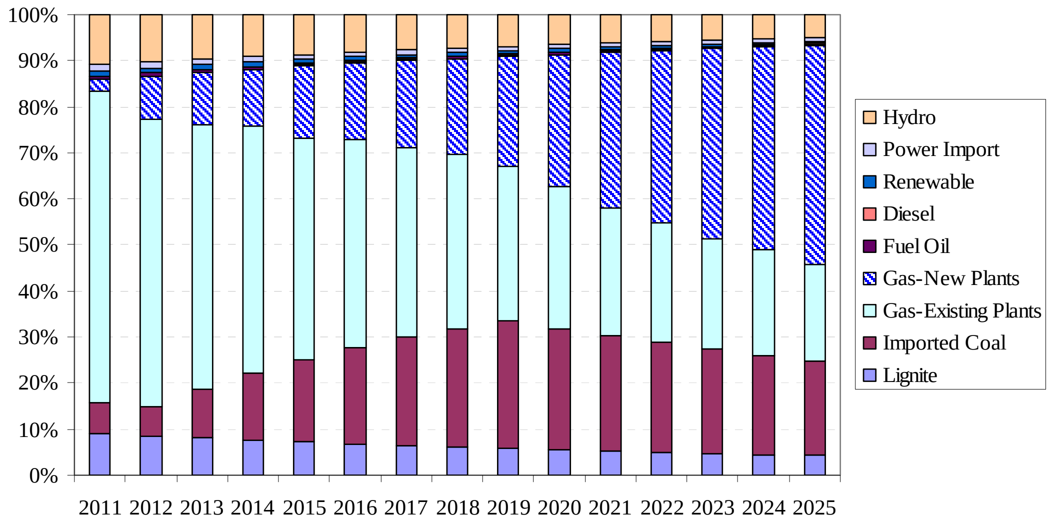

Fig. 3. Energy mix of the base case with high fuel prices.

b. The IGCC Case

Objective

The environmental emission is a major concern of conventional coal-fired power plants [22] but clean coal technologies are available to reduce these environmental consequences [23]. Therefore, Integrated Gasification Combined Cycle (IGCC) is considered in this simulation case.

Configuration

The results indicate that under baseline fuel price, the optimal configuration of new capacities in 2025 will be 44,740 MW, comprising 47x700 MW of gas-fired combined cycle, 14x500 MW of IGCC, and 22x220 MW of diesel-based gas turbine power plants. Meanwhile, this configuration does not change in case of high fuel prices.

Energy Mix

Figures 4 and 5 present energy mix of electric generating system according to baseline and high fuel price assumptions, respectively.

The energy mixes in Figures 4 and 5 show that natural gas remains the main source of electricity generation in Thailand during the planning horizon as it accounts for more than 60 percent of electricity generation in each year. Compared to the base case, the share of natural gas to energy mix of the IGCC case is slightly higher as the size of IGCC candidate plant is 200 MW less than that of conventional coal-fired candidate plant in the base case. Therefore, the IGCC case requires a larger number of gas candidate plants to fulfill this capacity difference.

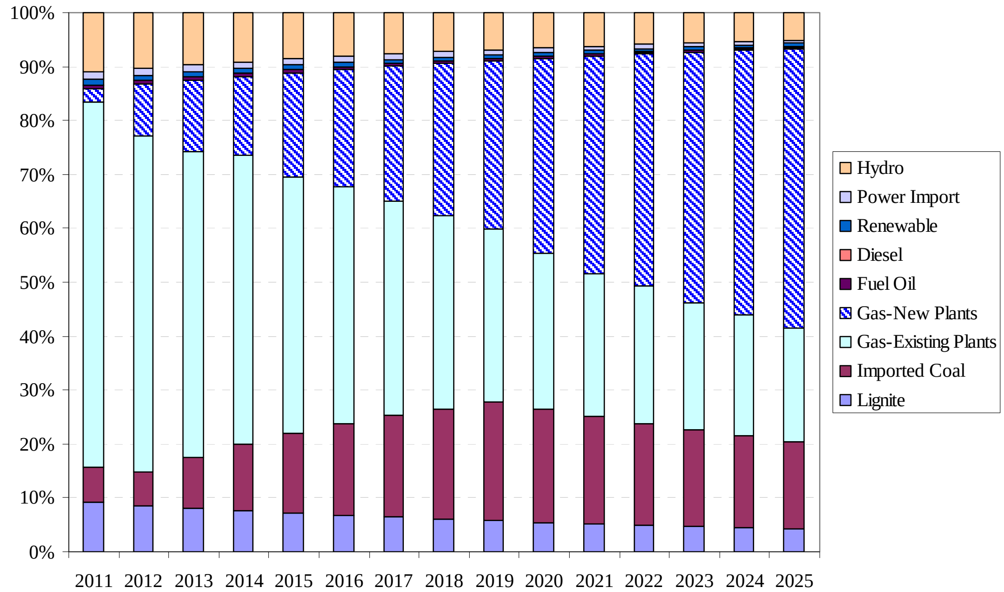

Fig. 4 Energy mix of the IGCC case with baseline fuel prices.

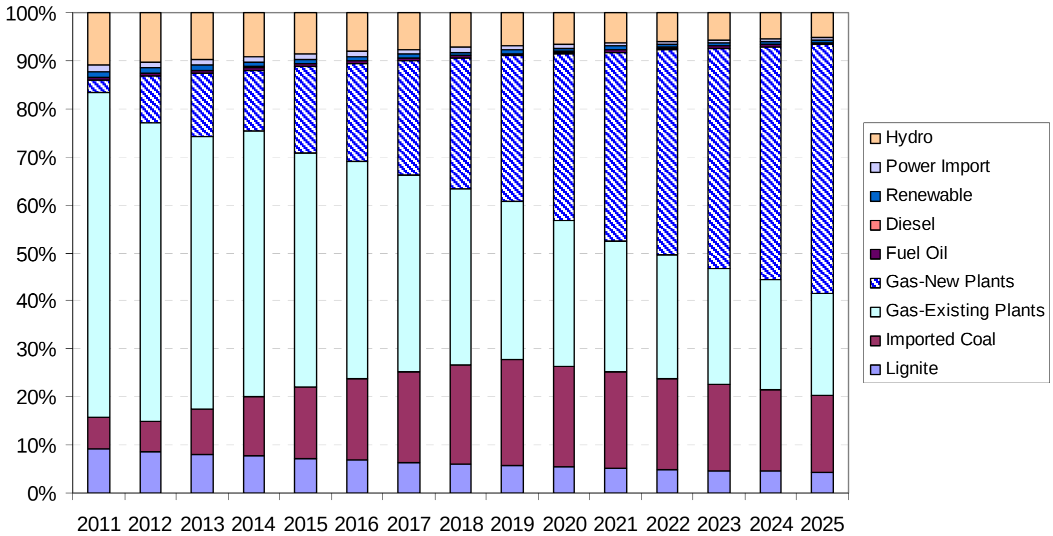

Fig. 5 Energy mix of the IGCC case with high fuel prices.

c. The Nuclear Case

Objective

Nuclear candidate power plant is added to the least cost electricity expansion plan in the nuclear case as it is expected to reduce high reliance on fossil fuels, especially when fuel prices continue to rise [24]. The addition of nuclear power plants is thus likely to enhance security of electricity supply in Thailand. Meanwhile, nuclear power plant is also recognised as one of the potential alternatives to reduce carbon emission from electricity generation [25], [26].

Configuration

The results show that in either case of baseline or high fuel prices, Thailand would require 46,980 MW of additional electricity capacities by 2025. This capacity requirement comprises 23x700MW of gas-fired, 14x700 MW of coal-fired, 14x220MW of diesel-based, and 18x 1,000 MW of nuclear power plants.

Energy Mix

Based on this configuration, electricity energy mix is then calculated and presented in Figure 5 for baseline fuel price and in figure 6 for high fuel price.

Similar to two previous cases, the energy mixes of Figures 6 and 7 confirm that natural gas remains the major fuel for power generation in Thailand during the planning horizon. However, an extensive addition of nuclear power plants from 2020 to 2025 will reduce the share of natural gas to capacity and energy mixes significantly from about 70% in 2011 to about 40% in 2025.

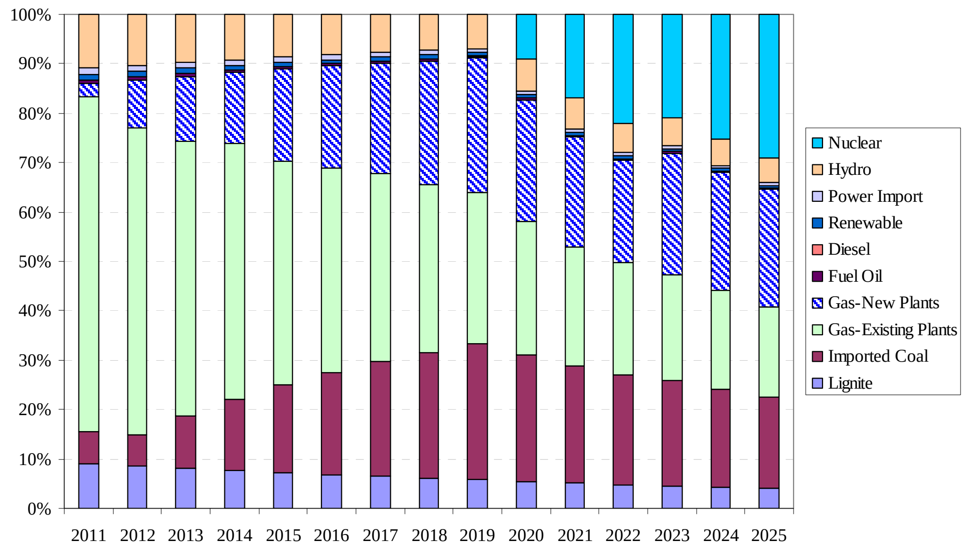

Fig. 6 Energy mix of the nuclear case with baseline fuel prices.

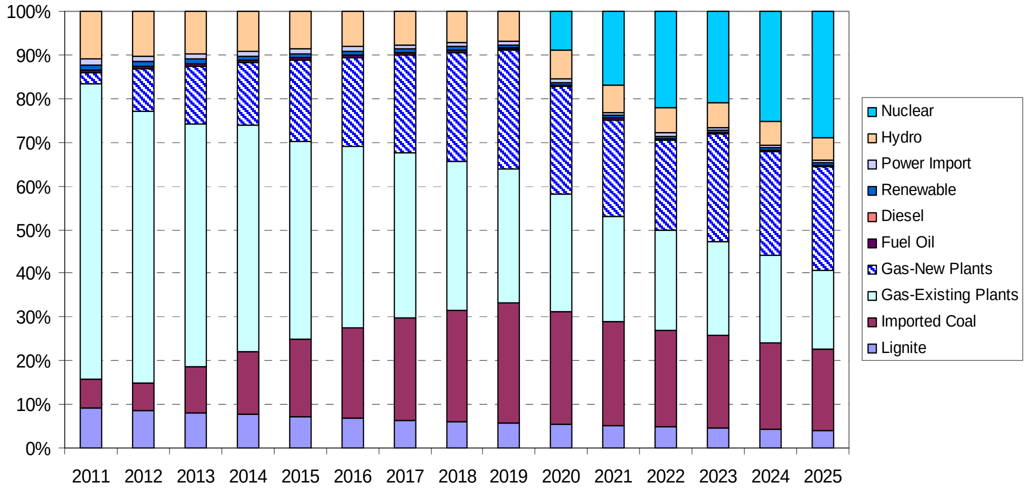

Fig. 7 Energy mix of the nuclear case with high fuel prices.

d. The No New Coal or Nuclear Alternative (NCNA) Case

Objective

This scenario portrays the situation that public resistance to coal power project strongly remains in the future resulting in a prohibition of any addition to new coal-fired power plants. Given that nuclear energy has never been introduced into the Thai system, the public opposition could influentially affect the prospect of nuclear power project as well. Thus, this prohibition of nuclear power plant is also considered in this no new alternative case.

Configuration

The simulation results suggest that, under both baseline and high fuel price assumption, the optimal configuration of additional electricity capacities in 2025 would consist of 57x700 MW of gas-fired and 22x220 MW of diesel-based power plants.

Energy Mix

The energy mixes of NCNA case with baseline and high fuel prices are presented in Figures 8 and 9, respectively.

It is obvious from Figures 8 and 9 that the absence of new coal and nuclear power plants leaves natural gas continuing to be a major fuel for power generation during the planning horizon. About 86 percent of electricity in 2025 will be generated from natural gas. This figure is 16% increase from than of 2011.

4. COMPARISON AMONG FOUR SCENARIOS

In this section, the results of electricity capacity expansion in two scenarios have been further analysed to evaluate impact on security of electricity supply in 4 perspectives, namely fuel diversity in electricity generation system, cost of electricity generation, environmental emission, and vulnerability from gas dependence. Each of these analyses is presented as follows.

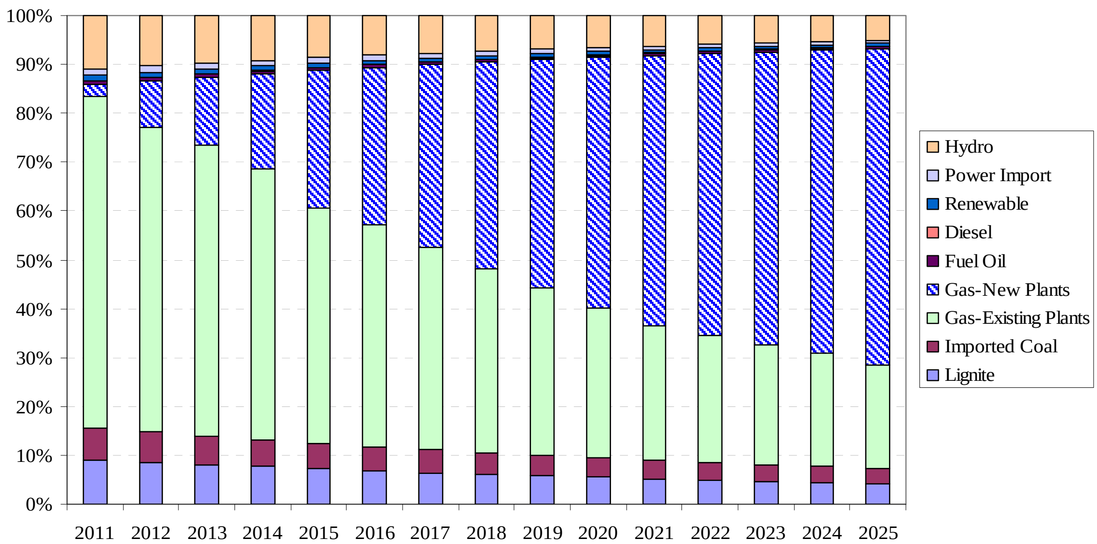

Fig. 8 Energy mix of the NCNA case with baseline fuel prices.

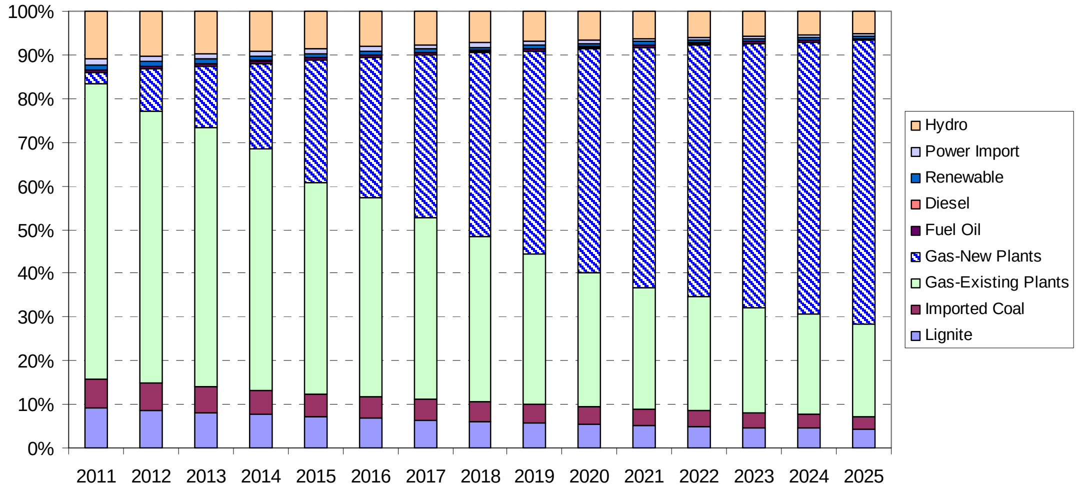

Fig. 9. Energy mix of the NCNA case with high fuel prices.

Fuel Diversity in Electricity Generating System

As high fuel prices in the high price case did not significantly change fuel mix in power generation, thus SWI of the high price case would not be considerably different from that of the base case. Therefore, the result of SWI calculation is presented in Figure 10 for that of the base case only.

Figure 10 indicates obviously that except in the nuclear case, fuel diversity in electricity generation in Thailand between 2011 and 2025 will be highly concentrated on a single source, which in this case remains natural gas. The security of electricity supply is thus an important concern as SWI during the planning horizon falls below 1.0, which is the minimum value of indicator for diversified system [10]. However, the tendency of improving SWI could be observed between 2013 and 2019 as a considerable number of new coal-fired power plants will be installed. After 2020, SWI of the base case, IGCC and no new alternative case will be declining again as the number of coal candidate reached its limit, leaving natural gas to remain the preferred option. The addition of nuclear power plants in the nuclear case improves diversity of electricity generating system significantly between 2020 and 2025, raising SWI during that period above 1.0.

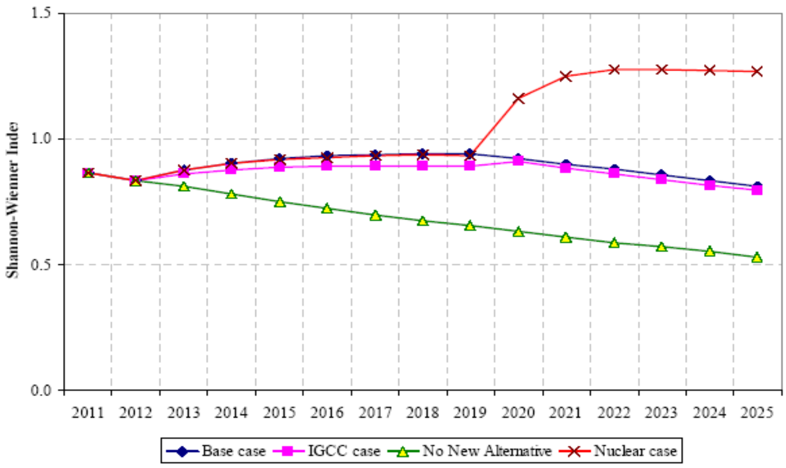

Fig. 10. SWI of four scenarios under baseline fuel prices.

Cost of Electricity Generation

Electricity price contains two main components, namely the marginal cost of electricity generation and that of transmission and distribution systems [27]. As this study focused on the capacity addition problem, the cost of electricity generation is obtained from the Average Incremental Cost (AIC)[2] [28]-[30]. Table 3 presents AIC of four scenarios under both baseline and high fuel prices.

Under baseline fuel prices, the cost of electricity generation in the IGCC and the no new alternative case

---

[2] Average Incremental Cost (AIC) of electricity generation is calculated as follows:

$$AIC = \left(TC - C_1 - \sum_{i=1}^{T} VC_1 / (1+r)^i \right) / \left(\sum_{i=2}^{T} (E_i - E_1)/(1+r)^i \right)$$

where TC is present value of total cost of power generation during the planning horizon, C_1 is the present value of capital cost in year 1, VC_1 is total costs of fuel and operation and maintenance in year 1, E_i is electricity generation in year i, E_1 is electricity generation in year 1, r is the discount rate and T is the planning horizon is 12.98% and 13.86% higher than that of the base case, respectively. The addition of nuclear candidate plants in the nuclear case reduces the cost of electricity generation by 13% from that of the base case.

In case of high fuel oil price in the international markets affecting prices of natural gas and oil products in Thailand, the cost of electricity generation in the base case, the IGCC case, the nuclear case, and the no new coal or nuclear alternative case will increase from those under baseline fuel prices by 10.40%, 12.98%, 7.37%, and 18.87%, respectively. The cost difference between the base case and the IGCC and the no new alternative case, increases in the high fuel price situation to 6.59% and 22.61%, respectively. However, the cost of electricity generation in the nuclear case in the high fuel price situation is 15.38% less than that of the base case as the fuel consumption cost reduces due to nuclear generation.

Table 3. Cost of electricity generation from four scenarios (in US cent/kWh).

	Baseline fuel prices	High fuel prices
Base case	5.77	6.37
IGCC case	6.01	6.79
Nuclear case	5.02	5.39
No New Alternative Case	6.57	7.81

Environmental Emissions

Based on the simulation results, the research primarily evaluates environmental emissions from energy mixes of all four scenarios. Basically, emissions of three pollutants, namely CO_2, NO_x, and SO_2, are included into the calculation. The CO_2, emission, which is the main source of emission among these three pollutants, is presented in Figure 11 for the absolute value and in Figure 12 for percentage increases from the base case. In addition, an average emission of each pollutant per unit of electricity generated is presented in Table 4.

Table 4. Average environmental emission per unit of electricity (in ton/MWh).

Emission	Base Case	IGCC Case	NNA Case	Nuclear Case
CO_2	0.53	0.49	0.44	0.49
SO_2	0.0037	0.0034	0.0030	0.0036
NO_x	0.0018	0.0018	0.0016	0.0016

It is observed from Table 4 that conventional coal-fired candidate power plant is obviously the main source of environmental emissions. If conventional coal plants are replaced by IGCC candidate power plant, an average emission per unit of electricity will be reduced by 7.54%, 8.11%, and 5.56% for CO_2, SO_2, and NO_x, respectively. The absence of new coal-fired power plants in the no new alternative case also confirms this observation as in this case the average emission of CO_2, SO_2, and NO_x, is 16.98%, 18.92%, and 11.11% less than that of the base case, respectively. Therefore, the promotion of coal-fired power projects requires a thorough consideration comparing cost saving in electricity generation and environmental consequences.

Addition of nuclear power plants can also be used to mitigate environmental emission from power generation in Thailand as Figure 11 shows the decline in emissions of all three pollutants after a number of nuclear power plants have been added into the system from 2020 to 2025. In terms of average emission per MWh of electricity, CO_2, SO_2, and NO_x emissions in the nuclear case are obviously less than those of the base case.

Vulnerability for Gas Dependence in Power Generation

The analysis of vulnerability from gas dependence in power generation is investigated from the ratio of total cost of natural gas supplies for power generation to the country's Gross Domestic Product (GDP). The cost of natural gas for power generation from 2011 to 2025 is directly obtained from the results of each scenario. The forecast of Thailand's GDP from 2011 to 2025 follows the assumption used in Thailand's official electricity demand forecast, which was based on the forecast of economic indicators carried out by the office of National Economic and Social Development Board (NESDB). The results of the vulnerability analysis are presented in Figures. 13 and 14 for the base case and high fuel case respectively.

It can be observed from Figures. 13 and 14 that between 2011 and 2019, the vulnerability indicator declines steadily for the base case, the IGCC case, and the no new coal or nuclear alternative case under both baseline and high fuel price scenarios. The result arises from the addition of coal-fired power plants during that period.

In turn, the vulnerability in the base case and the IGCC case increases between 2020 and 2025 as the number of coal-fired or IGCC candidate power plants reaches its restriction in 2019 leaving gas-fired power plant the major candidate for electric capacity expansion during that period. In contrast, the addition of nuclear energy between 2020 and 2025 has influentially reduced vulnerability from gas dependence during that period.

In no new coal or nuclear alternative case, the vulnerability tends to increase throughout the planning horizon as gas-fired power plant is the only major candidate available to this case.

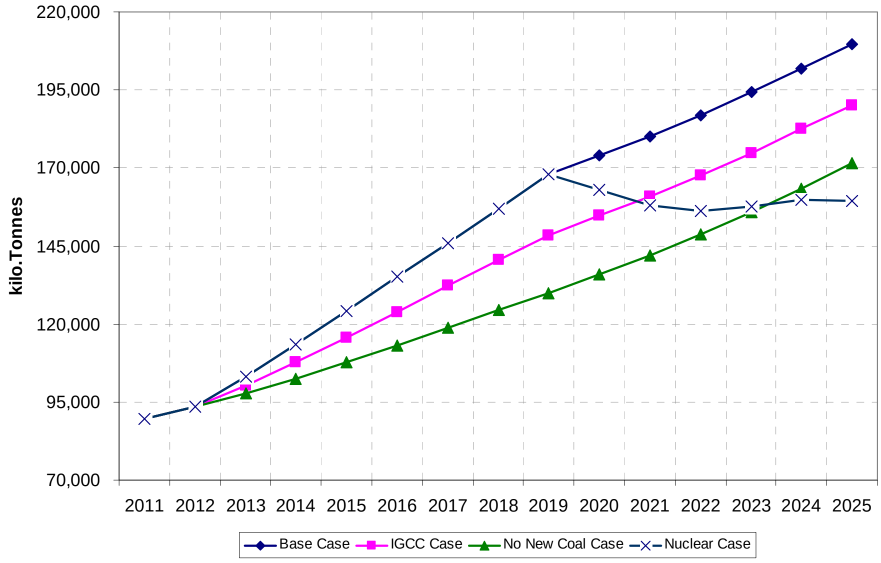

Fig. 11. CO_2 emission from four simulation cases with baseline fuel prices.

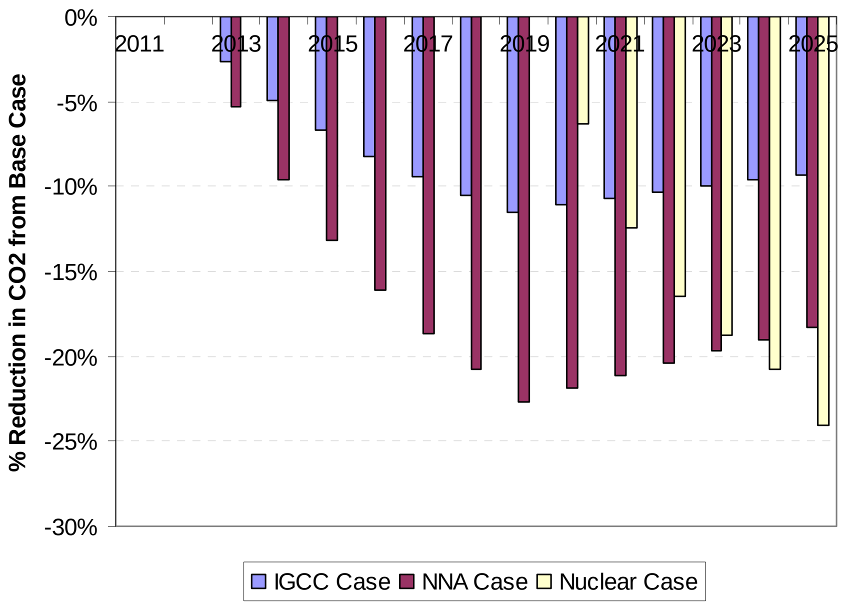

Fig. 12. Percentage of reduction in CO2 emission for three alternative cases compared with that of base case.

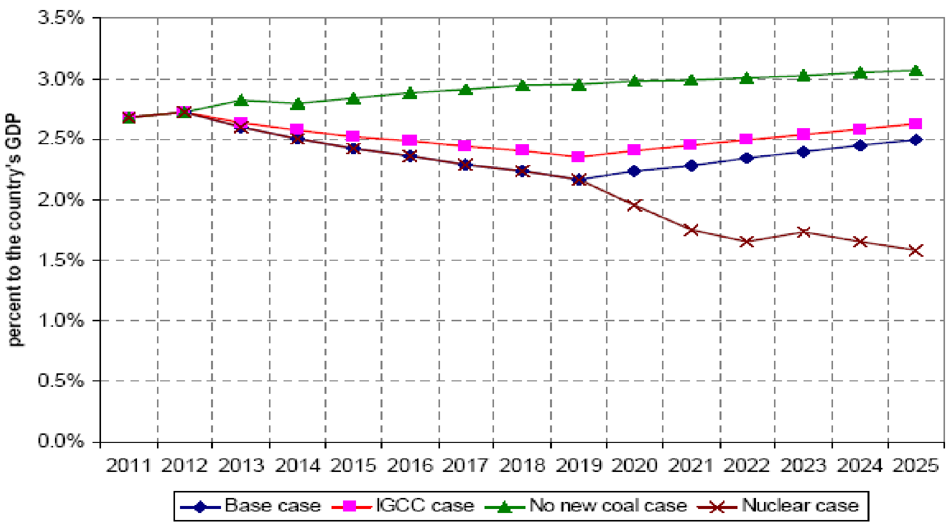

Fig. 13. Vulnerability from gas dependence under baseline fuel prices

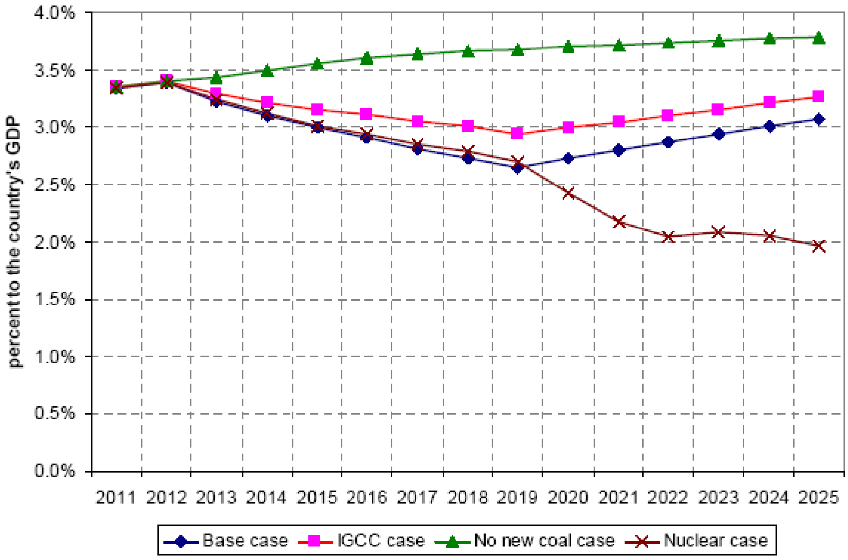

Fig. 14. Vulnerability from gas dependence under high fuel prices.

5. CONCLUSION

This paper discusses supply security and environmental impact of electricity expansion in Thailand. The analysis is presented through fuel diversity and economic vulnerability from fuel dependence, particularly focusing on natural gas. The results show that electricity generation so far has been concentrated on limited source of fuel, which is particularly natural gas in this case. In the foreseeable future, it is found that fuel use in electricity generation would remain less diversified and the country would continue to be vulnerable from high gas dependence in power generation.

However, the vulnerability from gas dependence in power generation would effectively be reduced and fuel diversity is going to be appreciably improved by a certain number of new coal-fired power plants added during the middle of the period of study. But promoting coal candidate seriously increases the environmental emission, which adds to the international concern of global warming.

Meanwhile, nuclear power plants could be a possible solution to enhance security of supply while reducing environmental emission. In addition, it is found that the addition of nuclear power plants offer the least cost plan of electricity capacity expansion. Therefore, nuclear option should be considered in the long-term planning of electric capacity expansion in Thailand. However, the development of nuclear power project requires extensive and thorough policy analyses on various relevant dimensions, including nuclear safety, radioactive waste management, legislation governing use of atomic energy in the country, and etc. In addition, the simulation results of this research show that natural gas will remain the major fuel for power generation in Thailand in the near future but the country would rely on imported gas increasingly. Therefore, policy on gas import is required to maintain security of electricity supply in terms of mitigating both quantity and price risks. Therefore these issues could be carried out as the further work of this study.

REFERENCES

[1] Hertzmaek, D., 2007. Risk assessment methods for power utility planning. Special report 001/07 March 2007; Energy Sector Management Assistance Programme of the World Bank, Washington D.C.

[2] Department of Alternative Energy Development and Efficiency (DEDE). 2004. Thailand energy situation 2004. Bangkok.

[3] International Energy Agency (IEA). 2004. Security of gas supply in open markets, Paris.

[4] Chirattananon, C. and Nirukkanaporn, S., 2006. Deregulation of ESI and privatisation of state electric utilities in Thailand. *Energy Policy*; 34 (16): 2521 – 2531.

[5] Limmeechokchai, B. and Suksuntornsiri, P., 2007. Assessment of cleaner electricity generation technologies for net CO_2 mitigation in Thailand. *Renewable and Sustainable Energy Reviews* 11(2): 315 – 330.

[6] Nakawiro, T. and Bhattacharyya, S.C., 2007. High gas dependence for power generation in Thailand: the vulnerability analysis. *Energy Policy* 35(12): 3335 – 3346.

[7] Del Campo, C., Monteiro, C.M.F. and Soares, J.O., 2008. The European regional policy and the socio-economic diversity of European regions: A multivariate analysis. *European Journal of Operational Research* 187(2): 600-612.

[8] Bunnell, F.L., 2008. Indicators for sustaining biological diversity in Canada's most controversial forest type—Coastal temperate rainforest. *Ecological Indicators* 8(2): 149-157.

[9] Costello, K., 2007. Diversity of generation technologies: implications for decision-making and public policy. *The Electricity Journal* 20(5):10-21.

[10] Grubb, M., Butler, L. and Twomey, P., 2006. Diversity and security in UK electricity generation: the influence of low-carbon objectives. *Energy Policy* 34(18): 4050-4062.

[11] Costello, K., 2005. A perspective on fuel diversity. The Electricity Journal; 18(4): 28-47.

[12] Stoll H.G., 1989. Least-cost electric utility planning. John Wiley, New York.

[13] International Atomic Energy Agency (IAEA). 1998. Wien Automatic System Planning (WASP) package: a computer code for power generating system expansion planning version WASP-user's manual, Vienna.

[14] Electricity Generating Authority of Thailand (EGAT). 2007. Power Development Plan 2007 (PDP2007), Bangkok.

[15] Thailand Load Forecast Subcommittee (TLFS), 2007.

[16] Energy Policy and Planning Office (EPPO). 2007. Electricity demand forecast and power development plan in Thailand. Bangkok.

[17] Energy Policy and Planning Office (EPPO). 2007. Presentation for public participation in Thailand's Power Development Plan 2007 (PDP2007), Bangkok (in Thai).

[18] Energy Information Administration (EIA). 2007. Annual energy outlook 2007 with projections to 2030. The U.S. Department of Energy, Washington D.C.

[19] British Petroleum Company (BP). 2007. BP statistical review of world energy, London.

[20] PTT public company limited (PTT). 2006. A presentation on long-term gas demand and supply in Thailand. Bangkok (in Thai).

[21] Santisirisomboon J., Limmeechokchai B. and Chungpaibulpatana, S., 2003. Least cost electricity options based on environmental impact abatement. *Environmental Science and Policy* 2003(6): 533 – 541.

[22] The World Bank. 1999. A planner's guide for selecting clean-coal technologies, World Bank technical paper no.387, World Bank, Washington D.C.

[23] International Energy Agency (IEA). 2005. Towards zero emission coal-fired power plants, IEA clean coal centre, Paris.

[24] University of Sussex and NERA economic Consulting. 2005. Economics of nuclear power, a report to the sustainable development commission.

[25] International Energy Agency (IEA). 2001. Nuclear power in the OECD, Paris.

[26] Massachusetts Institute of Technology (MIT). 2003. The future of nuclear power: an interdisciplinary MIT study, Cambridge.

[27] Malik, A.S. and Al-Zubeidi, S., 2006. Electricity tariff based on long-run marginal costs for central grid system of Oman. *Energy* 31(2006): 1703 – 1741.

[28] Shrestha, R.M., Shrestha, R. and Bhattacharya, S.C., 1998. Environmental and electricity planning implications of carbon tax and technological constraints in a developing country. *Energy Policy* 26(7): 527 – 533.

[29] Shrestha, R.M. and Marpaung, C.O.P., 1999. Supply- and demand-side effects of carbon tax in the Indonesian power sector: an integrated resource planning analysis. *Energy Policy* 27(1999): 185 – 194.

[30] Shrestha, R.M. and Marpaung, C.O.P., 2005. Supply- and demand-side effects of power sector planning with demand-side management options and SO2 emission constraints. *Energy Policy* 33(2005): 815 – 825.