MITIGATING CO₂ EMISSIONS FROM THE POWER SECTOR: LEAST-COST ANALYSIS OF POLICY OPTIONS IN THAILAND

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ABSTRACT

Traditionally, the method used in the electricity generation expansion planning has concentrated only on the supply-side options to identify the sequence of generation additions to meet the forecasted demand at a minimum cost. Electricity generation expansion planning with both supply- and demand-side options, commonly known as integrated resource planning, are also being used in some developed countries. With growing environmental concerns, especially the emission of air-pollutants from the power generation, demand-side management and clean and efficient generation technology options in the power sector development are getting increasing attention. In this paper, we compare the traditional planning approach with integrated resource planning. We also analyze the implications of CO₂ reduction targets for the power sector development in the framework of supply side planning by including clean supply-side technologies as candidate plants. During the planning horizon, generation capacity of 365 MW and a cumulative electricity generation of 61,681 GWh would be avoided through the use of efficient demand-side technologies compared to the business-as-usual (BAU) case. When the clean supply-side options are considered in the least-cost planning process, three units of 100-MW biomass-based plants are selected. The long run average cost of generation is found to increase by 0.32, 0.65 and 1.61% at the level of CO₂ emission reduction target of 5, 10 and 20% respectively.

1. INTRODUCTION

In the past decade, Thailand has achieved a high economic growth rate. As a result of this growth rate, Thailand's energy requirements have dramatically increased. The growth of electricity demand in Thailand has a significant impact not only in terms of capacity expansion but also in terms of environmental emission. In 1999, the power sector was a major energy consuming sector and the largest emitter of CO₂ in Thailand¹. This is mainly due to the high share of thermal power generation in the country. At present, it appears that the fossil fuel resources are limited and the combustion of fossil fuels pollutes the environment. However, the electric utility has tried to reduce the airborne emissions through the thermal efficiency improvement and alternative fuels. In Thailand, traditional approach to power sector capacity expansion planning is used. This approach is focused only on the identification of supply-side options to meet the forecasted demand at a minimum cost. Hereafter, we call this approach as traditional resource planning (TRP) approach. An alternative approach for the power sector development is integrated resources planning

(IRP) which considers both supply- and demand-side options to formulate the least cost power development plan. IRP offers a wider choice of resources to meet the demand and when DSM options are selected as least cost options, this approach would result in a lower level of air-pollutants emissions.

The purpose of this study is to determine the least cost CO₂ mitigation options in the power sector of Thailand. The options include demand-side management, cleaner and efficient generating technologies. Furthermore, the study analyzes the effect of limiting the CO₂ emission from the power sector on utility planning, economic, and environment.

2. METHODOLOGY

The framework of the study is based on the least cost generation expansion planning analysis. Under this framework, the objective is to determine the generation expansion plan that minimizes the total cost (comprising capacity, fuel, operation costs and DSM costs) of power generation over the planning horizon as shown in Figure 1². In addition, annual emission constraints are used to limit the emission of air-pollutants from the power sector. Emissions of CO₂, SO₂ and NO_x are calculated based on emission factors provided by the Intergovernmental Panel on Climate Change (IPCC)³.

2.1 Load data

The load data used in the IRP model are the average chronological load curves (CLCs). Three seasons, namely winter, summer, and rainy seasons, are considered in this study. Each season is represented by a CLC of the peaking day in that season. The annual peak loads for the study period are obtained from the load forecast of Electricity Generating Authority of Thailand (EGAT)⁴. In this study, the moderate economic recovery forecast has been used as a reference load data and as supporting information in the period of 2003-2011. The trend of the load is used to extend the load forecast from 2012-2017 at a constant system load factor of 0.73. The peak load is expected to increase from 18,399 MW in 2003 to 39,490 MW in 2017, as shown in Figure 2.

2.2 Supply-side options

The supply-side options in the IRP model are divided into 2 categories: existing power plants and candidate power plants.

Figure 1: The IRP model.

Figure 2: The forecast of the peak loads used in the IRP model.

2.2.1 Existing power plants

The existing power plants in 1998 consisted of 161 units of various generating stations with total capacity of 18,174.5 MW (excluding 0.53 MW of renewable energy), of which 2,874 MW (15.8%) was from hydro, 6,517 MW (35.9%) from conventional oil/gas and lignite-fired thermal, 5,074 MW (27.9%) from combined-cycle, 892 MW (4.9%) from gas turbine and diesel, and 2,818 MW (15.5%) purchased from other power suppliers⁴. All existing power plants are included in the IRP model as a fixed system of the plan. The typical characteristics of each plant type are taken from the EGAT 's report⁴.

2.2.2 Fuel choice and clean supply-side plants

Thailand has large lignite reserves but it has many contaminants⁵. The EGAT has been interested in the research and development of clean coal technology, such as Integrated Gasification Combined Cycle (IGCC)⁶. Additionally, Thailand has a high potential to utilize biomass energy for electricity generation particularly from agricultural wastes. Therefore, fuel choice in the IRP model is divided into two categories: conventional supply-side options and clean supply-side options, as shown in Table 1. The typical characteristics of conventional power plants are obtained from the EGAT's report⁴ while the characteristics of clean technologies are obtained from various sources⁷⁻⁸.

2.3 Demand-side management options

The demand-side options for GHG mitigation are efficiency improvements of electric appliances in the residential sector. The DSM program consists of three options. The first option is called DSM1, which includes replacing 20-W and 40-W fluorescent lamps with 18-W and 36-W fluorescent lamps, respectively. The second option is called DSM2, which includes replacing the conventional refrigerator with the most energy efficient refrigerator. The last option is called DSM3, which includes replacing the conventional air-conditioner with the most energy efficient air-conditioner.

Table 1: Characteristics of candidate supply-side options.

Plant type	Fuel type	Capacity (MW)	Heat rate (kcal/kWh)	CO ₂ emission factor ^t (g/kWh)
Conventional supply-side				
- Coal-fired	Imported coal	700	2391	947
- Coal-fired	Imported coal	1000	2321	919
- Oil-fired	Fuel oil	1000	2340	636
- Gas turbine	Diesel	200	2742	860
- Combined cycle	Natural gas	600	1859	473
Clean supply-side				
- IGCC ²	Imported coal	500	2200	821
- PFBC ²	Imported coal	500	2195	903
- Biomass	Biomass	100	2378	0
- Nuclear power ³	Nuclear power	1000	2566	0

Notes: IGCC = Integrated Gasification Combined Cycle, PFBC = Pressurized Fluidized Bed Combustion.
Sources: ¹ IPCC (1996), ² TEI (1990), ³ Limmeechokchai and Chungpaibulpatana (1999).

2.4 Assumptions

The planning horizon is 15 years (2003-2017) with 1998 taken as the base year. The minimum and maximum reserve margins of 15% and 25% are adopted respectively⁴. The natural gas supplied from the neighbouring countries is enough for approximately 11,650 MW of additional capacity⁴. The capacity of coal-fired power plants is not higher than 50% of the total system capacity.

2.5 Description of cases

2.5.1 The business-as-usual (BAU) case

The business-as-usual (BAU) case uses TRP approach for the power sector development and thus considers only supply-side options. The candidate thermal plants include oil-fired steam plants, coal-fired steam plants, combined-cycle plants and gas turbines.

2.5.2 CO₂ mitigation cases

The first CO₂ mitigation case involves the use of both cost effective supply- and demand-side technologies in the power sector. This implies the determination of least cost supply- and demand-side technology options under the framework of integrated resource planning. Hereafter, we refer to this as IRP case. Three demand-side-management (DSM) options are considered along with the supply-side options.

The second CO₂ mitigation case is focused only on supply-side options. It is different from the BAU case in that it also includes the clean power generation technology options such as IGCC, PFBC, biomass-based, and nuclear plants as candidate plants. The BAU case with clean supply-side options is hereafter called CSS00 case.

Furthermore, three more cases with annual limit on the amount of CO₂ emission are also analyzed. Under these cases, namely CSS05, CSS10 and CSS20, the level of CO₂ emission reduction targets are set at respectively 5, 10, and 20% of the annual CO₂ emission under CSS00 case. The description of options and CO₂ reduction targets considered in each of the cases is shown in Table 2.

3. RESULTS

3.1 Utility planning implications

The results of the least cost planning exercises from the IRP model show that coal-fired power plants take the largest share in the total additional capacity in the BAU case, the CSS00 and IRP cases and also in the case with CO₂ limitation, presented in Table 3. In the CSS00 case, 3 units of 100-MW biomass-based power plants are committed. However, the IGCC and PFBC plants are not selected due to their high total costs. The introduction of CO₂ limitation effects the shift of the power plant types from high-carbon-content fuel-based plants to low-carbon-content fuel-based plants. The higher percentage of CO₂ limitation, the lower is the capacity of coal-based plant. With higher CO₂ mitigation targets, the power generation from coal-based plants shifts to nuclear and biomass-based plants. However, the generation capacity added during the planning horizon in the CSS00 case, CSS00 with CO₂

Table 2: Description of cases considered.

Case	CO ₂ reduction target (%)	Supply-side options		Demand-side options
		Conventional	Clean	
BAU	-	Yes	No	No
IRP	-	Yes	No	Yes
CSS00	-	Yes	Yes	No
CSS05	5	Yes	Yes	No
CSS10	10	Yes	Yes	No
CSS20	20	Yes	Yes	No

Table 3: Number of committed plants in the BAU and mitigation cases.

Case	Total number of committed power plants during 2003-2017						Additional capacity (MW)	Total Generation (TWh)	LOLP (%)
	Coal 1000-MW	Coal 700-MW	CC 600-MW	Oil 1000-MW	Nuclear 1000 MW	Biomass 100-MW			
BAU	20	9	12	-	-	-	33,500	3,096	0.09
IRP	20	4	17-	-	-	-	33,000	3,034	0.09
CSS00	20	6	15	-	-	3	33,500	3,096	0.09
CSS05	20	-	17	-	3	3	33,500	3,096	0.09
CSS10	19	-	15	-	5	5	33,500	3,096	0.09
CSS20	12	1	19	3	5	14	33,500	3,096	0.08

Table 4: Cumulative generation avoided and peak load avoided in the IRP case.

DSM options	Cumulative generation avoided (GWh)	Peak load avoided in selected year (MW)			
		2003	2007	2012	2017
DSM1	13,261	28.4	30.0	32.8	36.4
DSM2	15,629	9.8	36.1	70.4	94.6
DSM3	32,792	10.9	59.1	140.5	233.7
Total	61,681	49.1	125.2	243.7	364.7

limitation cases are the same as in the BAU case. In the IRP case, both additional capacity and power generation are less than those in the BAU case.

The total additional capacity in the IRP case is less than the BAU case by approximately 1.5%. The total electricity generation in the IRP case is less than the BAU case by 61,681 GWh, as shown in Table 3. This effect is mainly due to energy savings from the DSM programs. Table 3 also shows the figures of loss-of-load probabilities (LOLPs) for all the cases considered. It is found that there is no change in the value of LOLP at different case except for CSS20 case.

The electricity generation and peak load avoided through the DSM programs in the IRP case are presented in Table 4. The DSM3 has the highest contribution to the avoided peak load and generation. In addition to the reduction in electricity generation the IRP case also reduces fuel consumption. The total fuel consumption in the IRP case is 640 million tons of oil equivalent (toe), while that in the BAU case is 658 million toe. Moreover, the other benefit of fuel saving is the reduction in emissions.

3.2 Economic implications

In the economic perspective, results from the IRP model show that the fuel and O&M costs take the largest share of total cost, by approximately 80%. The total expenditure including DSM costs in the IRP case in the planning horizon are less than that in the BAU case by US\$ 260 million due to the reduction of electricity requirement. Also in the CSS00 case, the total costs decrease by US\$ 6 million compared to the BAU case because of the decreasing fuel and O&M costs as shown in Table 5. When different levels of CO₂ limitation are introduced in the CSS00 case, the total cost increases due to the increasing of capital costs. The total costs increase by about 0.4%, 0.7%, and 1.6% in the CSS05, CSS10 and CSS20 cases respectively. The results of those costs directly affect the long run average costs (LRAC). The LRACs in all cases are higher than that in the BAU case except the CSS00 case.

3.3 Environmental implications

Results of the least cost plans from the IRP model affect not only the capacity-, generation- and fuel- mix but also the emissions. In the IRP case, the total CO₂, SO₂ and NO_x emissions are found to be less than the BAU case by 89 million tonnes, 1017 ktons, and 195 ktons, respectively as shown in Table 6. In the CSS00 case, one unit of 700-MW coal-fired power plant and one unit of 200-MW gas-turbine power plant are replaced by three units of 600-MW combined-cycle and three units of 100-MW biomass-based plants resulting in total CO₂ reduction by 13 million tons. The CO₂ emissions are reduced by 11.1, 15.7 and 25.5% in the CSS05, CSS10, and CSS20 cases, respectively. The cumulative CO₂, SO₂ and NO_x emissions during the planning horizon are shown in Table 6 and annual CO₂ and SO₂ emission for different cases are shown in Figure 3.

4. CONCLUSION

The results of least-cost expansion plan reveal that the CO₂ emission and other harmful emissions could be avoided through both the clean supply-side options in the CSS00 case and DSM options in the IRP case. In the IRP case, 89 million tons of CO₂ emissions are mitigated by the reduction of electricity generation. In the CSS00 case, the electricity generation switches from coal-based plants to combined-cycle and biomass-based plants, which emit less CO₂ emission, resulting in a decrease in CO₂

Table 5: Cumulative costs in all cases during 2003-2017.

Case	Cost components (10 ⁶ US\$)				LRAC (US cents per kWh)
	Capital cost	Fuel and O&M costs	DSM cost	Total cost	
BAU	5,031	25,152	-	30,183	3.10
IRP	4,873	24,816	234	29,923	3.11
CSS00	5,116	25,061	-	30,177	3.10
CSS05	5,730	24,561	-	30,292	3.11
CSS10	6,253	24,130	-	30,383	3.12
CSS20	6,892	23,769	-	30,661	3.15

Table 6: Cumulative pollutant emissions in all cases during 2003-2017.

Case	CO ₂ , 10 ⁶ tons	SO ₂ , 10 ³ tons	NO _x , 10 ³ tons	CO ₂ mitigation ¹ , 10 ⁶ tons
BAU	2,231	14,850	6,937	
IRP	2,142	13,833	6,743	89
CSS00	2,218	14,773	6,906	13
CSS05	1,984	12,506	6,333	247
CSS10	1,881	11,806	6,026	350
CSS20	1,663	9,333	5,582	568

Note: ¹ CO₂ emissions in all cases are compared with the BAU case.

Figure 3: Annual emissions of CO₂ and SO₂ in the selected cases.

emissions by 13 million tons during the planning horizon. When the CO₂ limitation is introduced along with clean supply-side options, the number of committed biomass-based plants and nuclear power increases in order to meet the CO₂ limitation constraints resulting in an increase in total cost and long run average cost of generation. Although the higher levels of CO₂ limitation affect the amount of CO₂ mitigation, the feasibility of biomass based generation and the public awareness of nuclear power in Thailand should be taken into consideration. The clean-coal technologies such as IGCC and PFBC are not selected in all cases because of their high total system costs. Therefore, the IRP case is the most appropriate plan to CO₂ mitigation. However, the abatement of CO₂ emissions will be increased if the DSM and clean supply-side options are simultaneously included in the BAU plan.

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6. NOMENCLATURE

BAU	= the business-as-usual case
CC	= combined-cycle power plant
CSS00	= the clean supply-side case
CSS05	= the clean supply-side case with 5% CO ₂ reduction target
CSS10	= the clean supply-side case with 10% CO ₂ reduction target
CSS20	= the clean supply-side case with 20% CO ₂ reduction target
DSM	= demand-side management
EGAT	= Electricity Generating Authority of Thailand
GT	= gas-turbine power plant
IGCC	= Integrated Gasification Combined Cycle
IRP	= integrated resource planning
LOLP	= loss-of-load probability
LRAC	= long run average cost (US cents/kWh)
O&M	= operating and maintenance
PFBC	= Pressurized Fluidized Bed Combustion
toe	= tone of oil equivalent
TWh	= teraWatt-hours

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