Comparative Assessment of Alternative Electricity Supply Options: The Case of Thailand with Nuclear Power

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Abstract

An assessment of the planned electricity generation expansion in Thailand is presented, and the alternative option with nuclear power is discussed for sustainable energy development. The establishment of a country specific database (CSDB) for Thailand is performed through the DECADES computer tool, developed by the International Atomic Energy Agency (IAEA). The CSDB includes energy sources, electricity generation technologies at power plants, and energy chains (starting from extraction level to generation level). Based on Thailand's CSDB, scenarios of power system expansion planning including nuclear power are formulated. The least-cost electricity generation expansion plans of the base case without nuclear power plants and a scenario with nuclear power plants are carried out through an optimization model in the DECADES tool. Results show that eight nuclear power plants of capacity 8,000 MW are committed in the planning period resulting in less installation of additional capacity of fossil-fired power plants and less CO_2 emissions.

Keywords: energy supply, least-cost electricity expansion planning, fossil-fired power plants, nuclear power, CO_2 emissions.

1. Introduction

The electricity consumption of Thailand has been rapidly increasing for more than ten years because of the high economic growth and the modernised living standard. During 1985-1995, the total electricity consumption increased by an average annual growth rate of 13.5% which is greater than the economic growth rate of 8.5% per year [1]. Table 1 shows the GDP and electricity consumption of Thailand. The rapid growth of electricity demand in Thailand contributes a significant impact to the electricity utility in terms of plant operation and capacity expansion. The fossil fuel resources are limited

and cause environmental pollution from power generation plants. Power generation from nuclear power is one of the options in the future. To meet the electricity requirement, the Electricity Generating Authority of Thailand (EGAT) needs to install more electricity generation capacity. This research project aims to establish a country specific database (CSDB) for Thailand and carry out a comparative assessment of alternative energy supply options for sustainable power generation expansion planning through the Database and Methodologies for Comparative Assessment of Different Energy Sources for Electricity Generation (DECADES), which has been developed by the International Atomic Energy Agency (IAEA) and implemented in Thailand through the Office of Atomic Energy for Peace (OAEP). Figure 1 identifies the major modules included in the DECADES program. The DECADES structure includes establishment of databases and information systems in five submodules; namely, RTDB, CSDBs, VSDB, TOXDB and HEIES, and comparative assessment tool (DEPAC). The DECADES tools can be utilized by a wide range of users at the national, regional and international levels to evaluate trade-off between technical, economic and environmental aspects of different electricity generation technologies, chains and systems. In this paper, the system load-duration curves were obtained from the recorded system load shapes of the electric utilities with adjusted peak load demands according to the economic crisis in Thailand in 1997. The configurations of the existing power system in 1997 was formulated with the candidate power plants including nuclear power plants to derive the least-cost electricity generation plans through the DECADES computer tool.

Table 1. The GDP and electricity consumption of Thailand.

Year	GDP		Electricity consumption	
	Million Baht	% change	GWh	% change
1985	1,191,255	4.65	20,032	7.86
1986	1,257,177	5.53	22,034	9.99
1987	1,376,847	9.52	24,894	12.98
1988	1,559,804	13.29	28,253	13.49
1989	1,749,952	12.19	32,834	16.21
1990	1,945,372	11.17	38,342	16.78
1991	2,111,861	8.56	43,398	13.19
1992	2,285,865	8.24	49,304	13.61
1993	2,481,278	8.55	56,279	14.15
1994	2,702,078	8.90	62,510	11.07
1995	2,941,183	8.85	71,225	13.94
1996	3,135,301	6.60	77,354	8.61

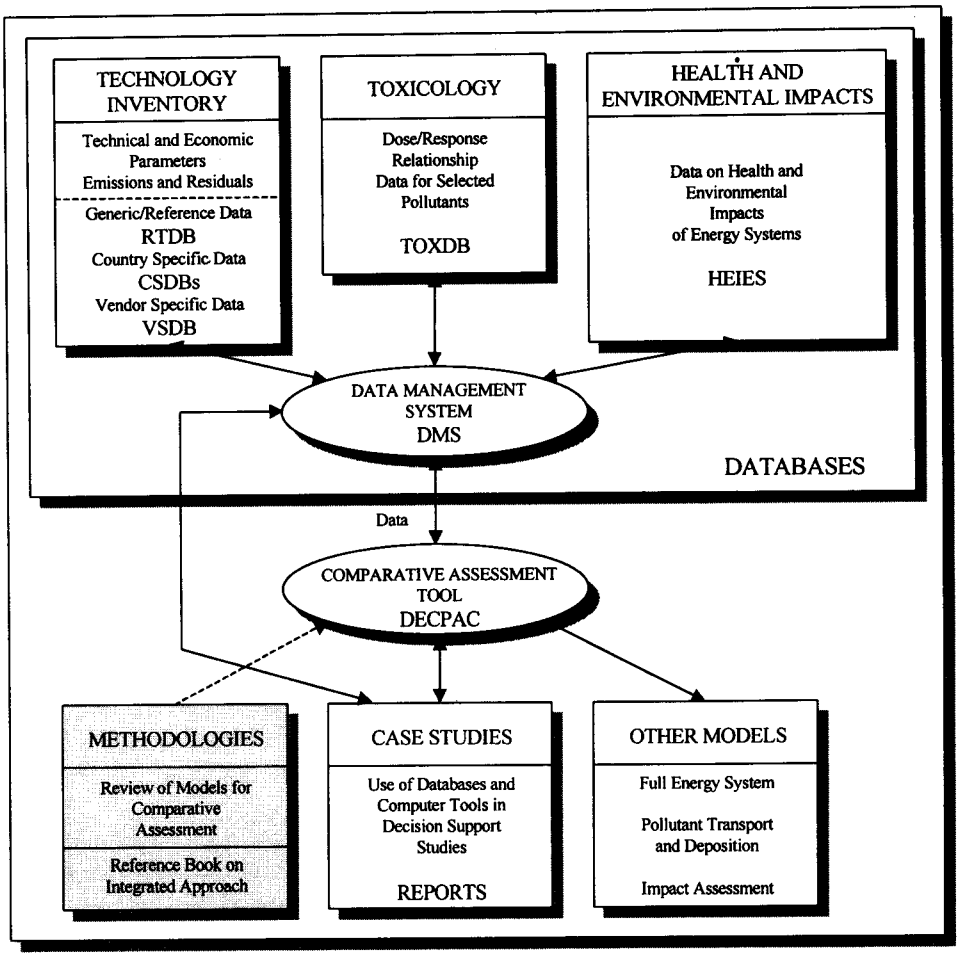

Fig. 1. The DECADES structure.

2. The Country Specific Database (CSDB)

The country specific database (CSDB) for Thailand was set up using the DECADES software. Thailand's CSDB includes three sections; namely, energy sources, technologies and energy chains [2]. The CSDB is developed in connection with the DECPAC module, an electric system analysis and planning module in the DECADES computer tool.

2.1 Energy Sources

There are various types of energy sources in Thailand. As power generation is concerned with environmental pollution, the characteristics of all fuel types should be identified. The characteristics of fuel type are separated into physical analysis; for example, heat value and specific weight, proximate analysis; for example, moisture content and ash content, ultimate analysis; for example, sulphur content

and carbon content, hydrocarbons (C_2H_4, C_3H_8), gases (CO, CO_2, etc.) and costs.

2.2 Technologies

Technologies refer to all technologies used in the energy chains starting from the extraction from the sources to waste disposal and emissions. However, only technologies of power plant level for each power plant are recorded as there is some unavailability of the data for front end steps (extraction, preparation, refining, and transportation) and back end steps (waste treatment technology at power plant, transportation of waste, and waste disposal).

2.3 Energy Chains

The energy chain is composed of logical groups of activities carried out from the extraction to waste disposal in order to produce the electricity. These activities are called "steps" in the chain. The chains of energy sources used in each power plant are set up to run with the DECPAC module.

3. Comparative Assessment of Different Energy Sources for Power Generation

The DECADES can compare alternative electricity supply options including renewable energy source and nuclear power [3,5]. In this study, the nuclear power option is assessed and discussed. Based on the CSDB of Thailand, two scenarios of power system expansion planning, the base case and the nuclear case, are formulated to meet the energy requirement in the planning horizon.

3.1 The Power Development Plan

The power development plan (PDP) of the electric utility identified the required long-term investment in system generation capacity to meet the demand load forecasted. In this study, the 1997-PDP plan is used as the reference. Due to the economic crisis in 1997, an annual electricity-consumption growth rate of 6% is assumed for the next decade. Table 2 shows the forecasted results of the system load. The study period is 1998-2015. The number of years in the study period and the annual peak loads in the base case are identical with those in the nuclear case. Figure 2 shows the average normalized load-duration curve of the base year (1997) used in the analysis. Four load-duration curves in a year, each for three months, are applied for each year throughout the planning period.

Table 2. Summary of forecasts of system loads.

Year	Peak demand (MW)	Energy (GWh)
1998	14,483	97,307
2000	16,646	111,839
2005	22,633	152,065
2010	31,887	214,240
2015	41,556	279,203

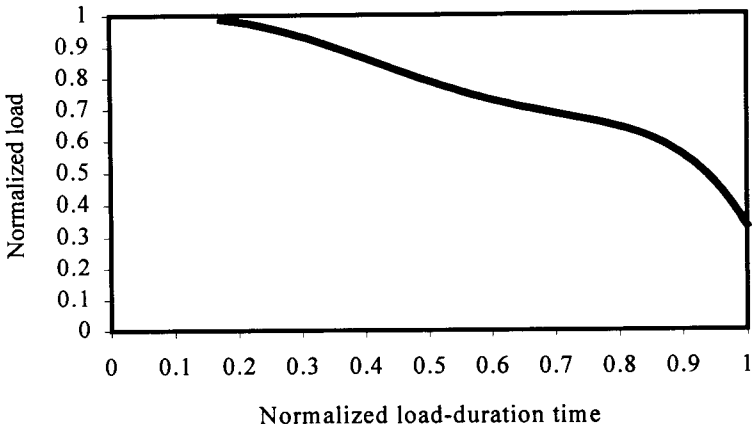

Fig. 2. The average normalized load-duration curve of the base year (1997).

3.2 Fixed System

Thailand's CSDB includes 20 thermal power plants and 29 hydro power plants in the fixed system in 1997. The thermal power plants include five oil-fired power plants, one lignite-fired power plant, six gas-fired power plants and eight diesel-fired power plants [2]. In 1997, the total installed capacity of the existing thermal power plants was 14,691 MW and the total installed capacity of hydro power plant was 3,048 MW.

3.3 Variable System

The candidate plants in the variable system for the base case include one coal-fired power plant with capacity of 1000 MW, one oil-fired power plant with capacity of 600 MW, one gas-fired power plant with capacity of 600 MW, and one 300-MW gas turbine using diesel as fuel for peaking unit. The candidate plants of the variable system in the base case and nuclear case are shown in Table 3. The typical characteristics of each plant type are obtained from the utility's report [4]. The characteristics of nuclear power plant are obtained from the IAEA [5, 6].

3.4 Constraints and Assumptions used in Power System Modelling

- The minimum reserve margin of 15% and maximum reserve margin of 25% are adopted as reliability criteria [4].
- The loss-of-load probability (LOLP) of one day per year or 0.274% is also adopted [4].
- The natural gas supplied through pipeline from the neighbouring countries is enough for the generation of approximately 11,650 MW or about 19 units of 600 MW capacity [4, 7].
- The capacity of coal-fired power plants is not higher than 50 percent of the total capacity of the system [7].
- The on-going projects of hydro power plants are not considered in the analysis.

- CO_2 emission is only considered at the generation level.

Table 3. Candidate plants in the variable system used in the comparative assessment.

Candidate plants			Included in the case study		CO_2 emission factor[1]
Name	Capacity (MW)	Fuel type	Base	Nuclear	g/kWh
CL10	1,000	Imported coal	Yes	Yes	910
CG06	600	Imported gas	Yes	Yes	395
OL06	600	Heavy oil	Yes	Yes	753
GT03	300	Diesel	Yes	Yes	842
NU10	1,000	Nuclear power	No	Yes	0

Note: [1] Intergovernmental Panel on Climate Change (1998).

4. Results of the Least-Cost Electricity Expansion Plans

4.1 The Expansion Plan for the Base Case

The existing installed capacity in 1997 was adapted for the DECADES runs as fixed or given systems. Old power plants were also scheduled for retirement. Feasible plants for electricity generation expansion were grouped as candidate plants in the variable system. The resultant optimum-expansion plan from the DECADES for the base case is shown in Table 4. The least-cost power expansion plan in the base case has a total additional thermal generation capacity of 32,700 MW in the year 2015. In 2015, coal-fired power plants take the largest share in the total installed capacity.

Table 4. List of the committed power plants in the base and nuclear cases.

Year	Number of plants in commitment										Additional capacity (MW)	
	CL10		CG06		OL06		GT03		NU10			
	Base	Nuclear	Base	Nuclear	Base	Nuclear	Base	Nuclear	Base	Nuclear	Base	Nuclear
1998	-	-	-	-	-	-	-	-	-	-	0	0
1999	-	-	2	2	-	-	-	-	-	-	1,200	1,200
2000	1	1	1	1	-	-	-	-	-	-	1,600	1,600
2001	-	-	2	-	-	-	-	-	-	1	1,200	1,000
2002	-	-	2	2	-	-	-	-	-	-	1,200	1,200
2003	1	1	1	1	-	-	-	-	-	-	1,600	1,600
2004	1	1	1	2	-	-	-	-	-	-	1,600	2,200
2005	1	1	-	-	2	2	-	-	-	-	2,200	2,200
2006	1	-	1	2	-	-	2	2	-	1	2,200	2,800
2007	-	-	3	1	-	-	-	-	-	1	1,800	1,000
2008	1	-	1	2	1	1	-	-	-	-	2,200	1,800
2009	2	2	1	1	-	-	-	-	-	-	2,600	2,600
2010	-	2	1	-	1	1	2	2	-	-	1,800	3,200
2011	3	1	-	-	-	-	-	-	-	-	3,000	1,000
2012	1	2	-	1	1	-	-	-	-	-	1,600	2,600
2013	2	-	3	-	-	-	1	-	-	2	4,100	2,000
2014	1	-	-	-	-	-	-	-	-	2	1,000	2,000
2015	-	1	-	1	3	-	-	-	-	1	1,800	2,600
Total	15	12	19	15	8	4	5	4	0	8	32,700	32,600

4.2 The Expansion Plan for the Nuclear Case

The load-duration curves, reliability criteria, and configuration of the fixed and variable systems for the base case are also applied to the nuclear case including nuclear power as an alternative electricity supply option. The resultant configuration is similar to that for the base case, but the total number of coal-fired, oil-fired, and gas-turbine power plants are reduced by three, four, four, and one respectively. However, eight nuclear power plants of capacity 8,000 MW are committed as shown in Table 4. The capacity mix of generation changes slightly. The capacity mix of electricity generation by fuel type and system LOLP are shown in Table 5. In the planning period, the capacity mix in the nuclear case yields decreasing fossil fuel consumption, thus resulting in high fuel-mixed security in power generation. In 2015, the total installed capacity of the fossil-fired power plant for the base case is 46,372 MW and the total installed capacity of fossil-fired power plants for the nuclear power case is only 38,272 MW, which implies less dependence on fossil fuels and less airborne emissions. The corresponding CO_2 emissions are shown in Fig.3.

Table 5. Capacity mix and LOLP for the base case and nuclear case in selected years.

ITEM	1998		2005		2010		2015	
	Base	Nuclear	Base	Nuclear	Base	Nuclear	Base	Nuclear
Capacity mix (%)								
Heavy oil	22.6	22.6	15.4	15.1	14.2	13.8	15.8	11.0
Coal	-	-	14.6	14.4	21.1	20.5	30.3	24.3
Lignite	14.8	14.8	9.6	9.5	6.9	6.7	5.3	5.3
Gas	41.3	41.3	46.6	43.7	44.6	38.6	37.9	33.1
Diesel	4.1	4.1	2.7	2.6	5.1	4.9	4.5	3.9
Hydro	17.2	17.2	11.1	11.1	8.1	7.8	6.2	6.2
Nuclear	-	-	-	3.6	-	7.7	-	16.2
LOLP (%)	0.085	0.085	0.208	0.116	0.253	0.057	0.203	0.189

In 2015, the least-cost expansion plan in the nuclear case results in a reduction in CO_2 emissions of 39.5 million tonnes compared to the base case, and the greenhouse effect is considerably mitigated.

5. Conclusions

The methodology used in the DECADES tool is useful for comparative assessment of alternative electricity supply options considering total system cost and environmental impacts. The resultant least-cost expansion plan for the nuclear case reveals a 17.5% reduction

in fossil-fired power plants. The nuclear power option also features a 21.2% reduction in CO_2 emissions at the power generation level. If the data related to the environment for each level of the energy chain before power generation are available, the DECADES will report the total environmental impacts such as emissions, land uses, and waste disposal.

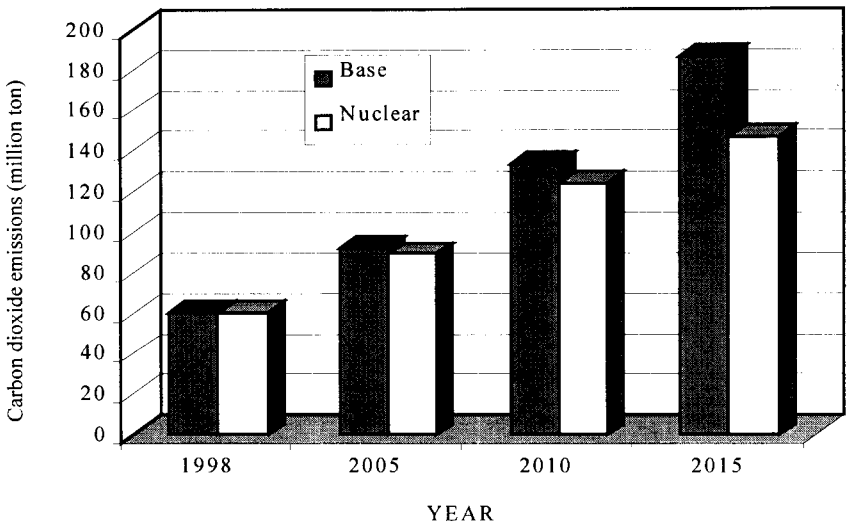

Fig. 3. Comparison of CO_2 emissions from fossil-fired power plants in selected years.

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