Impacts of Distributed Power Generation on Electricity Generation Expansion Planning and CO_2 Emission: A Case Study of Thailand

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Abstract

Recent developments in the electricity supply industry (in particular, moves to make the electricity generation market competitive) have increased the interest in distributed power generation. This study examines the economic, environmental and generation planning implications of three types of distributed generation technology options: solar photo-voltaic (PV), wind, and biomass in the power sector of Thailand during 2005-2019. This study is based on a long term integrated resource planning framework. It shows that distributed generation based on biomass would be cost effective in Thailand during the planning horizon. Power generation based on solar and wind are not found cost effective at current prices during the planning horizon. However, solar PV and wind based generation would be economically attractive if the capacity costs of these technologies were to decrease by 81% and 72% from their present levels, respectively. This study also analyzes the effects of CO_2 emission reduction constraints in the power sector. It is found that solar PV and wind power generation technologies would be cost effective at their present prices if there is a constraint to reduce total power-sector CO_2 emission by 13%.

Keywords: Distributed power generation, integrated resource planning, environmental emissions

1. Introduction

Thailand is moving towards deregulation and decentralization of the electrical power system. The introduction of competition into the generation segment is one factor driving distributed generation, decentralized small sized power plants located at or close to the load at distribution level. Furthermore, due to the economic crisis, government faces the difficulty of investing large amounts of money on power systems. Distributed generation is perceived to be an effective way to defer expensive additions in capacity-constrained systems and also to improve reliability of existing systems. The public concern about environmental problems in a country can promote distributed generation alternatives to conventional power generation. In Thailand, the development and penetration of distributed generation is low. By this study, analysis of the distributed generation power systems of Thailand will determine the potential technology and cost effectiveness under the integrated resource planning (IRP) framework.

2. Methodology, Data and Assumptions

2.1 Methodology

To study the effect of distributed generation (DG) plants on power systems in Thailand, 2 scenarios are considered. These are with and without contribution of DG under integrated resource planning (IRP) perspectives. In the case with contribution of DG, 3 types of DG technologies: solar, wind and biomass technologies are considered, to study the effect on power systems in Thailand. The effect of distributed generation on power systems is shown by the differences between the 2 scenarios in total cost, pollution emissions and utilities planning, as shown in Figure 1.

2.2 Input Data in the Base Case

Assumptions and Characteristics of power plant

This study uses the integrated resource planning analysis (IRPA) model, developed by AIT (Shrestha et. al, 2001), to investigate the effect of distributed generation (DG) on power systems in Thailand. The planning horizon is 15 years (2005-2019). The year 2001 is assumed as a base year with a discount factor of 8.25%. The two scenarios are considered in the planning horizon of 2005-2019, assuming that there are 2 seasons per year (season1: January to March, season 2: April to December) and 12 blocks in the load curve. Reserve margin is assumed to be 25% annually.

As of April 2000, the total self-generation and purchase capacity is 18,951.2 MW (excluding 0.5 MW of renewable energy), of which; 2,880 MW is from hydro; 6,492.5 MW from conventional oil/gas and lignite-fired thermal; 5,074.6 MW from combined-cycle; 662 MW from gas turbine and diesel; and 3,842.1 MW from purchased power. The candidate plants consist of 12 thermal plants; 300, 700, and 1,000 MW of oil-fired power plants; 300, 500, 700, 1,000 MW of coal-fired plants; 100, 200 MW of gas turbine plants; 300 and 700 MW of combined cycle plants; and 3 pump storage plants (2 plants at 400 MW, and one at 660 MW).

Load Data

Data on load demand of power systems consists of a normalized load curve, annual system load in percentage and annual system peak demand in MW. The annual peak loads and load demand of power systems for the study period are obtained from a load forecast of EGAT [3]. The peak load is expected to increase from 21,221.2 MW in 2005 to 41,604.8 MW in 2019. Annual system load factors are 72.51% in 2005 and 76.88% in 2019.

Demand Side Management (DSM) Options

There are 11 types of DSM options considered in this study, which are, 1) Replacing 60W incandescent lamps with 13W compact fluorescent lamp (CFL) in the residential sector, 2) Replacing 60W incandescent lamps with 18W slim fluorescent lamp (SFL) and magnetic ballast in the residential sector, 3) Replacing 60W incandescent lamps with 18W SFL and electronic ballast in the residential sector, 4) Replacing standard refrigerators with efficient refrigerators in the residential sector, 5) Replacing standard air-conditioners (ACs) with efficient ACs in the residential sector, 6) Replacing standard ACs with efficient ACs in the commercial sector, 7) Replacing standard motors (size less than 5 hp) with energy efficient motors (EEMs) in the industrial sector, 8) Replacing standard motors (5-20 hp) with EEMs, 9) Replacing standard motors (20-50 hp) with EEMs, 10) Replacing standard motors (50-125 hp) with EEMs, and 11) Replacing standard motors (125-500 hp) with EEMs.

Transmission and Distribution Losses

Based on data collected from EGAT, transmission loss is considered to be 2.5% and distribution loss is 10% in this study.

2.3 Input Data and Characteristics of Distributed Generation

Solar Technology (Photovoltaics)

The cost of fuel consumption of photovoltaics (PV) system is assumed to be zero. The life time of PV is 20 years. It is assumed that there is no pollution emission from PV power generation and the transmission loss is zero percent for DG technology because DG will supply electricity close to the load using a low voltage distribution line. PV generates power as shown in Table 1. Data on cost expenses consists of capacity cost at 6,000 K$ per MW (k$/MW), fixed O&M cost at 0.818 k$/MW-month, operating cost at 0.001 k$/MW. Unit capacity is 0.5 MW.

Biomass Technology

There are three types of biomass fuel: rice husk, wood residue, and bagasse. Capacity cost of bagasse based plant is 2,392.86 k$/MW, operating cost is 0.00061 k$/MWh and the fixed O&M costs are 2.95 k$/MW-month with the units capacity of 5.6 MW [9]. The total maximum units are 27 units at a potential of 151 MW. Fuel wood-based plant has installed capacity cost at 2,790.32 k$/MW. The operating cost and fixed O&M costs are the same as bagasse-based plants. The unit capacity is 3.1 MW. The total maximum units selected is 33 units. Rice husk-based plant has installed capacity cost at 1,158.75 k$/MW while operating costs and fixed O&M costs are the same as bagasse-based plants. The unit capacity is 8 MW with maximum of 35 units. These biomass-based plants are assumed to generate at maximum capacity at any hour.

Wind Technology

The wind technology site selected in this study is the Nord Tank wind turbine generator, which was recently installed and located at Promthep Cape, Phuket Island and operated by EGAT [2]. The cut-in speed of Nord Tank is at 4 m/sec and reaches the maximum output of 114.9 kW at 11 m/sec. The unit lifetime is 25 years. The capacity cost is 2,058 k$/MW, fixed O&M costs are 1.67 k$/MW-month, operating cost is at 0.001 k$/MWh and unit capacity is 0.15 MW. The load pattern of wind technology (Nord Tank) can be separated into 2 seasons as shown in Table 2.

3. Results and Discussions

3.1 Implications of photovoltaic power generation on power systems

Effects of PV can be found in 3 different ways. In this study, the implications of PV power generation on economics, environment, and utility planning can be analyzed from the different generation expansion plans between the base case scenario and the case with contribution of PV power generation.

In the case of PV power generation, the generation expansion plan achieved the same result as in the base case. There is no unit of PV selected to generate power because the present price and characteristics of PV are not economically competitive under cost minimization. Therefore, it is interesting to ask the question: At what price would PV be feasible for generating power. Based on the same conditions under the sensitivity analysis method, PV would be financially attractive if the capacity cost was decreased by 81% from the present price (from 6,000 k$/MW to 1,140 k$/MW). This would promote power generation from PV to be competitive to other technologies. Table 3 shows the effects of PV power generation, at 81% cost subsidy from present price, on additional installed capacity.

Economic implications of photovoltaic power generation

Total cost of the case with contribution of PV power generation decreases from the base case, of 42,894.03 million US dollars to 42,890.55 million US dollars, (decreasing from 27,932.7 GWh total power generation from PV). The capacity cost increases to 195.19 million US dollars, fuel and variable costs decrease by 176.76 million US dollars, and fixed O&M costs slightly decrease by 21.91 million US dollars. Thus, fuel and variable cost are the major parts in the total cost (almost 80%). Fixed O&M costs share around 9.15% of total cost in both cases while the share of capacity cost is around 9.71% of the total. Capacity cost increases from the base case because of the increase in capacity cost of PV-based plants.

However, government subsidies, which make the price of PV decrease, must be included in the total cost. Therefore, the total cost becomes 49,023.87 million US dollars after including the cost of subsidies. The cost of subsidy is 6,133.32 million US dollars or 12.51% of total cost. Table 4 shows the effects of PV power generation on total cost.

Environmental implications of photovoltaic power generation

The CO_2, SO_2, and NO_x emissions decrease from the base case because PV is a clean and environmental friendly technology. The pollution emission of PV power generation is zero for all three types of pollution. The reduction of CO_2, SO_2, and NO_X emissions are 1.36%, 0.015%, and 1.23% respectively, compared to the base case (at total PV power generation of 2,7932.7 GWh). The emission reductions are shown in Table 5.

Sensitivity analysis of photovoltaics under emission constraints

At the present cost and its specific load pattern of PV conditions, there is no incentive to promote power generation from PV without any subsidy or technological improvement. By using the emission reduction constraint, it may promote the PV power generation easier. By limiting the number of annual CO_2 emissions at 1%, 5%, 10%, 11%, 12%, 13%, 14%, 15%, 20%, 25% reductions from the base case, it was found that the introduction of PV could be done by setting emission constraints at 13% annually reducing from the base case at present price of PV without any subsidy.

Utility planning implications of photovoltaic power generation

From Table 6, power generated from PV helps reduce the installed capacity of the coal and lignite-based plants. One unit of new coal-based plant is replaced by power generated from PV. The share of installed capacity of PV in the capacity mix is 2.88% of the total installed capacity. This also has the same effect on the generation mix. Generation mixes from PV and heavy oil-based plants increase to replace generation from coal and lignite-based plants.

3.2 Implication of wind power generation on power systems

The generation expansion plan from the case of contribution of wind power generation achieved the same result as in the base case. Similarly, in the case of contribution of PV power generation, wind-based plants are also not economically competitive under cost minimization. Sensitivity analysis method shows that a capacity cost of 567 k\$/MW or 72% subsidy of the present price (1,333 k\$/MW) would promote power generation from wind based plant on power systems at of 4,109 MW total during the planning horizon. Table 7 shows generation expansion plans of the base case and the case with contribution of wind power generation at breakeven point (72% cost subsidy from present price).

The wind-based plant can generate power at a specific period of time and is potentially limiting, according to its specific load pattern. Therefore, generation expansion planning in the case of the contribution of wind power generation required higher additional installed capacity than the base case, to sustain power generation required on the power demand.

Economic implications of wind power generation

The total cost of the case with contribution of wind power generation is 42,881.82 million US dollars (from wind power generation at 70,777.6 GWh) which is a decrease of 12.21 million US dollars from the base case. Total cost increases 683.71 million US dollars. There are savings of 695.92 million US dollars, which is composed of saving from fuel and variable costs 642.18 million US dollars and 53.74 million US dollars from fixed O&M cost. The savings from fixed O&M and fuel and variable costs are higher than the increase in capacity cost resulting in lower total cost. Thus, share of fuel and variable cost plays an important role, 78.28% and 76.80% of total cost in the base case and the wind power generation case respectively. Fixed O&M costs share around 9.10% of total cost in both cases. Share of capacity cost increases from 9.26% in the base case to 10.58% in the wind power generation case due to the higher in capacity cost of wind based plant and the total number of additional installed capacity.

However, the subsidies, which make the price of wind technology decrease, would be included into the total cost. Therefore, the total cost without any subsidies becomes 49,011.08 million US dollars after including cost of paying subsidies at 6,129.26 million US dollars. The share of subsidy cost is 12.5% of the total cost. Table 8 shows the effects of wind power generation on total cost.

Environmental implications of wind power generation

The pollution emission of wind power generation is assumed to be zero for all three types of pollution. The number of CO_2, SO_2, and NO_X emission reductions are 3.24%, 1.33%, and 2.95% respectively, compared to the base case. The emission reductions are shown in Table 9.

Sensitivity analysis of wind power generation under emission constraints

At the present cost and its specific load pattern of wind technology conditions, there is no incentive to promote power generation from wind without any subsidy or technological improvement. By using the emission reduction constraint, it may promote the wind power generation easier. The number of annual CO_2 emissions are set at levels of 10%, 11%, 12%, 13%, 14%, and 15% reductions from the base case. It is interesting to note that wind technology at present prices and characteristics would promote the generation of power in systems by setting the CO_2 emission reduction constraint at 13% annually from the base case without any subsidy.

Utility planning implications of wind power generation

Power generated from wind-based plants would effect additional installed capacity required of the coal and lignite-based plants. One unit of new installed capacity required coal-based plant (1,000 MW) is replaced by a wind-based plant at 4,109 MW. The share of installed capacity of wind-based plants in the capacity mix is 8.80% of the total installed capacity in 2019. The generation mix of wind power generation is 2.33% of the total. Power generation from wind and heavy oil-based plants increase to replace generation from coal and lignite-based plants.

3.3 Implication of biomass power generation on power system

The scenario of contribution of distributed generation considers power generation from biomass, which consists of 3 types of fuel: rice husk, bagasse and wood residue.

Utility planning implications of biomass power generation

Table 11 shows that total additional capacity required in the base case is more than the biomass case because the size of biomass-based plant is smaller than a conventional power plant. Thus, the small size of power plant can serve and meet the power demand easier than the larger size. So the introduction of biomass power generation can save total additional capacity requirements. In this study all biomass-based plants are selected at a maximum potential load. One unit of new installed coal-based plant is replaced by power generated from biomass. The share of biomass-based plants in capacity mix is 1.24% of the total installed capacity. Generation mixes of coal and lignite decrease from the base case. Power generations from PV and heavy oil increase to replace generations from coal and lignite-based plants.

Economic implications of biomass power generation

Total cost is decreased from the base case, from 42,894.03 million US dollars to 42,526.56 million US dollars, which is decreasing from totally 71,879 GWh power generation from biomass. Capacity cost increases 281.61 million US dollars, fuel and variable costs decrease 684.45 million US dollars, and fixed O&M costs slightly increase 35.37 million US dollars. The savings in fuel and variable costs are more than the increase of capacity cost resulting in lower total cost. Fuel and variable costs still share a major part of total cost, about 78%. Shares of capacity cost are 9.26% and 10% of total cost in the base case and the biomass power generation case, respectively. Fixed O&M costs share 9.19% of total cost in the base case and 9.35% of total cost in biomass power generation case. Table 13 shows the effects of biomass power generation on total cost.

Environmental implications of biomass power generation

Pollution emission reductions from biomass power generation can be found in Table 14, CO_2 emission reduction is 68.44 million ton or around a 3.26% decrease from the base case. The percentages of reduction of SO_2 and NO_x from the base case are 1.7% and 3%, respectively.

4. Conclusions

PV is not yet financially attractive at present prices. An 81% subsidy of the present price would make PV economically competitive compared to other technologies. Technological improvement in the future would make the price of imported PV components decrease. Then, PV would be attractive in the future. Emission reduction constraints at 13% annually reduction can also promote power generation from PV even at present prices, without any subsidy. Power generation from PV will replace one unit of newly installed coal plant during the planning horizon. Total pollution emissions and fuel consumption during the planning horizon also decrease from this replacement, together with the change in capacity mix and generation mix.

Wind technology, which has a lower capacity cost than PV but still is not economically competitive at present prices because the potential of wind energy is very low. As seen The cut-in speed required for generating power is normally higher than the average wind speed in Thailand. Therefore, at this potential of wind energy in Thailand, wind technology required 72% subsidy of present prices to be cost effective. CO_2 emission reduction constraints at 13% annually would promote power generation from wind even at present prices. Power generation from wind would effect power systems in the same manner as the PV, replacing one new additional capacity required of coal-based plant, and also changing the capacity and generation mixes. Biomass technology at present day is competitive with other technologies. Biomass-based plant technologies are all selected at full potential load. But the system reliability is also lower in the case of biomass power generation. The efficiency of the biomass-based plant is lower compared to other technologies, resulting in higher fuel consumption. However, the fuel cost of biomass is quite low. It is also easy to find a local site area. Therefore, there would be some benefits from the saving in fuel price.

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Table 1: Load pattern of photovoltaics system.

Time	00.00-06.00	06.00-08.00	08.00-10.00	10.00-14.00	14.00-16.00	16.00-18.00	18.00-24.00
PV (Normalized Load to Max. Capacity)	0.0	0.3	0.7	1.0	0.7	0.3	0.0

Table 2: Load patterns of wind technology in season 1 and season 2.

Time	Season 1	Season 2
	Normalized Load to Max. capacity	Normalized Load to Max. capacity
00.00-02.00	0.1249	0.1615
02.00-04.00	0.1357	0.1698
04.00-06.00	0.1350	0.1707
06.00-08.00	0.1109	0.1785
08.00-10.00	0.1363	0.1915
10.00-12.00	0.1221	0.1880
12.00-14.00	0.0857	0.1837
14.00-16.00	0.0000	0.1767
16.00-18.00	0.0000	0.1759
18.00-20.00	0.0703	0.1689
20.00-22.00	0.0913	0.1559
22.00-24.00	0.0997	0.1476

Table 3: Effects of PV power generation on additional installed capacity.

Year of Selection	IRP Base Case		PV Power Generation	
	Plant Name	Total Capacity Addition (MW)	Plant Name	Total Capacity Addition (MW)
2006	Kirindharn Pump.	660	PV	2
			Kirindharn Pump.	660
2007	Coal FGD1000	2,000	Coal FGD1000	1,000
			PV	606
2008	Coal FGD1000	1,000	Coal FGD1000	1,000
	Chulabhorn 1-2	400	Chulabhorn 1-2	400
	Chulabhorn 3-4	400	Chulabhorn 3-4	400
2009	Coal FGD1000	1,000	Coal FGD1000	2,000
2010	Coal FGD1000	1,000	Coal FGD1000	1,000
2011	Coal FGD1000	3,000	Coal FGD1000	2,000
2012	Coal FGD1000	1,000	Coal FGD1000	2,000
2013	Coal FGD1000	2,000	Coal FGD1000	1,000
2014	Coal FGD1000	2,000	Coal FGD1000	3,000
2015	Coal FGD1000	3,000	Coal FGD1000	2,000
2016	Coal FGD1000	1,000	Coal FGD1000	1,000
2017	Coal FGD1000	2,000	Coal FGD1000	3,000
2018	Coal FGD1000	4,000	Coal FGD1000	3,000
2019	Coal FGD1000	1,000	Coal FGD1000	1,000
			PV	654
Total Capacity		25,460		24,993

Table 4: Effects of PV power generation on total cost.

Total Cost Components	Base Case (million US$)	% share of total (%)	PV Case (million US$)	% share of total (%)
Capacity Cost	3,969.96	9.26	4,165.15	9.71
Fuel & Variable Cost	33,575.99	78.28	33,399.23	77.87
Fixed O&M Cost	3,941.32	9.19	3,919.41	9.14
DSM Cost	1,406.76	3.28	1,406.76	3.28
Total Cost	42,894.03	100.00	42,890.55	100.00

Table 5: Change of CO_2, SO_2, and NO_x emissions.

Pollution emission reductions	CO_2 Emission	SO_2 Emission	NOx Emission
	Gg	Mg	Mg
IRP base case	2,097,214.10	17,262,171.60	6,793,609.40
PV breakeven point case	2,068,784.70	17,259,529.70	6,709,801.70
Emission Reduction	28,429.40	2,641.90	83,807.70
Emission Reduction per generation unit (Unit/GWh)*	1.02	0.09	3.00

*Total Generation of PV during planning horizon is 27,932.7 GWh.

Table 6: Capacity Mix and Generation Mix of the Base case and the PV case.

Fuel Type	Capacity Mix in 2019 (MW)				Generation Mix in 2019 (GWh)			
	Base Case	%Share of total	PV case	%Share of total	Base Case	%Share of total	PV case	%Share of total
Coal + Lignite	6,634.0	61.1	25,634.0	58.5	188,985.0	71.3	181,857.0	68.7
Natural Gas	4,638.0	10.7	4,638.0	10.6	33,830.0	12.8	33,830.0	12.8
Heavy Oil	2,970.0	6.8	2,970.0	6.8	18,233.0	6.9	20,744.0	7.8
Diesel Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPP	1,979.0	4.5	1,979.0	4.5	14,513.6	5.5	14,513.6	5.5
Solar	0.0	0.0	1,262.0	2.9	0.0	0.0	4,118.0	1.6
Hydro	7,340.6	16.9	7,340.6	16.8	9,562.8	3.6	9,562.8	3.6
Total	43,561.6	100.0	43,823.6	100.0	265,124.4	100.0	264,625.4	100.0

Table 7: Effects of wind power generation on additional installed capacity.

Year of Selection	IRP Base Case		Wind Power Generation	
	Plant Name	Total Capacity Addition (MW)	Plant Name	Total Capacity Addition (MW)
2006	Kirindharn Pump.	660	Wind based plant	4
			Kirindharn Pump.	660
2007	Coal FGD1000	2,000	Coal FGD1000	1,000
			Wind based plant	1,732
2008	Coal FGD1000	1,000	Coal FGD1000	1,000
	Chulabhorn 1-2	400	Chulabhorn 1-2	400
	Chulabhorn 3-4	400	Chulabhorn 3-4	400
2009	Coal FGD1000	1,000	Coal FGD1000	1,000
			Wind based plant	2,188
2010	Coal FGD1000	1,000	Coal FGD1000	1,000
2011	Coal FGD1000	3,000	Coal FGD1000	3,000
2012	Coal FGD1000	1,000	Coal FGD1000	1,000
2013	Coal FGD1000	2,000	Coal FGD1000	2,000
2014	Coal FGD1000	2,000	Coal FGD1000	2,000
2015	Coal FGD1000	3,000	Coal FGD1000	3,000
2016	Coal FGD1000	1,000	Coal FGD1000	1,000
2017	Coal FGD1000	2,000	Coal FGD1000	2,000
			Wind based plant	184
2018	Coal FGD1000	4,000	Coal FGD1000	4,000
2019	Coal FGD1000	1,000	Coal FGD1000	1,000
Total Capacity		25,460		28,569

Table 8: Effects of wind power generation on total cost.

Total Cost Components	Base Case (million US$)	% share of total (%)	Wind Case (million US$)	% share of total (%)
Capacity Cost	3,969.96	9.26	4,653.67	10.85
Fuel & Variable Cost	33,575.99	78.28	32,933.81	76.80
Fixed O&M Cost	3,941.32	9.19	3,887.58	9.07
DSM Cost	1,406.76	3.28	1,406.76	3.28
Total Cost	42,894.03	100.00	42,881.82	100.00

Table 9: Change of CO_2, SO_2, and NO_X emissions.

Pollution emission reductions	CO_2 Emission	SO_2 Emission	NOx Emission
	Gg	Mg	Mg
IRP base case	2,097,214.10	17,262,171.60	6,793,609.40
Wind Technology breakeven point case	2,029,166.60	17,032,303.90	6,593,272.00
Emission Reduction	68,047.50	229,867.70	200,337.40
Emission Reduction per unit (Unit/GWh)*	0.96	3.25	2.83

*Total Generation of wind technology during planning horizon is 70,777.6 GWh.

Table 10: Capacity Mix and Generation Mix of the base case and the wind case.

Fuel Type	Capacity Mix in 2019 (MW)				Generation Mix in 2019 (GWh)			
	Base Case	%Share of total	Wind case	%Share of total	Base Case	%Share of total	Wind case	%Share of total
Coal + Lignite	26,634.0	61.1	25,634.0	54.9	188,985.0	71.3	181,857.0	68.8
Natural Gas	4,638.0	10.7	4,638.0	9.9	33,830.0	12.8	33,830.0	12.8
Heavy Oil	2,970.0	6.8	2,970.0	6.4	18,233.0	6.9	18,521.0	7.0
Diesel Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPP	1,979.0	4.5	1,979.0	4.2	14,513.6	5.5	14,513.6	5.5
Wind	0.0	0.0	4,109.0	8.8	0.0	0.0	6,161.0	2.3
Hydro	7,340.6	16.6	7,340.6	15.7	9,562.8	3.6	9,562.8	3.6
Total	43,561.6	100.0	46,670.6	100.0	265,124.4	100.0	264,445.4	100.0

Table 11: Effects of biomass power generation on additional installed capacity.

Year of Selection	IRP Base Case		Biomass Power Generation	
	Plant Name	Total Capacity Addition (MW)	Plant Name	Total Capacity Addition (MW)
2005			Rice Husk	280
2006	Kirindharn Pump.	660	Kirindharn Pump.	660
			Bagasse	11
2007	Coal FGD1000	2,000	Coal FGD1000	1,000
			Bagasse	140
2008	Coal FGD1000	1,000	Coal FGD1000	1,000
	Chulabhorn 1-2	400	Chulabhorn 1-2	400
	Chulabhorn 3-4	400	Chulabhorn 3-4	400
			Fuel Wood	102
2009	Coal FGD1000	1,000	Coal FGD1000	2,000
2010	Coal FGD1000	1,000	Coal FGD1000	1,000
2011	Coal FGD1000	3,000	Coal FGD1000	2,000
2012	Coal FGD1000	1,000	Coal FGD1000	1,000
2013	Coal FGD1000	2,000	Coal FGD1000	2,000
2014	Coal FGD1000	2,000	Coal FGD1000	2,000
2015	Coal FGD1000	3,000	Coal FGD1000	3,000
2016	Coal FGD1000	1,000	Coal FGD1000	1,000
2017	Coal FGD1000	2,000	Coal FGD1000	2,000
2018	Coal FGD1000	4,000	Coal FGD1000	4,000
2019	Coal FGD1000	1,000	Coal FGD1000	1,000
Total Capacity		25,460		24,993

Table 12: Capacity mix and generation mix of the base case and the biomass case.

Fuel Type	Capacity Mix in 2019 (MW)				Generation Mix in 2019 (GWh)			
	Base Case	%Share of total	Biomass case	%Share of total	Base Case	%Share of total	Biomass case	%Share of total
Coal + Lignite	26,634.0	61.1	25,634.0	58.5	188,985.0	71.3	181,857.0	68.7
Natural Gas	4,638.0	10.7	4,638.0	10.8	33,830.0	12.8	33,830.0	12.8
Heavy Oil	2,970.0	6.8	2,970.0	6.9	18,233.0	6.9	19,612.0	7.8
Diesel Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPP	1,979.0	4.5	1,979.0	4.6	14,513.6	5.5	14,513.6	5.5
Biomass	0.0	0.0	533.0	1.2	0.0	0.0	5,179.0	1.6
Hydro	7,340.6	16.9	7,340.6	17.0	9,562.8	3.6	9,562.8	3.6
Total	43,561.6	100.0	43,094.6	100.0	265,124.4	100.0	264,554.4	100.0

Table 13: Effects of biomass power generation on total cost.

Total Cost Components	Base Case (million US$)	% share of total (%)	Biomass Case (million US$)	% share of total (%)
Capacity Cost	3,969.96	9.26	4,251.57	10.00
Fuel & Variable Cost	33,575.99	78.28	32,891.54	77.34
Fixed O&M Cost	3,941.32	9.19	3,976.69	9.35
DSM Cost	1,406.70	3.28	1,406.76	3.31
Total Cost	42,894.03	100.00	42,526.56	100.00

Table 14: Cumulative Pollution Emissions during 2005-2019.

Case	Pollution Emission		
	CO_2 (Mton)	SO_2 (kton)	NO_X (kton)
IRP base case	2,097.21	17,262.17	6,793.61
Biomass Case	2,028.77	16,968.83	6,589.97
Emission Reduction	68.44	293.34	203.64

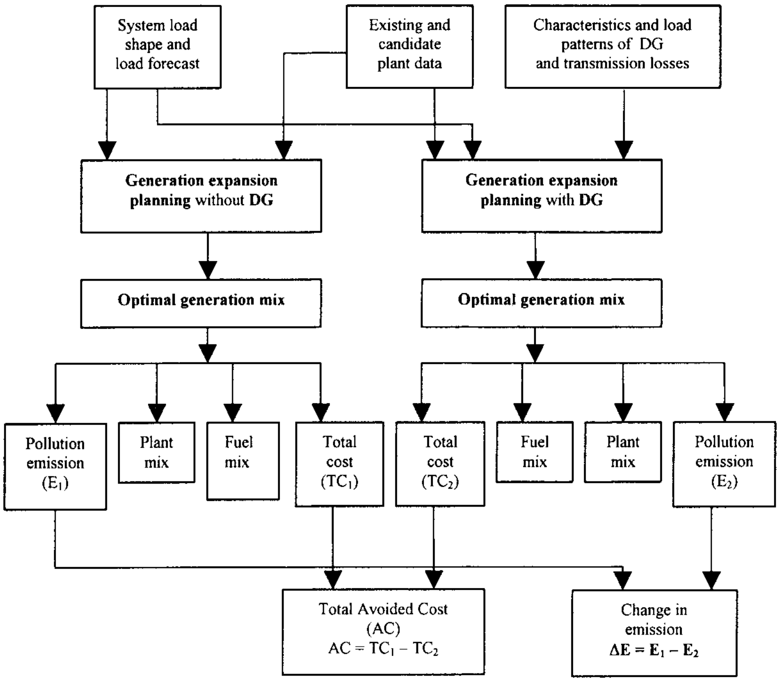

Figure 1: Flow chart to determine the effect of DG on power systems in Thailand.

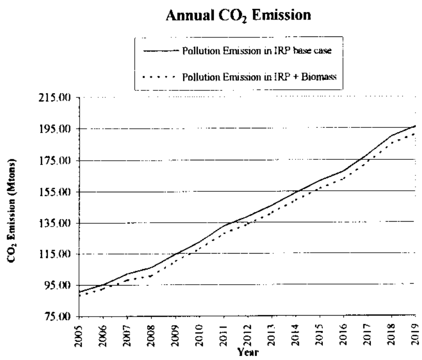

Figure 2: Comparison of CO_2 emissions.

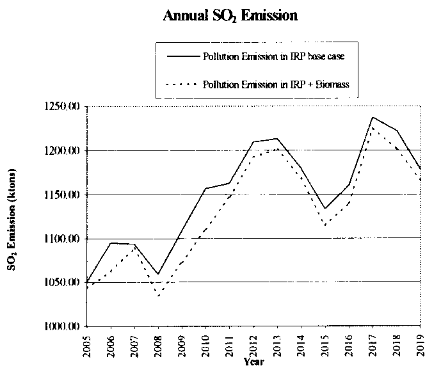

Figure 3: Comparison of SO_2 emissions.