How to Estimate a Correct Buyback Rate from Diesel Cycle and Gas Turbine Cogeneration and the Appropriate Measures to Protect the Environment in Thailand

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ABSTRACT

The Electricity Generating Authority of Thailand (EGAT) has drawn up regulations for the purchase of electricity from Small Power Producers(SPPs). Diesel cycle and gas turbine cogeneration can produce electricity to sell to EGAT and steam to use in manufacture.

There are two ways in which EGAT purchases electricity from SPPs; the firm and the non-firm pattern. The levelized electricity costs in the firm pattern (capacity cost plus energy cost) over 10, 15, 20 and 25 years are 0.045, 0.047, 0.049 and 0.054 US$/kW-h respectively [1]. The levelized electricity costs in the non-firm pattern will not be shown in this paper.

The price of 14 MW of diesel cycle cogeneration generated electricity if sold to EGAT is sold at a loss. (The useful life-time is 10 years if using distilled oil or natural gas or fuel oil. Every fuel makes a loss. In a useful life-time of 15 years distilled oil still makes a loss. The Internal Rate of Return for natural gas is 11% and for fuel oil 9%). So steam produced can be used in a factory to greater advantage and to reduce the loss.

Gas turbine cogeneration of 90 MW produces electricity sold to EGAT. In a useful life-time of 10 years distilled oil makes a loss. The IRRs are 7% and 2% when using natural gas and fuel oil. In a useful life-time of 25 years, the maximum IRRs are 16.88%, 33% and 29% using distilled oil, natural gas and fuel oil respectively.

Cogeneration uses fossil fuel and produces CO_2, CO, NO_X, and SO_2 emissions. These emissions will accumulate in the atmosphere and help create the Green - house effect. This effect directly strikes the world environment, nature and mankind.

Using a scrubber to reduce costs 0.0063 US$/kW-h [3], a controlled complete burn will reduce CO, NO_X, and HC.

There are two ways to establish a carbon tax to protect the environment: Firstly, to directly tax emissions in order to promote the technical reduction of the pollutant, which, today, is neither realistic nor attractive to the energy producer. Secondly, an estimation can be based on the difference in cost between the capital investment in a cogeneration plant (US$/kW-h, low but polluting) and in a hydroelectric plant (US$/kW-h, high but pollution-free). In this paper only the second method is examined.

As a result CO_2 taxes of 6.643 - 7.829 US$/ton CO_2 ; 26.492 - 38.66 US$/ton CO_2 and 12.566 - 18.254 for distilled oil; natural gas and fuel oil were obtained respectively.

1. INTRODUCTION

The rate of electrical power demand has been very high in recent years. The maximum electrical power demand in 1994 was about 10% higher than in 1993 and energy demand was about 12% higher.

The results of forecasts by The Electrical Demand Forecast Sub-committee in 1993 expected the rate of increase of electrical demand to diminish. The National Economic and Social Development Plans 7 to 10 show that:

Table 1. The National Economic and Social Development Plans Versions 7-10 [3].

Plan version	Year	Electrical demand (MW)			Average Rate of Increase (%)
		From	To	Increase	
7	1992-1996	8,045	13,009	4,964	10.09
8	1997-2001	13,009	19,029	6,020	7.90
9	2002-2006	19,029	25,371	6,342	5.92
10	2007-2011	25,317	33,532	8,161	5.74

The investment cost for increased electrical standby is a heavy load on the Thai government. There are many ways to approach the solution: for example; The use of high efficiency appliances, persuading people to conserve energy and the promotion of cogeneration in the industrial sector.

The Electricity Generating Authority of Thailand (EGAT) has drawn up regulations for the purchase of electricity from Small Power Producers(SPP) EGAT will purchase electricity not exceeding a 60 MW capacity from each SPP. If over 60 MW, EGAT will consider electrical availability and security, for each SPP, under 90 MW. This paper shows cogeneration systems which use heavy oil, natural gas and distilled oil as fuel. In the first pattern, the firm pattern, SPP must supply electricity of a certain, decided capacity. The Payment Time Contract (t) over 5 years is determined from EGAT's long-run avoided capacity cost in purchasing electricity from SPPs for 5<=t <=10, Capacity cost is 6.469 US$/kW-month ; for 5<=t <=15, Capacity cost is 8.284 US$/kW-month ; for 5 <= t <= 20, Capacity cost is 8.955 US$/kW-month ; for 5 <= t <= 25, Capacity cost is 11.913 US$/kW-month.

The energy payment is determined from EGAT's long run avoided energy cost (fuel cost, operation cost, maintenance cost), resulting from purchasing electricity from the SPP at 0.0335 US$/kW-h.

Secondly on the non-firm pattern, there is no capacity payment . The SPP will produce electricity to be used in its own factory, the remainder to be sold to EGAT at an energy payment, determined by EGAT's short run avoided energy cost, resulting from purchasing electricity from the SPP. The energy payment is based on the "Time of Day "(TOD) energy payment of about 0.0343 US$/kW-h. This pattern is not shown in this paper.

In addition, in order to protect the environment, a tax on Carbon Dioxide was introduced. This tax on cogeneration will be used to influence consumer demand and introduce protective measures. The method to calculate the tax is demonstrated in the second part of the paper.

2. CALCULATION PROCEDURE

In this case, the following were considered: diesel cycle cogeneration with a capacity of 14 MW and a useful life-time of 15 years and a gas turbine and steam turbine cogeneration capacity of 90 MW and a useful life of 25 years with operating hours of 7,008 hours per year using diesel oil, natural gas and heavy oil. Its parameters are shown in Tables 2 and 3.

Table 2. Total plant cost of diesel cycle, gas turbine and steam turbine cogeneration with capacities of 14 MW, 90 MW and 90 MW respectively [2][12][13].

Investment cost	Diesel cycle cogen (14 MW)	Gas turbine cogen (90 MW)	Steam turbine cogen (90 MW)
Direct cost (US $)			
1. System and installation cost	10,570,000	31,500,000	40,500,000
2. Water disposal system	106,820	288,000	388,800
3. Land price	528,500	1,575,000	2,025,000
4. Water treatment	1,585,500	4,725,000	6,075,000
Total direct cost (US $)	12,790,820	38,088,000	48,988,800
Indirect cost (US $)			
1. Contingencies	2,558,164	7,617,600	9,797,760
2. Engineering and construction management	1,918,616	5,713,200	7,348,320
Total indirect cost (US $)	4,476,780	13,330,800	17,146,080
Total plant cost (US $)	17.2676 m	51.4188 m	66.1349 m

Table 3. A description of cogeneration fuel .

	Diesel oil	Natural gas	Fuel oil
1. Fuel price (US$/ton)	378.12	84.24	137.47
2. Fuel consumption (ton/hour) for diesel cogen (14 MW)	2.18	1.84	3.14
3. Fuel consumption (ton/hour) for gas turbine cogen (90 MW)	31.05	26.3	31.39

Capacity payment

The capacity payment is determined from EGAT's long-run avoided capacity cost in purchasing electricity from SPPs. The capacity payment is then determined from the contracted term that the SPPs will generate and supply electricity to EGAT as given in Table 4.

Table 4. Criteria in determining capacity payment.

Length of contract	Capacity payment
Not exceeding 5 years :	No capacity payment
From 5 years to 25 years :	Equivalent to the long-run avoided capacity cost during the contracted term that the SPPs generated and supplied electricity.

From 5 years to 20 years.

$$C_{P_n} = \frac{[I_O - (P_{V_{n_{1-5}}} I_{n_{1-5}}) + (P_{V_{25}} B_{25-n_1})]CRF_{n_{1,d}}}{12} \quad (1)$$

$$B_{25-n_1} = \frac{[100 - D(25-n_1)]I_{n_{1-5}}}{100} \quad (2)$$

From 20 years to 25 years.

$$C_{P_n} = \frac{I_O CRF_{n_1,d}}{12} \quad (3)$$

Energy Payment

For any SPP which is eligible for a capacity payment , the energy payment is determined from EGAT' s long-run avoided energy cost resulting from purchasing electricity from the SPP.

$$E_P = \frac{(C_1 F_1 kW_{h1} + C_2 F_2 kW_{h2} + - - - - - C_N F_n kW_{h\,n}) + OM}{kW_{h\,t}} \quad (4)$$

The Effect of Hydrocarbon fuel on the Environment

Electrical energy demand in Thailand is increasing because of rapid economic expansion . The electricity produced by EGAT in December 1994 totaled 12,990 MW which was 2.8% more than in the previous year [3]. It consisted of cogeneration; heat energy; hydro - electricity; gas turbine and diesel appliances amounting to: 6102 MW; 4100 MW; 2565 MW; 210 MWand 14 MW respectively. In 1994 electrical production in Thailand was 71 409 GW-h up from the previous year's 11.6%. Fuels which are used are: natural gas; fuel oil; lignite; hydro-electricity; diesel oil; and others, amounting to 30 920GW-h; 19 647 GW-h; 14 131 GW-h; 4404 GW-h; 1385 GW-h; and 922 GW-h respectively. Electricity production which uses fossil fuels such as: fuel oil; diesel; natural gas and lignite when it burns readily will have CO_2, CO, NO_x, HC andSO_2 emissions. These emissions will accumulate in the atmosphere and create a Green-house effect. This effect directly strikes the world environment, nature and mankind. Many countries try to eradicate this pollution by growing forests to reduce CO_2,

installing scrubbers to reduce SO_2, and controlling the complete burn to reduce CO, NO_x and HC emissions [4].

IEA countries are rethinking their fiscal policies. Taxes on energy products are changing including the idea of " carbon credits " both positive and negative. Positive: They can be used to preserve the environment and reduce consumption [14]. Negative: Many Industrial Manufacturing Sector in developing country used much more money for changing technology.

In Europe taxes on SO_2, NO_x and hydrochloric acid emissions are applied when combustion amounts to more than 200 MW [5]. Recently carbon or CO_2 taxes have been introduced in Scandinavia. Though the carbon tax itself is relatively large, other energy taxes have been reduced and thus a balance is achieved.

Forecast of Carbon Dioxide emission from fuels

The estimation of carbon dioxide emission is based on the carbon contents of fuels and amounts of fuel used. It was assumed that the combustion of hydrocarbon fuels are complete and yield only carbon dioxide and water. The carbon dioxide emission is therefore related to the carbon atoms in the fuel and can be estimated from the following equation:-

$$C + O_2 \rightarrow CO_2$$

If c = Fractional mass of carbon in the fuel and M = Mass of the fuel, then , the amount of carbon dioxide emission is $44cM/12$ or $3.67\,cM$.

For fossil fuels, the carbon content in diesel oil , natural gas lignite and fuel oil is 86.5%, 64.3%, 85.4%, 33.1% respectively and the sulfur content in distilled oil, natural gas and fuel oil is 0.5%, 0.007% and 2% respectively [6].

The heating values in distilled oil, natural gas and fuel oil are 45.2MJ/kg ; 45MJ/kg and 42 MJ/kg respectively.

Carbon dioxide has been identified as deleterious in the greenhouse effect on global warming for almost a century. Greenhouse gases emissions of developing countries are 45%. Thailand contributes 1.2% and ranks eighteenth in the world [5].

Thailand has progressed from an agricultural economy to industrial in the past 10 years. Consequently the need for energy has changed from mainly renewable energy to modern energy namely coal, petroleum products and natural gas.

In the period of 1992-1996 and 1996-2001, national plan of the National Economic and Social Development Board, the average energy growth rates of Thailand were forecast at 8.2% and 7.47% per year respectively. This showed that energy consumption is very high. The National Energy Administration has reported that the consumption of fossil fuels would increase from 49 M tons in 1992 to 99.7 M tons in 2001 [9].

In 1994 energy consumption to produce electricity by EGAT from lignite, distilled oil, natural gas and fuel oil were 12.16, 0.428, 5.40 and 4.61 M tons respectively. So the electricity produced from distilled oil, natural gas, fuel oil and lignite were: 1.616 GW-h; 30.39 GW-h; 19.11 GW-h and 14.13 GW-h respectively [15]. The CO_2 emissions in 1994 are shown on Table 5.

The capital electrical production costs of diesel cycle and gas turbine cogeneration using distilled oil, natural gas and fuel oil are shown in Table 6.

3. RESULTS AND DISCUSSION

Using Eqs. 1-3 the capacity payment for EGAT's price was calculated. The capacity payment for diesel and gas turbine cogeneration as shown in Table 9 was calculated using the annual cost method.

The energy payment for EGAT's price was calculated using Eq. 4 while the energy payment for diesel and gas turbine cogeneration by using diesel oil, natural gas, and fuel oil was calculated using the annual cost method. The results are shown in Table 10.

Table 5. CO_2 emissions in Thailand in 1994 by electricity generation.

Distilled oil	Natural gas	Fuel oil	Lignite	Unit
1.362	12.74	14.448	13.87	M tons
3.175	2.359	3.134	1.141	ton/ ton fuel
0.843	0.419	0.756	0.982	kg/kW-h

Table 6. The capital investment cost of diesel cycle and gas turbine cogeneration (US$/kW-h) .

Useful life (Years)	Cogeneration technology					
	Diesel cycle cogeneration			Gas-Turbine cogeneration		
	Distilled oil	Natural gas	Fuel oil	Distilled oil	Natural gas	Fuel oil
15	0.0473	0.0418	0.0434	-	-	-
25	-	-	-	0.0462	0.0367	0.0391

Table 7. The capital investment cost of hydroelectric production [2].

Technology	Hydroelectric (Discount rate 12 %)(average useful life-time 25 years)
Cost (US$/kW-h)	0.0592

Assumptions

1. Capacity 80 MWand plant factor 33.25%.
2. Useful life-time :-
   - project : 50 years
   - dam and irrigation : 50 years
   - high voltage systems : 40 years
   - electric system and equipment : 25 years
   - substation : 25 years
3. Operation and maintenance :-
   - dam 1 %
   - high voltage systems 1%
   - electric system & equipment 2.5 %
   - irrigation 3 %

4. Investment .
   - gas turbine 335.306 US$/MW
   - dam 917,160 US$/MW
   - electric system 123,274.160 US$/MW
   - substation 22,189.349 US$/MW
   - irrigation 641,025 US$/MW
   - high voltage systems 412,500 US$/MW
   - diesel price 0.1499 US$/liter
   - heating value 8,959.6 kcal/liter
   - fuel price 0.0652 US$/kW-h
5. Depreciation - on a straight line
6. The year project began : 1989 .
7. Escalation rate
   - fuel price 6%
   - Operation and maintenance cost 6%

Table 8. CO_2 Replacement tax for Diesel cogeneration and Gas turbine cogeneration using Distilled fuel, Natural gas and Fuel oil

Diesel cogeneration			Gas turbine cogeneration			
Distilled fuel	Natural gas	Fuel oil	Distilled fuel	Natural gas	Fuel oil	units
0.0119	0.0174	0.0158	0.0129	0.0225	0.0201	US$/kW-h
Reducing SO_2 by scrubber costs 0.0063 US$/kW-h so the tax on CO_2 emissions should be :						
0.0056	0.0111	0.0095	0.0066	0.0162	0.0138	US$/kW-h
6.643	26.492	12.566	7.829	38.66	18.254	US$/ton CO_2

Table 9. Capacity payment cost for diesel cycle and gas turbine cogeneration.

Year	EGAT's price (US$/kW-month)	Diesel cycle cogeneration (US$/kW-month)	Gas turbine cogeneration (US$/kW-month)
10	6.509	17.367	7.923
15	8.047	13.676	6.218
20	8.955	-	5.424
25	11.913	-	4.991

Table 10. Energy payment cost for diesel cycle and gas turbine cogeneration using distilled oil; natural gas ; fuel oil (US$/kW-month).

Year	Diesel cycle cogeneration				Gas turbine cogeneration		
	EGAT's price	Distilled oil	Natural gas	Fuel oil	Distilled oil	Natural gas	Fuel oil
10	0.0335	0.0375	0.0276	0.0331	0.0327	0.0221	0.0245
15	0.0335	0.0375	0.0276	0.0331	0.0327	0.0221	0.0245
20	0.0335	-	-	-	0.0327	0.0221	0.0245
25	0.0335	-	-	-	0.0327	0.0221	0.0245

Table 11. Levelized electricity cost (US$/kW-h). A comparison between diesel cycle and gas turbine cogeneration using distilled oil , natural gas and fuel oil.

Year	Diesel cycle cogeneration				Gas turbine cogeneration		
	EGAT's price	Distilled oil	Natural gas	Fuel oil	Distilled oil	Natural gas	Fuel oil
10	0.045	0.052	0.046	0.048	0.050	0.042	0.044
15	0.047	0.047	0.042	0.043	0.048	0.038	0.041
20	0.049	-	-	-	0.047	0.037	0.040
25	0.054	-	-	-	0.0462	0.036	0.039

Table 12. The Internal Rate of Return (IRR) for diesel cycle and gas turbine cogeneration systems using distilled oil , natural gas and fuel oil .

Year	Diesel cycle cogeneration			Gas turbine cogeneration		
	Distilled oil	Natural gas	Fuel oil	Distilled oil	Natural gas	Fuel oil
10	lose	lose	lose	lose	7%	2%
15	lose	11%	9%	lose	19%	14%
20	-	-	-	4%	25%	19%
25	-	-	-	16.88%	33%	29%

From Tables 9 and 10 the total cost (capacity payment plus energy payment cost) was leveled. The result is shown in Table 11. Comparing the levelized electricity cost and EGAT'S price with the levelized electricity cost in the diesel cycle and gas turbine cogeneration system, using distilled oil, natural gas and fuel oil and calculating the IRR for each technology and each fuel, the IRR result is shown in Table 12.

The SPPs which use diesel cycle cogeneration to produce electricity will make a loss selling to EGAT, but will make a profit of over 25% in the following cases:

1. If EGAT buys at 0.069 US$/kW-h levelized cost over a 10 year contract.
2. If EGAT buys at 0.063 US$/kW-h levelized cost over a 15 year contract.

The SPPs which use gas turbine cogeneration to produce electricity will make a profit of over 25%:

1. If EGAT buys at 0.069 US$/kW-h levelized cost over a 10 year contract.
2. If EGAT buys at 0.063 US$/kW-h levelized cost over a 15 year contract.
3. If EGAT buys at 0.062 US$/kW-h levelized cost over a 20 year contract.
4. If EGAT buys at 0.061 US$/kW-h levelized cost over a 25 year contract.

In order to introduce an environmental tax for fossil fuel in Thailand, the diesel cycle and gas turbine cogeneration with the non-pollutant, hydroelectric generation system were compared. Fossil fuels produce pollutants like CO_2, CO, NO_x, HCs and SO_2, which damage the atmosphere. By calculating the difference in electrical production costs (in US$/kW-h), a basis on which to estimate the appropriate tax were established. The cost of SO_2 reduction by the scrubber method considering that CO, NO_x, HCs is completely burned therefore emission is negligible, can be subtracted from the total emission replacement cost (as shown in Table 8) to find the CO_2 emission replacement cost.

Today, the reduction of CO_2 production is technically feasible but is extremely expensive and does not reach break-even point. One approach is to apply an environmental tax, which influences user behavior and the revenue generated can be used to protect the environment.

As a result CO_2 taxes are being charged as follows: 6.643-7.829 US$/kW-h ; 26.492-38.66 US$/kW-h and 12.566-18.254 US$/kW-h for distilled oil; natural gas and fuel oil, respectively.

4. CONCLUSION

Cost/Price Consideration in Cogeneration

At present the SPP makes a loss on each fuel based on the levelized electricity cost on EGAT's price for SPP produced electricity from diesel cycle cogeneration.

If electricity is produced by gas turbine cogeneration using natural gas, the greatest benefit can be obtained in a firm contract exceeding 15, 20 and 25 years, the IRRs are about 19%, 25%, and 33% respectively.

Using fuel oil after 20 and 25 years, the IRRs are about 19% and 28% respectively.

The environmental Consideration

An environmental tax on cogeneration is established by comparing the technological investment cost, low but polluting, with the capital investment cost of hydroelectric plant installation, high but non-pollutant. This tax influence can be used to protect the environment .

As a result , CO_2 taxes are being charged as follows: 6.643-7.829 US$/ton CO_2 ; 26.492-38.66 US$/ton CO_2 and 12.566 -18.254 US$/ton CO_2 for distilled oil ; natural gas and fuel oil respectively

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NOMENCLATURE

C_{pn} = Capacity payment which EGAT buys from SPPs for a contract of "n " years.

n_i = Years in which the capacity payment calculation is "n_i"10, 15, 20, 25, years. Contract periods: cases 5-10 years, 10-15 years , 15-20 years and 20-25 years.

I_o = Present average investment of cogeneration which comes on line in the next 5 years (US$/kW)

$I_{n1\text{-}5} = I_o E_{n\text{-}1\text{-}5}$

= Average investment for cogeneration which will be produced in years , n1-5 (5 means cogeneration building and operating time) (US$/kW)

$E_{n\text{-}1\text{-}5}$ = Accumulated escalation factor in years n1-5

P_{Vn1} = Present worth factor at year " n1"

$B_{25\text{-}n1}$ = Cogeneration cost in 25-n1 years (US$/kW)

D = Depreciation rate of 4% per year

$CRF_{n1,d}$ = Capital Recovery Factor in year "n1" with a discount rate (d) of 12%

E_p = Energy payment is determined from EGAT 's long-run avoided energy cost resulting from purchasing electricity from the SPPs (US$/kW-h)

kW_{ht} = Total electrical energy produced from cogeneration which will be on line in the next 5 years (kW-h)

C_1 = Rated consumption (Btu/kW-h)

F_1 = Fuel price for cogeneration order n (US$/Btu)

kW_{hn} = Electrical energy produced from cogeneration order n (kW-h)

n = Nos. of cogeneration systems which will be on line in the next 5 years

OM = Operation and maintenance (US$/kW-h)

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