Assessing CO_2 Abatement Cost for Thailand's Power Generation

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Abstract: Thailand's power generation over a decade has relied on natural gas as a major energy source accounting for more than 70% of total energy supply for generating electricity. Thailand has limited natural gas resources, so Thailand has been importing natural gas from Myanmar since 1998. The latest Thailand power development plan (PDP 2010 Rev. 3) has a goal to improve energy security by reducing the reliance on natural gas by installing new coal-fired power and nuclear power plants, which can reduce the CO_2 emission. The big problem is the strong objection of the public from nuclear power plants because of the fear of uncontrolled accidents from disaster, human errors, and radiation from uranium waste.

This study assesses CO_2 abatement cost according to the PDP 2010 plan. Also, it proposes alternative scenarios in case nuclear power plants (Alt.1) or neither new coal nor nuclear power plants (Alt. 2) cannot be constructed. It was found that there is another option to increase energy supply security and reduce the CO_2 emission without installing new nuclear and coal power plants. This can be achieved by increasing the renewable energy installed capacity and also improving the base load power plant. It was found that the CO_2 abatement cost from renewable energy scenario (Alt.2) is 52.4% less than PDP scenario, but the average of electricity generation is only 1.7% higher than the PDP plan.

It is important for the Thai government to take time and give real, honest information about nuclear power plants along with promoting the use of renewable energy. In the other hand, if Thailand invests for renewable energy, it would have a positive effect on Thailand's ability to improve renewable technology because widespread used could reduce the future cost of investment. This needs effective renewable energy policy and regulations as well as attractive incentives for renewable energy developers.

Keywords: PDP 2010, CO_2, abatement cost, nuclear, coal.

1. Introduction

1.1 Thailand's energy situation

Fossil fuels account for more than 80% of total energy supply to generate electricity in the world [1] This high use intensifies the issue of global warming, especially the problem of climate change, which becomes a major concern for future electricity expansion planning. Thailand has been relying on fossil fuels to generate electricity since 1980, accounting for more than 75% of its electricity generation, and up to 88% in 2011 [2]. In the past, fuel oil was a major energy source for electric power generation. Then in 1981, natural gas was discovered in the Gulf of Thailand for the first time, and used for generating about 9.68% of electricity, and consumption rapidly increased to 29% in 1982. Subsequently, the portion of natural gas consumption steadily increased, and in 1987, replaced fuel oil as a major energy source.

For the past decade, Thailand was highly dependent on natural gas for power generation. More than 67% of total electricity supply [2] was due to its own natural gas resources, environmental appeal of natural gas, low capital intensity, and shorter gestation periods for gas power plant projects [3] Thailand has natural gas reserves, but they are limited, and have been decreasing over time due to use in other sectors. This has caused Thailand to import natural gas from Myanmar since 1998 to serve the increasing demand of natural gas for electricity generation. Issues concerning energy security arose due to excessive reliance on natural gas for electricity generation. These issues are the crucial concerns for Thailand's future electricity expansion planning.

The Power Development Plan (PDP 2010 Rev. 3) will install 2,000 MW of new nuclear power plants, further increasing energy security by diversifying energy supply while reducing CO_2 emissions [4]. Moreover, the plan will install 3,200 MW of coal-fired power plants with new clean coal technology by 2030. The low production costs of these new coal fired power plants will reduce the cost of electricity generation and decrease reliance on the natural gas supply. However, the problems facing this plan are a strong public opposition against radioactive uranium wastes and potential nuclear catastrophes, greenhouse gas emissions from coal-fired power plants, and locational restrictions that affect the potential for future electricity capacity expansion.

It is essential for electricity planning to investigate the alternative solutions of the issue if strong objections from the public regarding new nuclear and coal fired power plants continues. If new plants cannot be constructed according to PDP plan, appropriate alternatives must be made to reduce CO_2 emission, and maintain reasonable prices for the cost of electricity generation.

This study is to propose alternative policy options for primary energy supply mix if the nuclear power plants cannot be implemented due to strong opposition of local minority groups and the general public. The assessment of the proposed alternative scenarios will also be conducted for several key parameters: unit cost of electricity, CO_2 emission per kWh, and abatement cost of CO_2 reduction.

1.2 National power development plan of Thailand year 2010 (PDP 2010 Rev. 3)

The strategic vision for the development of Thailand's electricity sector between 2010 and 2030 is set in the Power Development Plan (PDP 2010). The PDP plan was formulated by the Electricity Authority of Thailand (EGAT) under the policy framework of the Ministry of Energy, specifying terms of reliability in power supply, fuel diversification, power purchase from neighboring countries, and power demand forecast, etc. An earlier version of the PDP plan was the Thailand Power Development Plan (PDP 2007), which covered the period of 2007-2021. After 10 months of applying the PDP 2007 revision 1, situations and conditions affecting the plan significantly changed. A major change was that power demand was lower than what was originally forecast due to the global economic recession. If the plan remained unchanged, the power generation system would

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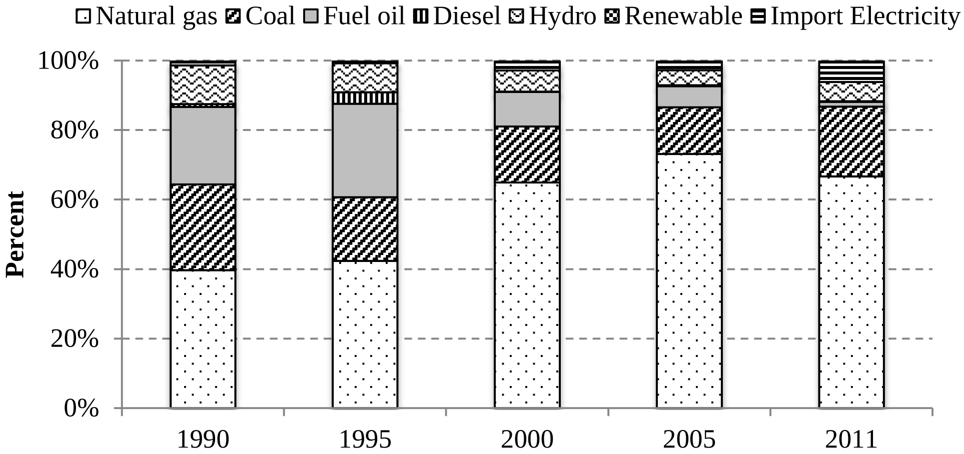

Figure 1. The percent share of primary energy mix used for electricity generation in Thailand during 1990-2011 [2].

reflect a high reserved margin. Furthermore, the power development projects in Laos PDR, with tariff MOU having expired. Thailand was required to review and re-negotiate their proposed tariff. The PDP 2007 revision 1 was modified and became the PDP 2007 revision 2, which contained the country's generating capacity goal of supplying 2,000 MW of electricity from nuclear power plants in 2021, and an expectation that this would further increase by 2,000 MW later in that decade. The plan seemed to increase the use of coal and renewable energy in power generation, thereby reducing dependence on natural gas [4].

In December 2008, the electricity demand had decreased significantly due to the economic conditions. The Ministry of Energy reviewed and designed the PDP 2010, which covered the period 2010-2030. According to the PDP 2010, there is also a goal of expanding generation from nuclear power plants to 5,000 MW, and new coal-fired power plants to about 7,200 MW by 2030. Later, the PDP2010 Rev. 2 was revised and endorsed by the Cabinet on 3 May 2011, to shift the schedule of the first unit on nuclear power project forward by 3 years from 2020 to 2023 for the reasons of safety measures review, legislation framework, regulatory framework and stakeholder involvement review as well as additional supporting plans [4].

According to the PDP 2010 Rev.3, there is also a goal of expanding generation from nuclear power plants to 2,000 MW, and new coal-fired power plants to about 4,400 MW by 2030. As a result, the latest PDP plan decreases nuclear and new coal power plants at 3,000 MW and 2,800 MW, respectively. This plan would be beneficial as reserve margins can be maintained at the appropriate level to electricity demand. Moreover, the Thai government targets to increase renewable energy in the PDP 2010 Revision 3 by an additional 9,481 MW by 2030 according to the Alternative Energy Development Plan (AEDP). This can help to decrease energy import dependency while also reducing GHG emissions. With this target, the installed capacity of renewable energy for 2030 will be 13.4% of total installed capacity.

1.3 Current status of CO_2 emission in Thailand's power generation

A major concern about energy security in power generation is not limited to balancing energy supply in order to meet demand, but also includes its environmental emissions. This has been a crucial concern to the public, and it is likely to remain an influential hurdle for electricity capacity expansion in the future. Thailand's power generation has been increasing and heavily based on fossil fuels, which was dominated by natural gas from 40 % to 66 % of total electricity generation during 1990-2011as shown in Fig. 1. Coal-based power generation, which accounted for about 20% of total electricity supply, was the second most important source of fuel, while the role of hydroelectric power generation was limited to about 5% of total electricity generation. Oil- based power generation and power imports from neighboring countries played a limited role during the above period because they were replaced by natural gas and coal based sources instead.

In 2011, the power generation emitted CO_2 at about 85,226 thousand ton of CO_2 or taking account at about 40.4% of total CO_2 emissions. As a result, the power generation is the biggest sector that emitted CO_2 followed by transportation, industry, and others sectors as shown in Fig. 2. The trend of CO_2 emissions per unit (kg of CO_2/kWh) from power generation was about 0.63 kg of CO_2/kWh in 1990, and decreased to 0.60 kg of CO_2/kWh in 2011, or only approximately 4.76% as shown in Fig. 3. This is because Thailand's power generation has been reliant on fossil fuel. As mentioned earlier, importing natural gas from Myanmar is a major concern for Thailand power generation in the case of uncontrolled accidents to the gas pipeline, which happened several times in past three years. Thailand power generation had to use another fuel such as fuel oil and diesel to generate electricity instead. This affected the cost of electricity generation for customers and released a higher CO_2 from power generation.

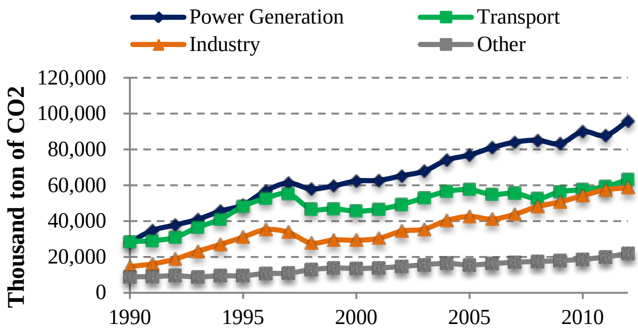

Figure 2. CO_2 emissions in Thailand by sector during 1990-2011 [2].

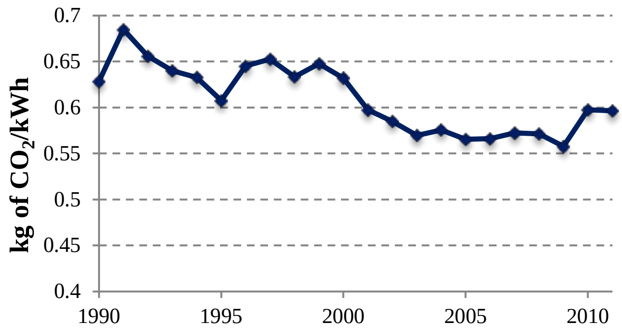

Figure 3. CO_2 emission per unit in Thailand's power generation during 1990-2011 [2].

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2. Experimental

2.1 Unit cost of electricity generation

The production cost of electricity generation is one of the economic aspects for power generation planning in Thailand. In this study we use the long run marginal cost which calculated by the marginal capacity cost and the marginal energy cost as following.

$$MCC = I + C_{fix}/crf - S*pwf \quad (1)$$

$$MEC = (C_{fuel} + C_{var})/crf \quad (2)$$

$$LRMC = (MCC*crf/8760*CF) + MEC \quad (3)$$

where:

LRMC	is long-run marginal cost (Baht/kWh)
MCC	is marginal capacity cost (Baht/kW)
MEC	is marginal energy cost (Baht/kWh)
I	is marginal initial capacity cost (Baht/kW)
C_{fix}	is annual marginal fixed operating and maintenance (O&M cost) (Baht/kW)
S	is salvage value (Baht/kW)
crf	is capital recovery factor $r/[1-(1+r)^{-1}]$
pwf	is present worth factor $1/(1+r)^t$
r	is discount rate (%)
t	is time period (years)
C_{fuel}	is annual marginal fuel cost (Baht/kWh)
C_{var}	is annual marginal variable O&M cost (Baht/kWh)
CF	is capacity factor which is its total production to its potential production if operated constantly at full capacity

In this study assumed that traditional power plants are operated with the capacity factor at 85% of their gross capacities. All necessary information to calculate unit cost, efficiency and capacity factor of power plants are given in Table 1 (The market exchange rate in year 2008 is 1$US dollar = 34 Baht). Unit costs of power plants appearing in the PDP plan were obtained from the study of EGAT. Other information, when it could not be obtained from EGAT's report [4] is supplemented by the report from the Joint Graduate School of Energy and Environment (JGSEE) [5] and The National Energy Technology Laboratory (NETL) [6] and Energy Information Administration (EIA) [7].

2.2 CO_2 emission per kWh

Environmental problems have become a major concern. This issue also has been added to contemporary studies on energy supply security issues. The Asia Pacific Energy Research Center (APERC) has defined the environmental aspect to energy security as the sustainable development and use of energy resources that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [8]. The indicator for environmental impact due to energy security is not yet well defined since environmental damages are not internalized costs in a market economy. There are several approaches to evaluate this indicator. However, each approach yields a large variation in outcomes compared with alternative approaches. APERC proposed an indicator that can be measured by a fraction of non-carbon based primary energy to a total primary energy supply of a country to measure the effects of global warming. Many studies, for instance Gnansounou [9], measured this indicator by calculating a ratio of the total amount of CO_2 emission to produce a unit of final energy or kilogram of CO_2 per kWh of electricity generation as shown in Eq. (4)

$$CO_2 \text{ emission per unit (kg of } CO_2/kWh) = \frac{\text{Total } CO_2 \text{ emission}}{\text{Total electricity generation}} \quad (4)$$

2.3 Estimation of abatement cost of CO_2 reduction

The nominal electricity generation cost in Thailand does not include the externality of damage costs. However, because of increased concerns about the impact of global warming at international and local levels, the Thai government decided to diversify types of primary energy supply to strengthen its energy security. The Thai government also aims to mitigate CO_2 emission by adopting nuclear technology in its plans.

In this study, we attempt to compare the amount of CO_2 emissions from different technologies and their associated electricity generation costs. Typically those technologies with low greenhouse gas emission tend to be associated with high costs of electricity generation. In contrast, ones with high greenhouse gas emissions tend to cost less. The differences in CO_2 emissions and electric generation costs, thus, can evaluate an abatement cost of CO_2 reduction.

CO_2 abatement costs of electricity generation can be assessed by comparing the scenario with the highest intensity of CO_2 emission per kWh with other scenarios. Generally, the unit cost of electricity generated by a fossil technology with higher CO_2 emission tends to be cheaper than that of cleaner fossil technology. Therefore, the CO_2 abatement cost can be compared by Eq. (5)

$$\text{Abatement cost of } CO_2 \text{ reduction (Baht/kg } CO_2) = \frac{(COE_{Ref} - COE_j)}{(E_{Ref} - E_j)} \quad (5)$$

where:

COE_{Ref}	is a unit cost of electricity generation in (Baht/kWh), of a highest CO_2 emission scenario
COE_j	is a unit cost of electricity in (Baht/kWh) for any scenario j
E_{Ref}	is an intensity of CO_2 emission per kWh (kg CO_2/kWh), of a highest CO_2 emission scenario
E_j	is an intensity of CO_2 emission per kWh (kg CO_2/kWh) for any scenario j

According to Eq. (5), it implies that each unit mass of CO_2 reduction it needs an amount of Δ COE baht for abatement (where Δ COE = $COE_j - COE_{Ref}$).

Table 1. Data of each types of power plants in Thailand.

Type of power plant	Cost (Baht/kWh)	Heat rate (MJ/kWh)	Capacity factor (%)	Lifetime (years)	Initial cost (Baht/kW)	O&M (Baht/kW)
Nuclear Power Plant [7]	2.79	10.96	85	60	115,464	58,887
Coal fired power plant (EGAT, Lignite) [4]	2.94	12.57	85	30	88,706	45,240
Combine Cycle (Domestic gas) [4]	3.96	8.73	85	25	24,990	12,745
Combine cycle (Marginal gas) [4]	4.34	8.73	85	25	24,990	12,745
Gas Turbine [4]	13.65	12.62	85	20	12,308	6,277
IGCC [6]	1.7	8.56	85	30	67,558	1,476
NGCC (advanced technology) [6]	2	7.08	85	25	37,400	1,496
Biomass [5]	3.5	-	35	20	70,006	35,703
Biogas [5]	3.24	-	30	20	56,168	28,646
Solar [5]	13	-	14	20	219,980	112,190
Wind [5]	6	-	16	20	75,004	38,252
Municipal solid waste [5]	5	-	22	20	160,004	81,602
Small Hydro [5]	2.2	-	44	20	55,998	28,559
Import (large hydro power) [5]	2.5	-	97	30	48,057	7,209

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3. Assumption under each scenario

3.1 Reference or BAU scenario (BAU)

A BAU scenario assumes there are no new policies or PDP plans to reduce natural gas dependency and the CO_2 emissions from the power generation sector. This scenario follows the trend of the energy mix in the year 2009 and all existing power plants still remain in the system. Also, it assumes no improvement in the efficiency of the power plants. Therefore, the system would still be relying on natural gas as a major source to generate electricity and use the same technology for each power plant.

3.2 Power Development Plan scenario (PDP 2010 Rev. 3)

Under this scenario, we assume that the government successfully diversifies its electricity portfolio to include to nuclear and coal resources. Therefore, in this study, we assume that the development of new power plants can be achieved on time following to PDP 2010 plan Rev. 3, as mentioned in section 2.

3.3 Alternative 1: Non nuclear power plants scenario (Alt.1)

This scenario examines what would happen in case 5,000 MW of nuclear power could not be constructed due to strong public opposition. Building coal power plants also has strong public opposition because of CO_2 emissions, but it seems that the public accepts coal fired power plants more readily than nuclear ones, due to a widespread fear of large nuclear accidents. The problem of radioactive waste from nuclear power plants is also a major concern to the public. So, in this scenario to reduce natural gas's share in power generation and improve the diversity of energy, this scenario will replace nuclear with 5,000 MW of coal-fired power. Also, the retirement of coal-fired power plants will be replaced by installing Integrated Gasification Combined Cycle (IGCC) to improve its efficiency in the power system.

3.4 Alternative 2: None nuclear power plants and none new coal-fired power plants (Alt. 2)

According to the PDP plan, renewable energy potential is less than 5% of total electricity capacity. The PDP plan follows a 15-year Renewable Energy Development Plan (REDP) of the Ministry of Energy plan up to the year 2022 [10] and the VSPP purchase projected by distribution authorities afterward. This scenario is under the assumption that if both new nuclear power plants and new coal-fired power plants cannot be constructed according to the PDP plan, renewable energies would be used to improve the diversity of energy, reduce the share of natural gas used, and reduce CO_2. Therefore this scenario will increase the installed capacity of renewable energy to the maximum potential which is shown in Table 2.

Table 2. Possible technical capacity installation of renewable energy in Thailand and total estimated installed capacity of renewable energy according to PDP 2010 [10].

Type	Maximum renewable energy potential of (MW)	Total installed capacity in PDP 2010 (MW)
Solar	5,000 - 50,000	1,107.23
Wind	1,600	1,321.07
Small hydro power	700	281.33
Biomass	4,400	3,032.04
Biogas	190	176.04
Municipal Solid Waste	400	183.32

4. Results and discussions

4.1 Electricity generation mix by energy type

Fig. 4 presents the projection of primary energy supply mix of installed capacity for all cases in this study in 2030. As a result, natural gas still play an important role in power generation of every scenario which is taking accounts for 75.4%, 43.2%, 51.4%, and 52.8% for BAU, PDP 2010, alternative 1 (Alt. 1) and alternative 2 (Alt. 2), respectively.

According to the PDP plan, it has the goals of reducing the percent share of natural gas by installing nuclear plants and coal-fired power plants. In 2030, electricity generation share from coal and nuclear will be 10.4% and 2.8%, respectively. If Thai government cannot construct 2,000 MW of nuclear power plants but can install coal fired power plants instead, Alt. 2 will have electricity generation from coal higher than that of PDP plan at 24.3%. However, the problem of strong public opposition against installing new nuclear and coal-fired power plants is still a big issue for Thailand's power generation.

If Thai government cannon neither nuclear and new coal-fired power plants by the end of 2030 but will add the maximum potential for renewable energy capacity according to the AEDP plan, electricity generation from natural gas and renewable energy of Alt.2 will be higher than that of the PDP plan at 4.8% and 32.5%, respectively. This scenario can decrease electricity generation from coal lower than PDP at 50.5% because of the percentage share of renewable energy and natural gas. However, it would increase electricity generation cost because the cost of renewables is still high.

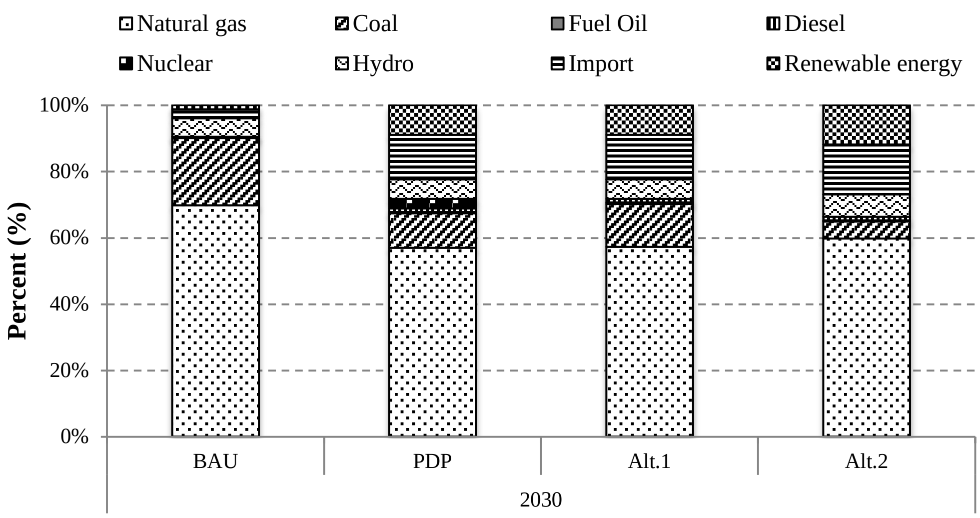

Figure 4. Supply of primary energy mix for each scenario in 2030.

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4.2 Unit cost of electricity, CO_2 emission per kWh, and abatement cost of CO_2 reduction

Table 3 and Fig. 5 show that BAU scenario is the highest emission intensity of CO_2 per kWh at 0.48 kg of CO_2/kWh. Moreover, the averaged unit cost of electricity generation is also the highest at 4.6 Baht/kWh. In contrast, Alt. 2 scenario has the fewest CO_2 emissions, since this scenario requires neither nuclear nor coal-fired power plants, but a larger share of electricity is generated from renewable energy resources than given in PDP plan. The released amount of CO_2 per unit under the Alt. 2 scenario is lower than that of the BAU, PDP 2010 or Alt.1, at 37.5%, 18.9% and 25.0%, respectively.

For the Alt. 2 scenario, the unit cost of electricity is the second highest next to the BAU scenario. However, Alt.2 contains the lowest intensity of CO_2 emissions per kWh, even lower than the nuclear scenario of PDP 2010. Thus, by adopting both the most efficient and advanced clean coal technology and the most advanced gas fired technology, in conjunction with more utilization of renewable energy, with a help of partial imported electricity from neighboring countries (presently, most of imported electricity from neighboring countries is generated by hydro power which produces no greenhouse gases) rather than directly import in the primary energy form. It could help to mitigate the emission of CO_2, without any construction of nuclear power plants.

For the PDP 2010 scenario, the electricity cost is the second least expensive and substantially releases less CO_2 emissions than Alt. 1 and BAU. Even though new nuclear power plants will be constructed according to PDP 2010 to help mitigate greenhouse gases, it also includes the construction of several coal-fired power plants, which offsets the abatement of CO_2 by nuclear power plants. Therefore, the PDP releases CO2 emission higher than the Alt. 2 at about 18.9%. In this study, fuel prices and technology costs used were quoted from the Electric Generation Authority of Thailand [2]. The Thai authorities hypothesize that, over the long term, the annualized investment cost of nuclear technology and a price of uranium fuel is cheaper and relatively more stable than the price of coal. It is estimated that the unit cost of electricity generation from nuclear technology is cheaper than that of coal. As a result, average electricity generation cost of the PDP plan is only 0.4% lower than the Alt.1 in 2030.

To analyze an abatement cost of CO_2 emissions, the scenario releasing the highest amount of CO_2 per kWh is used as a reference emission. Then the reference value is compared with lesser CO_2 emission scenarios. Since BAU is the scenario, which emits the highest intensity of CO_2 emission per kWh, then the BAU scenario is used as the reference value to compare the abatement costs of CO_2 for each scenario. As a result, Alt. 1 is least favorable scenario for the CO_2 emissions' abatement costs at 5.57 Baht/kg of CO2. This is because of the installation of new coal power plants instead of nuclear power plant at 2,000 MW.

The PDP 2010 is the second least favorable scenario for the CO_2 emissions' abatement costs. Under the PDP scenario, the average electricity unit cost is significantly cheaper than BAU at 8.0% and it can reduce 22.9% CO_2 emissions per kWh than BAU. As a result, its abatement cost is the second expensive at 3.70 Baht/kg of CO_2 ($0.12/kg of CO_2)

The lowest CO_2 emission intensity scenario is Alt. 2. The CO_2 emission per kWh is approximately 31.7% lower than the dirtiest CO_2 emission intensity scenario of BAU. However, it can only be achieved by increasing the electric bill. The unit cost of generated electricity in Alt. 2 is higher than PDP 2010 and Alt.1 1.7% and 2.1%, respectively. As a result, the abatement cost of CO_2 of Alt. 2 scenario is the least expensive scenario at 1.76 Baht/kg of CO_2 or cheaper than the PDP at 52.4% in 2030.

Table 3. A comparison of electricity generation cost, CO_2 emission per unit of electricity generated and abatement cost of CO_2 emission in 2030 under each scenario.

Scenario	Average electricity generation cost (Baht/kWh)	CO_2 emission per kWh (kg of CO_2/kWh)	Abatement cost of CO_2 emission (Baht/kg of CO_2)
BAU	4.60	0.48	(reference value)
PDP 2010	4.23	0.37	3.70
Alt.1	4.21	0.40	5.57
Alt.2	4.30	0.30	1.76

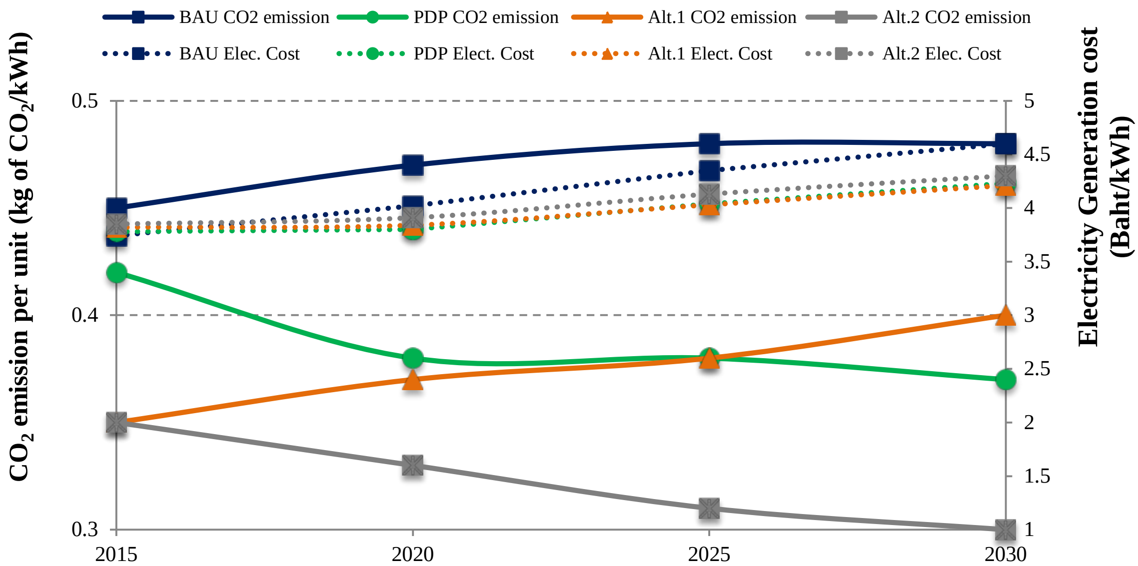

Figure 5. Average unit cost of electricity and a total amount of CO_2 emission under each scenario, during 2015-2030.

5. Conclusion

To respond to the policy to reduce CO_2 emissions from power generation, the PDP plan will invest in the construction of new nuclear power plants in the future. But, the PDP plan is not the most worthwhile scenario in terms of investing to reduce CO_2 emissions, even if power plants can be constructed according to the plan. As a result, at the end of 2030, the alternative 2 would be the most worthwhile scenario to invest in to reduce CO_2 emissions, with an avoided cost of CO_2 reduction about 1.76 Baht/kg of CO_2.

However, as mentioned before, the PDP plan still has a major problem due to strong public opposition to nuclear and coal-fired power plants. Therefore, the government needs to reconsider aspects of the PDP plan, especially it is goals installing of new nuclear power plant in the country. Most Thai people do not agree on nuclear power because of a fear of power plant accidents, like Chernobyl in 1986, and most recently the 2011 Japanese earthquake and its effect on nuclear power plants.

It is important for the Thai government to take time and give real, honest information about nuclear power plants to the Thai people for careful. In the other hand, if Thailand invests for renewable energy, it would have a positive effect on Thailand's ability to improve renewable technology because widespread used could reduce the future cost of investment. Moreover, in order to reduce energy imports and improve energy security, technologies used in base load power plants need to be improved.

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