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Original Article

Renewable energy utilization and CO_2 mitigation in the power sector: A case study in selected GMS countries

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Abstract

Renewable energy is an alternative resource to substitute fossil fuels. Currently, the share of renewable energy in power generation is very low. The selected Greater Mekong Sub-region (GMS), namely, Cambodia, Laos, Thailand and Vietnam is a region having abundant of renewable energy resources. Though these countries have a high potential of renewable energy utilization, they are still highly dependent on the imported fossil fuels for electricity generation. The less contribution of renewable energy in the power sector in the region is due to the high cost of technologies. Renewable energy technology cannot compete with the conventional power plant. However, in order to promote renewable energy utilization and reduce dependency on imported fossil fuel as well as to mitigate CO_2 emissions from the power sector, this study introduces four renewable energy technologies, namely, biomass, wind, solar PV, and geothermal power, for substitution of conventional technologies. To make the renewable energy competitive to the fossil fuels, incentives in terms of carbon credit of 20$/ton-ne CO_2 are taken into account. Results are analyzed by using the *Long-Range Energy Alternative Planning System* (LEAP) modeling. Results of analyses reveal that in the renewable energy (RE) scenario the biomass power, wind, solar photovoltaics, and geothermal would contribute in electricity supply for 5.47 GW in the region, accounted for 3.5% in 2030. The RE scenario with carbon credits could mitigate CO_2 emissions at about 36.0 million tonne at lower system cost when compared to the business-as-usual scenario.

Keywords: GMS, biomass, wind, PV, geothermal, carbon credits, CO_2 mitigation, LEAP.

1. Introduction

The increasing electricity demand in selected Greater Mekong Sub-region (GMS) countries, namely Cambodia, Laos, Thailand, and Vietnam, is related to the social economic development in the region. Otherwise, if we look into the electricity supply, most countries in the region are still highly depending on the imported fossil fuel for electricity generation. For the power sector in Cambodia, the main fuel supplies for electricity generation are diesel and heavy fuel oil, -accounting for a 90% share or about 250 MW in 2007. On the other hand, the power sector in Thailand and Vietnam use coal and natural gas in electricity generation. In 2007, coal was used to generate electricity for 13.4% and 25% or about 3,500 MW and 3,250 MW, while natural gas was accounted for 70% and 31% or about 16,133.0 MW and 3,425.5 MW in Thailand and Vietnam, respectively. Among selected GMS countries, Laos is less dependent on fossil fuels in power generation. The major electricity supply in Laos mainly comes from hydropower, accounting for 73% or 224 MW, and imported electricity, 25.4% or 42.5 MW. Besides Laos, most countries in the region still have a high risk regarding electricity supply security. The high dependence on imported fossil fuels for electricity generation is the most concern on the future electricity supply. Based on the power development plan (PDP) in each country, Cambodia is aiming to

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utilize hydropower to reduce its high dependence on imported fossil fuel. By 2020, the total supply capacity in the country is expect to increase to 1,564.8 MW, while hydropower would account for 65.3% and coal for 26.2% in the electricity supply, with the remainder being imported elec-tricity (MIME, 2008). At the same time, Laos also planned to develop more hydropower to supply the domestic demand. Within the total capacity supply of about 1,488.4 MW, hydropower would contribute in the electricity supply for 92%, coal 4.5%, and imported electricity for 3.5% (EDL, 2007). While Cambodia and Laos planned to use more domestic hydropower in the electricity supply, Thailand and Vietnam tend to expand the electricity supply by using fossil fuels and develop the first nuclear power plant in the region. In 2020, Thailand planned to introduce the first nuclear unit that could partially substitute the high dependence on natural gas. Thailand expects to extend the capacity supply to about 42,202.7 MW. The supply fuel mix in the power sector of Thailand would comprise mainly by natural gas with 64%, coal with 15.4%, hydro with 4.5%, nuclear with 2%, imported electricity with 9.3%, and other renewable energy would accounted for 3.5% (EGAT, 2009-2). Meanwhile, the total supply capacity in Vietnam expects to increase to 47,180.35 MW. Vietnam also aims to introduce the first nuclear power plant in 2020. Then the electricity supply in Vietnam would be contributed mainly by coal for 48.9%, natural gas for 29%, hydro for 12%, nuclear for 3.6%, and imported electricity for 5.8% (EVN, 2007).

From the PDP perspective, in 2020, Cambodia and Laos aim to develop domestic hydropower, which is accounted for more than 65% and 90% in the power supply, while Thailand and Vietnam would highly rely on the imported fossil fuels for electricity generation. The fossil fuel would contribute more than 80% of electricity supply in both countries by 2020. The high dependence on the fossil fuels for electricity generation would lead to increasing greenhouse gas (GHG) emissions in the region. In 2007, the power sector in the selected GMS countries emitted CO_2 about 128.8 million tonne. Coal-fired and natural gas power plants contributed for 56.8% and 42.1%, respectively. At the same time, Thailand and Vietnam are the main CO_2 emitters in the power sector, accounting for 70.7% and 28.3%, respectively, of the total CO_2 emissions in GMS, while Cambodia contributed for only 1.0%.

In general, most countries in the GMS region have abundant renewable energy resources. They would become a necessity of alternative supply in order to reduce high dependency on imported fossil fuels in the future. The less contribution of renewable energy in the power sector is due to the high cost of these technologies because renewable energy sources cannot compete with the present conventional power generation technologies in terms of production cost. However, developing countries could mitigate $CO\text{-}_2$ emissions through renewable energy utilization. The carbon credits under the Clean Development Mechanism (CDM) could share benefits between developed countries and developing countries.

The objective of this study is to develop a renewable energy (RE) scenario in the power sector in order to promote the utilization of domestic renewable energy resources in individual country as well as the whole GMS region to reduce the high dependency on imported fossil fuels and to mitigate the greenhouse gas (GHG) emissions in electricity generation.

2. Renewable Energy Potential in GMS

The Greater Mekong Sub-region has abundant renewable energy resources. There are huge hydro potentials of 55.2 GW, biomass power of 7.0 GW, wind power of 155.3 GW, and geothermal power of 472 MW. The average solar radiation is 5.0 kWh/m^2/day. These resources have been rarely exploited (REA, 2005; Lidula *et al.*, 2007-).

3. Methodology

3.1 LEAP Modeling

This study uses a scenario based energy-environment model called *Long-Range Energy Alternative Planning System* (LEAP) to forecast (a) the electricity demand and supply in the business-as-usual (BAU) scenario, (b) the CO_2 emission from the power sector, and (c) the CO_2 emission mitigation under a renewable energy (RE) scenario in the selected GMS countries. Originally LEAP was developed by Stockholm Environment Institute (SEI). LEAP uses a bottom-up approach to make projections on the future energy demand and examines a wide variety of technologies and strategies that best address environmental and energy issues. LEAP allows for the analysis in technological specification and end-use details and it incorporates a full range of energy systems, which organizes the energy carriers, transformation with losses in the process, and the final energy form of end use. Moreover, LEAP is easy to run on any personal computers. Results include basic standard data of energy composition, energy contents, and emissions. For an environmental assessment, LEAP can provide the results of pollution emission factors from each stage of fuel processing in power generation, including the cost of electricity generation and GHG emissions, extraction process, distribution, and end-use activities (Shin *et al.*, 2005). In addition, LEAP could be used to simulate emission inventories and external costs of fossil electricity generation along with different future energy consumption patterns and pollution abatement policies under user-defined assumptions (Zhang *et al.*, 2007). LEAP could be used for analysis in the economic sectors such as providing appropriate results of future energy demand of household consumers in different income levels and economic perspectives in different areas between urban and rural under scenarios of improvement in quality of livelihood (UNDP-Cambodia, 2008).

3.1.1 Demand calculation

In LEAP, in the final energy demand analysis, energy demand is calculated as the product of the total activity level and energy intensity at each given technology. Energy demand is calculated for the current accounts year and for each future year in each scenario.

$$D_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \quad (1)$$

where *D* is the electricity demand, *TA* the total activity, *EI* the energy intensity, *b* the branch, *s* the scenario, and *t* the years (ranging from the base year to the end year).

3.1.2 CO_2 emission calculation

Total CO_2 emission from the electricity sector *CE* is calculated from

$$CE = \sum_i \sum_j cef_{j,i} \cdot e_{j,i} \cdot P_{j,i} \quad (2)$$

where is the CO_2 emission factor of fuel type *i*, is the unit production energy consumption of fuel type *i* used in technology *j*, and is the production output by fuel type *i* to technology *j*.

3.2 Key assumptions

In this study, several assumptions are needed for long-term planning as following:

- o Total electricity demand in selected GMS countries is based on the PDP of each country.
- o The biomass price in Cambodia varies from 13$ to 23$ per tonne (Abe *et al.*, 2007). In this study, it is assumed to be 25$ per tonne for the whole planning period.
- o For incentives of the carbon credit based on carbon market under the Clean Development Mechanism (CDM) project, the carbon price can fluctuate. Currently, the carbon price varied from €10 to €15 or about 14.76$ to 22.14$ per tonne- CO_2 (TGO-Thailand, Point-carbon). Because of the carbon price fluctuation in the market in this study the incentive of the carbon credit is assumed to be fixed at €13.55 or 20$ per tonne- CO_2.
- o Power plant characteristics are given in Table 1.
- o A discount rate is assumed to be 10% for all power plant technologies.
- o Fossil fuel prices in this study are taken from the Energy Information Administration (EIA, Henry-hub, 2007). In this study, an annual fuel price escalation of 3% is assumed for fossil, biomass and nuclear fuels. In 2007, crude oil price was 72.33$/bbl, while the oil products were higher with about 38% of the crude oil price. The natural gas price was 6.96$/MBtu and the coal price was 25.82$/tonne.

3.3 Levelized generation cost

The levelized cost of electricity generation is the sum of the total capital investment, operating and maintenance (O&M) costs, and fuel cost. The levelized cost changes depending on the incremental costs of technology in capital cost related to the type of generations and the discount rates. Each technology has specific characteristics, construction time, electrical output, etc. (Alonso *et al.*, 2007). On the other hand, the effect on the levelized cost is associated with fuel

Table 1. Characteristics of power plants.

	Capital (US$/kW)[a]	Fixed O&M ($/kW month)[b]	Variable O&M ($/MWh)[b]	Lifetime (year)[b]	Efficiency (%)[c]	Fuelcost ($/Gcal)[d]	Capacity factor(%)	Merit order[e]
Import electricity	1,200.0	0.760	-	30	40	-	55	1
Coal steam	837.0	1.212	0.889	25	32	4.52	80	1
Oil steam	736.0	0.887	0.651	25	32	64.22	80	3
Diesel oil CT	395.0	0.633	0.465	25	25	68.46	80	3
Natural gas CC	557.0	0.837	0.819	20	32	27.72	80	2
Hydro	1,200.0	0.760	-	30	40	-	55	1
Biomass	850.0	3.58	5.0	30	30	5.25	80	1
Wind	1,000.0	1.35	-	30	40	-	25	1
Solar PV	5,500.0	2.5	-	25	30	-	15	1
Nuclear	1,020.0	3.084	-	30	40	5.39	85	1
Geothermal	1,700.0	2.38	-	30	40	-	30	1

Source: [a] Nguyen (2009),
[b] Santisirisomboon *et al.* (2003),
[c] Artite *et al.* (2010),
[d] Fuel cost is calculated based on prices in 2007.
[e] Dispatched power plant based on load profile: (1) Base load, (2) Intermediate load, (3) Peak load.

costs that fluctuate in the global market.

4. Scenario Development

4.1 Business-as-usual scenario

In the business-as-usual (BAU) scenario, the power expansion plan is derived from the power development plan (PDP) of each country. The increase of electricity demand varies due to the different perspectives of the economic development plan of each country. In this study, the planning period is 2007-2030. The BAU scenario is developed on the basis of the following criteria.

4.1.1 Population growth

The population projection would increase with an average of 1.8% per year in Cambodia, 1.7% in Laos, and 1.2% in Vietnam, while the lowest population growth rate of 0.5% is in Thailand (WDI, 2008). In this study the population growth rates follow the trends in each country during the planning period.

4.1.2 Urbanization and household size

The urbanization ratio is a factor that indicates the highest electricity demand as in the urban areas most people are living at a higher standard, materialistic and consuming more energy. In this study, the urbanization of the country would increase steadily during the planning period. Based on the world development indicators (WDI, 2008), Cambodia and Laos are expected to increase the urbanization to 30%, Vietnam would increase to 35% and Thailand is expected to increase to 45% by 2030. In 2007, the household sizes are 5.2 in Cambodia, 6.1 in Laos, 3.8 in Thailand, and 4.6 in Vietnam (WDI, 2008). In this study, the household sizes are assumed to be unchanged during 2007-2030.

4.1.3 Electricity sector demand

The forecasted electricity demand growth in selected GMS countries is varying depending on government plans and assumptions. The electricity intensity in the household would increase from 1,219 to 3,000 kWh and 1,361 to 3,000 kWh per household for Cambodia and Laos, respectively. Thailand would increase from 1,791 kWh to 3,500 kWh per household, while Vietnam increases from 1,618 kWh to 4,000 kWh per household by 2030. The growth in electricity intensity in the household is based on the expectation of improving welfare and social economic development. However, forecasted electricity demands in the commercial and industrial sector were found to be increasing with an annual average growth rate of 12% in Cambodia (EDC, 2007), 11% in Laos (EDL, 2007), 5% in Thailand (EGAT, 2007-2), and 8.8% in Vietnam (EVN, 2007). On the other hand, the improvement of load factors in all countries is introduced as shown in Table 2.

4.1.4 Electrification

Based on the power development plans of the GMS countries, Cambodian electrification would increase to 70% by 2030. This ratio is still lower than Laos. Laos would increases up to 90% by 2030. Vietnam is expected to increase to 95% by 2030, while Thailand presently has a very high access to the electricity grid with an electrification of 99%.

4.1.5 Transmission and distribution losses

Besides electrification, many developing countries are facing the challenge of high transmission and distribution (T&D) losses. In 2007, among selected GMS countries, Cambodia has the highest rate of transmission and distribution losses about 16.75%. However, in the rural area the electricity loss is as high as 25%; (EAC, 2007). The power losses in Laos

Table 2. Electricity demand growth rates in the GMS region.

GMS Countries	Household (kWh/yr/HH)	Commercial (%)[c]	Industrial (%)[c]	Others (%)[c]	Load factor (%)[d]
	2007 - 2030				2030
Cambodia	1,219[a] - 3,000[b]	12	12	12	70
Laos	1,361 - 3,000	11	11	11	65
Thailand	1,791 - 3,500	5	5	5	75
Vietnam	1,618 - 4,000	8.8	8.8	8.8	68

Note: HH stands for household.
[a] Electricity intensity per household, based on data 2007electricity demand in household sector.
[b] Assumption, expect increase electricity intensity per household by 2030,
[c] Annual average electricity growth rate projection 2020, based on PDP from each country.
We assumed an annual electricity growth rate keep constant up to 2030.
[d] Expecting load factor improvement by 2030.

was about 16.41%, and followed by Vietnam at 14.5% losses, while the electricity losses in Thailand is very small, at 5% only. However, the T&D loss would be reduced significantly by improving technical standards and good management and administration. In this study, T&D losses in GMS countries are expected to reduce to 10% in Cambodia and Laos, 8.5% in Vietnam, while Thailand would be constant at 5% until 2030.

4.2 Renewable energy scenario

The objective of this study is to promote the utilization of domestic renewable energy resources in individual countries. The potentials of renewable energy resources in the GMS region are discussed in Section 2. Four renewable energy technologies, biomass, solar photovoltaic (PV), wind, and geothermal are proposed in the RE scenario. The major renewable energy source is biomass. This study found a potential of 6200 MW biomass in RE scenario (Thailand: 4000 MW, Vietnam: 1500 MW, Cambodia: 500 MW, and Laos: 200 MW). Wind capacity is proposed for 800 MW in Thailand, 500 MW in Vietnam, 150 MW in Cambodia, and 100 MW in Laos. Solar PV capacity is proposed for 500 MW in Thailand, 100 MW in Vietnam, 50 MW in Cambodia, and 50 MW in Laos. Geothermal is found to be 300 MW only in Vietnam.

4.3 Carbon credit scenario

To make the renewable energy competitive to the fossil fuels, incentives in terms of carbon credit (CCD) of 20$/tonne- CO_2 are taken into account. In the CCD scenario, carbon credits are applied to both BAU and RE scenarios. Results in the CCD scenario are presented of levelized costs of electricity generation in GMS.

5. Results and Discussion

The results are presented in three parts: (1) the electricity demand and supply composition in the BAU and RE scenarios, (2) corresponding CO_2 mitigation from the power sector, and (3) effects of carbon credits on total costs in the CCD scenario.

5.1 BAU scenario

5.1.1 Electricity demand in GMS

The electricity demand in the selected GMS countries is expected to increase from 202 TWh in the base year to 924.4 TWh in 2030 in the BAU scenario as presented in Figure 1. The industrial sector is the largest electricity consumer in the GMS region, and accounted for 51.5% of total consumption, and followed by the household sector (22.3%). The commercial sector consumes about 16.7%, and other use is accounted for 9.5%. The major electricity consumer in both Thailand and Vietnam is the industrial sector. However, the household sector still remains in the largest share of electricity consumption in Cambodia and Laos.

5.1.2 Electricity Supply in GMS

To meet the forecasted demand, the power expansion plan is developed. In the BAU scenario, the electricity supply in the region is increasing and depending on the conventional power plants. The total electricity supply in the region would increase from 219.1 TWh in 2007 to 991.17 TWh in 2030 (see Figure 2).

In 2030, coal and natural gas combined cycle (NGCC) plants are the major contributors in electricity supply, and accounted for 42.6% and 35.3% in total generation, respectively. To fulfill the forecasted demand with limited domestic supplies, the imported electricity must be increased. The total imported electricity in the selected GMS countries will increase from 7.78 TWh in the base year to 75.96 TWh in 2030.

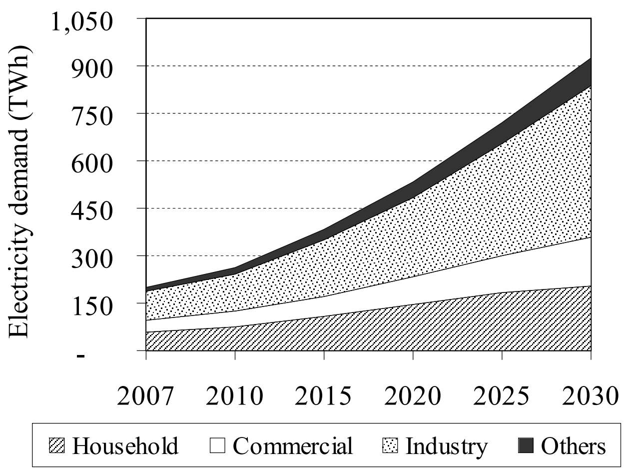

Figure 1. Electricity demand in selected GMS in the BAU scenario.

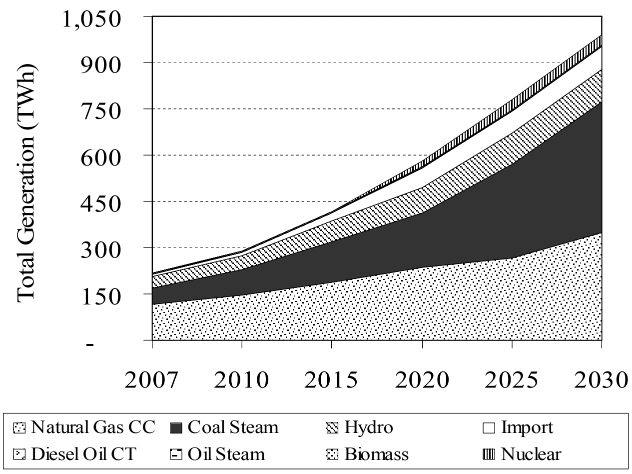

Figure 2. Electricity supply in selected GMS in the BAU scenario.

Table 3. Power capacity in the BAU scenario.

Supply sources	Capacity requirement (GW)					
	2007	2010	2015	2020	2025	2030
Import electricity	1.0	1.9	3.9	8.8	10.0	10.3
Coal steam	6.8	12.1	18.8	25.8	45.1	61.2
Oil CT	0.1	-	0.2	0.2	-	-
Diesel oil CT	0.5	-	0.3	0.4	0.2	0.2
Natural gas CC	19.6	24.9	32.4	41.2	48.3	63.1
Hydro	5.3	6.5	10.5	13.4	16.6	16.5
Biomass	0.4	0.4	0.4	0.4	0.4	0.4
Nuclear	-	-	-	2.3	4.9	4.9
Geothermal	-	-	-	-	-	-
Total	33.7	45.9	66.5	92.4	125.5	156.5

Notes: CT stands for combustion turbine.

The imported electricity would contribute in the power supply for 7.7%, while the hydro power was accounted for 10.5%, nuclear power provides for 3.3%. The GMS would increase the installed capacity from 33.7 GW in 2007 to 156.52 GW in 2030 as presented in Table 3.

5.1.3 GHG Emissions

Based on the result of emissions from LEAP model, among selected GMS countries, Thailand and Vietnam are the major GHG emitters in GMS. The emissions from both countries increase roughly from 91.1 million tonne and 36.41 million tonne in the base year to 280.78 million tonne and 374.93 million tonne in 2030 for Thailand and Vietnam, respectively (see Figure 3).

In addition, the increase in conventional fossil-based plants in the region results in increasing GHG emissions in the power sector. The total GHG emissions from power sector in selected GMS countries are increasing gradually during the study period. In the BAU scenario the total emission in the region increases from 128.8 million tonne of CO_2 equivalent in 2007 to 662.05 million tonne in 2030, respectively. The coal-based plant is the largest CO_2 emitter in the power sector, and accounted for 66.7% of total emission in 2030.

5.2 Renewable energy scenario

5.2.1 Renewable energy supply composition

In the RE scenario, the electricity generation from the biomass plant expects increase from 3.36 TWh to 38.43 TWh by year 2007 and 2030, respectively. Results from LEAP model show that capacity requirement of biomass power plant would contribute in the total electricity supply of the region for 4.82 GW, wind power accounted for 0.4 GW by 2030 as shown in Table 4. The introduction of renewable energy technology would contribute in the total electricity supply in selected GMS countries for 3.5% or 5.47 GW by 2030.

5.2.2 GHG mitigation

In the BAU scenario, the total emission in the region increases from 128.8 million tonne of CO_2 equivalent to 662.05 million tonne in 2007 and 2030, respectively. However, the emission mitigation from the power sector in the region would decrease significantly through the RE scenario. When implementing four renewable energy technologies, results revealed that the RE scenario could mitigate the mission from the BAU scenario for 5.43% in 2030. Total CO_2 emissions in the power sector of GMS decrease from 662.05 million tonne in the BAU scenario to 626.05 million tonne in the RE scenario, respectively, by the end of the study period as shown in Table 5.

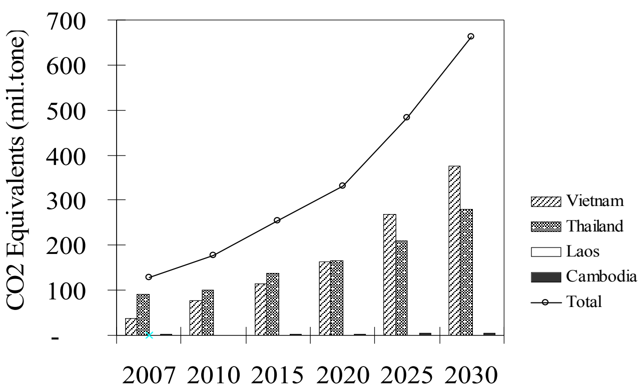

Figure 3. CO_2 emissions in the power sector in selected GMS countries in the BAU scenario.

Table 4. Supply capacity in selected GMS countries in the RE scenario.

Supply sources	Capacity requirement (GW)					
	2007	2010	2015	2020	2025	2030
Import electricity	1.0	1.9	3.9	8.8	9.9	10.2
Coal steam	6.8	12.5	17.5	24.6	43.4	57.0
Oil steam	0.1	-	0.2	-	0.2	0.1
Diesel oil CT	0.5	-	0.4	-	0.5	0.5
Natural gas CC	19.6	22.9	30.9	39.4	45.8	62.3
Hydro	5.3	6.7	10.6	13.3	16.4	16.1
Biomass	0.4	1.9	2.8	3.5	4.0	4.8
Wind	-	0.0	0.1	0.2	0.3	0.4
Solar PV	-	0.0	0.0	0.0	0.1	0.1
Nuclear	-	-	-	2.3	4.9	4.9
Geothermal	-	-	-	0.1	0.1	0.2
Total	33.7	45.9	66.5	92.4	125.5	156.6

Table 5. CO_2 emissions in the power sector.

Years	GHG emissions (million tonne)			
	BAU	RE	GHG Mitigation	
2007	128.80	128.80	-	0.00%
2010	178.06	170.24	7.82	4.39%
2015	254.48	234.47	20.01	7.86%
2020	332.47	312.00	20.47	6.16%
2025	482.90	456.92	25.99	5.38%
2030	662.05	626.05	36.00	5.44%

5.3 Levelized cost

5.3.1 BAU Scenario

In the BAU scenario, hydro power has a lower cost compare to other technologies as presented in Figure 4. The levelized cost of hydro power is approximately 21.7$/MWh, while the highest levelized generation cost is the solar PV at 383.6$/MWh. Diesel CT and oil steam also have high costs at 253.25$/MWh and 184.92$/MWh, respectively. For conventional technologies, natural gas combine cycle power plant is ranked at the third high price at 85.8$/MWh, followed by coal steam at 31.3$/MWh (see Figure 4). Most conventional technologies have high fuel costs, but the capital costs of these technologies are much lower than renewable energy and nuclear. From the capital cost aspect, the solar PV has the highest cost and followed by biomass, geothermal, and wind power. Its capital cost is about 383.6$/MWh, 46.87$/MWh, 38.37$/MWh, and 35.53$/MWh, respectively. On the other hand, the capital cost of nuclear power is only 15.67$/MWh, and the total levelized cost of nuclear power is about 35.44$/MWh.

5.3.2 Carbon credit scenario

When carbon credits are included, wind and geothermal have lower levelized generation costs, about 13.94$/MWh and 16.78$/MWh, respectively. Biomass technology cost decreases from 46.87$/MWh in the BAU scenario to 25.28$/MWh in the CCD scenario. Results showed that carbon credits could make the biomass competitive with the coal steam power plant in terms of levelized generation costs of 31.1$/MWh and 25.28$/MWh, respectively (see Figure 5).

5.4 Total generation cost

5.4.1 BAU and RE Scenarios

In the BAU scenario, the total generation cost in selected GMS counties would increase from 13.14 billion

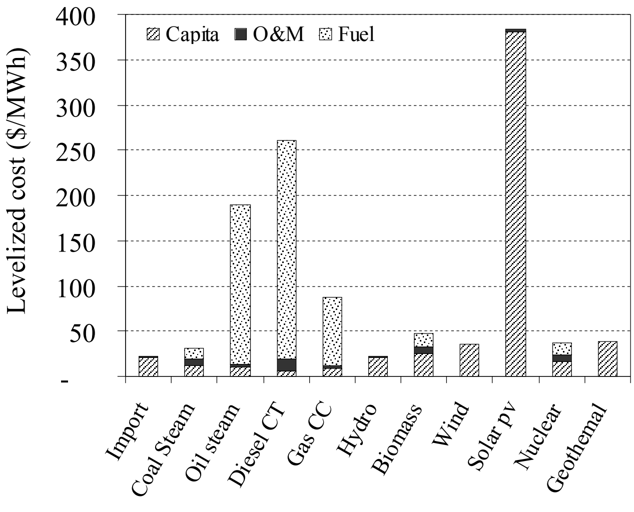

Figure 4. Levelized generation costs in the BAU scenario.

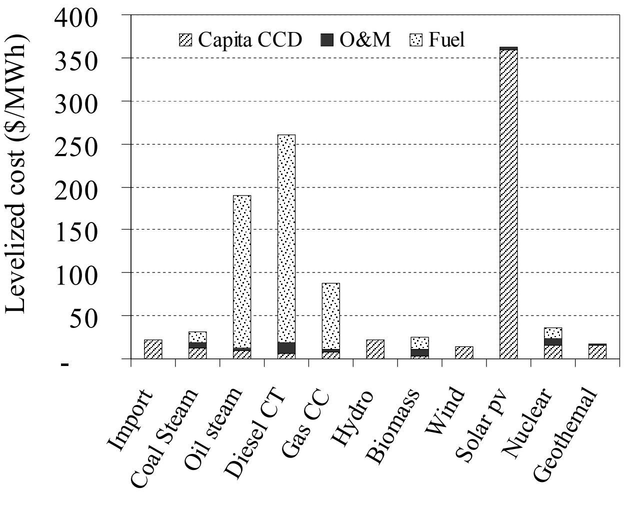

Figure 5. Levelized generation costs with CCD.

US$ in 2007 to 48.56 billion US$ in 2030. It increases more than three times from the based year. In 2030, total electricity generation cost in the region in the RE scenario is about 49.11 billion US$, and is higher than the BAU scenario due to higher levelized generation cost of renewable energy.

5.4.2 Carbon credit scenario

Under incentives of carbon credit perspective, the incentives would significantly reduce total generation cost in the RE scenario. Total generation cost in the RE scenario is 49.11 billion US$, while the incentive could bring the total cost slight lower to 48.18 billion US$. The incentives could reduce the total generation cost in the RE scenario about 2.0% compared with the RE scenario in base case. In addition, the carbon credits make total generation cost in BAU scenario lower about 70 million US$.

6. Conclusions

In this study, utilization of renewable energy in the selected GMS countries was found to have a high potential in GHG mitigation and can also reduce the dependency on imported fossil fuels. In the RE scenario, renewable energy technologies shares 3.5% (5.47 GW) in total capacity requirement, and could reduce CO_2 emissions by about 36.0 million tonne in 2030. Total electricity generation costs in the BAU scenario are 48.56 billion US$, while in the RE scenario the total generation cost are 1.13% higher than for the BAU scenario. However, to make the renewable energy technologies competitive with the conventional technologies in BAU scenario, the carbon credits of 20$/tonne CO_2 has been introduced to the RE scenario to reduce total generation cost by 2.0%. In addition, the carbon credits reduces the total generation cost in the BAU scenario by 0.15%. It was found that the carbon credits under the CDM of the Kyoto Protocol would make renewable energy technologies competitive with the conventional power generation at lower CO_2 emissions, and the GMS countries could contribute higher CO_2 mitigation under CDM. The renewable energy technologies are very important in the GMS region. These technologies do not only reduce the imported fossil fuels dependency but also mitigate CO_2 emissions and improve electricity supply security in the GMS region.

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