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Marginal abatement cost of electricity generation from renewable energy in Thailand

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Abstract

Electricity is very important for daily living and plays a major role in national development in Thailand with around 20.5% proportion in national final energy consumption, mainly from burning fossil fuels which have a direct effect to the greenhouse gas emission level of the country. Hence, the country has launched the Nationally Determined Contribution (NDC) Roadmap which covering on the 2021 to 2030 period and focused mainly on the energy, especially on power generation, and transport sector mitigation activities. This study has focused on the estimation of the marginal abatement cost (MAC) of electricity generation from renewable energy which consists of (i) natural type (solar energy, wind power, and hydro energy), and (ii) bioenergy type (biomass, biogas, and waste). As widely known, MAC is one of the most important tools for policy decision in prioritization in greenhouse gas emission reduction strategy which represents the importance and necessity of electricity production from each renewable energy type that affects the reduction of greenhouse gas (GHG) emissions of the country. We found that the marginal abatement cost (MAC), from various size and type, of natural type from -4,780.80 to 5,248.32 THB/tCO₂eq and bioenergy type are from -4,913.28 to 134.29 THB/tCO₂eq. The factors that affect to MAC of each renewable energy type are mixed results but the major factors are plant factor, investment cost, location, and size (in terms of economy of scale), respectively.

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Keywords: Marginal abatement cost; Electricity generation; Renewable energy; Thailand

1. Introduction

Electricity generation from renewable energy is a strong measures to reduce greenhouse gas (GHG) emissions. Essentially, Thailand's mainly electricity generation from burning fossil fuels (natural gas and coal) which have

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directly effect to the GHG emission level of the country so the country which under the United Nations Framework Convention on Climate Change (UNFCCC) have implementation agreement to prepare the Nationally Determined Contribution (NDC) Roadmap that is directly relevant to energy sector, especially on power generation, and transport sector mitigation activities. As well as the government has encouraged the use of renewable energy in electricity generation through Thailand's Power Development Plan (PDP) and Alternative Energy Development Plan (AEDP) by increasing the proportion of electricity generation from renewable energy around 15%–20% by DEDE [1] and reduce the proportion of natural gas to around 30%–40% in 2036 by EPPO [2]. Electricity from renewable energy targets for each type of fuel in 2036 consists of (i) solar energy 31% (ii) biomass 28% (iii) wind power 15% (iv) large hydro energy 15% (v) biogas 3% (vi) small hydro energy 2% and (vii) waste 1% by DEDE [1].

From the government was emphasize to electricity generation from renewable energy, there are also the important keynote that needs to be considered are to design and deploy the suitable and valuable policies to cope with energy reduction and climate change, policymakers need information about the options which covering the technology and economics point of view by Vogt-Schilb and Hallegatte [3]. Global leader countries are interesting and discussing targets for GHG emissions reduction including climate change policy in order to mitigate the effects on the environment, human societies, and economies by McKinsey and Company [4] and Limin Du et al. [5]. McKinsey & Company presented a global mapping of opportunities to reduce the emissions of GHG across regions and sectors, that is global GHG abatement cost curve or Marginal abatement cost. Which is present the opportunities, possibilities, and potential of GHG reduction of the world by McKinsey and Company [4]. Marginal abatement cost, in the expression by using the marginal abatement cost curves (MAC Curve), is one of the most important tools to represent information on abatement costs of specific technology and potentials for a set of mitigation measures, e.g. power sector, industry, household or transport sector. And it can be a guideline to the government in order to achieve the GHG reduction targets by Isacs et al. [6] and de Souza et al. [7]. Furthermore, help to set strategic priorities, aimed and understanding about potential to reduce GHG emission in each sector. MAC Curve demonstrate the relationship between GHG emission reduction and price or cost, which means “the marginal cost for abating one additional unit of carbon dioxide” by Fei TENG et al. [8].

This study has focused on estimation the marginal abatement cost of electricity generation from renewable energy in Thailand to support the Twelfth National Economic and Social Development Plan in Strategy 4: Strategy for Environmentally-Friendly Growth for Sustainable Development. The results of assessing were able to support and help the organizations that are responsible for determining the measures and policy can be priorities of GHG mitigation measures and can be used to formulate appropriate policies. Moreover, it can be used to determine the policy guidelines for energy economics such as carbon tax, carbon credit trading or energy subsidies in order to effectively support measures or policies that are greenhouse gases reduction targets in the short and long term. Because of this study actually reflects the aspect of Thailand which uses data directly from the power plant survey and related organization and the method used suitable according to the existing data in Thailand.

2. Marginal abatement cost (MAC)

Marginal abatement cost (MAC) is the cost assessment of energy project implementation and evaluation the result by using financial and economic data such as payback benefit, net present value (NPV) or return on investment (ROI) that there are the main tools used to analyze investment, operation, and maintenance cost of the technology.

There are various methods used to calculate the MAC such as Cost-effectiveness Analysis which is project or technology can be calculated by using present value by Wang et al. [9] or annual worth analysis by Sarnholm and Gode [10] to find out the energy saving value and convert to ton carbon dioxide equivalent (tCO₂eq).

There are several studies related to MAC, McKinsey and Company [4] was presented the results in graph form that known as Marginal abatement cost curve or MAC Curve by sorting order that the lower-cost energy technology to reduce emission per ton of carbon dioxide equivalent as represented in the left-hand side and higher-cost technology as shown in the right-hand side. Timilsina et al. [11] developed a method for assessing marginal abatement cost for energy efficiency measures in the building sector of Armenia and Georgia. Their research has shown that reducing carbon dioxide in 2015–2035 from implementing energy efficiency measures in the building sector (Residential and business buildings) can reduce 16.4 MtCO₂eq and 6.2 MtCO₂eq, respectively.

In this study, marginal abatement cost calculation can be described by an equation that is the difference between the electricity generation cost in policy scenario and baseline scenario divided by the difference between the GHG emission in baseline scenario and policy scenario. Which this the cost consists of investment, operation,

and maintenance cost. The data of investment cost uses data directly from the power plant survey and related organization and operation and maintenance cost was estimated by used operation and maintenance (O&M) percentage assumption. Then it was convert money value and adjusted by a Consumer Price Index (CPI) at the reference year 2015 which is from [12]. The MAC equation can be express as follow:

$$MAC = \frac{(C_{PS,y} - C_{BS,y})}{(E_{BS,y} - E_{PS,y})} \quad (1)$$

where: MAC is Marginal abatement cost of electricity generation from renewable energy (THB/tCO₂eq), C_{PS} is electricity generation cost in policy scenario (THB/kWh), C_{BS} is electricity generation cost in baseline scenario (THB/kWh), E_{PS} is Greenhouse gas (GHG) emission in policy scenario (tCO₂eq/kWh), E_{BS} is Greenhouse gas (GHG) emission in baseline scenario (tCO₂eq/kWh), and y is year.

3. The results of marginal abatement cost of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy)

This section includes significant results of marginal abatement cost of electricity generation from renewable energy in natural type consist of solar energy, wind power, and hydro energy. In Section 3.1 explain the concept of baseline scenario and policy scenario determination. And the results of MAC as presented in Section 3.2.

3.1. Baseline scenario and policy scenario determination

From Eq. (1) seen that have to determine baseline scenario for estimating marginal abatement cost. Thailand's electricity generation from renewable energy of natural type (solar energy, wind power, and hydro energy) is produced for replacement electricity generation from fossil fuels (natural gas and coal). Therefore, baseline scenario of estimating marginal abatement cost of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) is electricity generation from fossil fuels (natural gas and coal) and policy scenario is electricity generation from renewable energy of natural type. The detail as shown in Table 1.

Table 1. Baseline scenario and policy scenario of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy).

Type	Baseline scenario	Policy scenario
Solar energy	Electricity generation from natural gas (NG) and coal	Electricity generation from solar energy
Wind power		Electricity generation from wind power
Hydro energy		Electricity generation from hydro energy

3.2. Result of marginal abatement cost of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy)

The result of estimating marginal abatement cost of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) from 2013 to 2015 as shown in Table 2.

Marginal abatement cost results can be shown in Y -axis of MAC curve and X -axis will be shown the greenhouse gas (GHG) emission reduction. Which the GHG emission reduction of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) in Thailand has a publish results in Second Biennial Update Report of Thailand: BUR2 by ONEP [13], The detail as shown as Table 3.

The results of marginal abatement cost (MAC) of electricity generation from renewable energy (natural type) found that solar energy has the highest, followed by wind power and hydro energy, respectively. The marginal abatement cost curve (MAC curve) as illustrated in Figs. 1–3.

4. The results of marginal abatement cost of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste)

This section includes significant results of marginal abatement cost of electricity generation from renewable energy in bioenergy type consist of biomass, biogas, and waste. In Section 4.1 explain the concept of baseline scenario and policy scenario determination. And the results of MAC as presented in Section 4.2.

Table 2. Estimation of marginal abatement cost of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) from 2013 to 2015.

Type/Year	Marginal abatement cost (THB/tCO ₂ eq)		
	2013	2014	2015
Solar energy	1576.44 to 5003.98	1581.96 to 5021.49	1653.42 to 5248.32
Wind power	795.93 to 1215.49	798.72 to 1219.74	834.80 to 1274.84
Hydro energy	−4558.23 to −1856.02	−4574.18 to −1862.52	−4780.80 to −1946.65

Table 3. The greenhouse gas (GHG) emission reduction of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) from 2013 to 2015.

Measures/Year	GHG emission reduction (MtCO ₂ eq/Year)		
	2013	2014	2015
The electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy)	0.98	4.04	3.60

4.1. Baseline scenario and policy scenario determination

Firstly, we have to determine baseline scenario for estimating marginal abatement cost. Thailand's electricity generation from renewable energy of bioenergy type (biomass, biogas, and waste) is produced for replacement electricity generation from fossil fuels (natural gas and coal). Therefore, baseline scenario of estimating marginal abatement cost of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) is electricity generation from fossil fuels (natural gas and coal) and policy scenario is electricity generation from renewable energy of bioenergy type. The detail as shown in [Table 4](#).

Table 4. Baseline scenario and policy scenario of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste).

Type	Baseline scenario	Policy scenario
Biomass	Electricity generation from natural gas (NG) and coal	Electricity generation from biomass
Biogas		Electricity generation from biogas
Waste		Electricity generation from waste

4.2. Result of marginal abatement cost of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste)

From Eq. (1), the result of estimating marginal abatement cost of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) from 2013 to 2015 as shown in [Table 5](#).

Table 5. Estimation of marginal abatement cost of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) from 2013 to 2015.

Type/Year	Marginal abatement cost (THB/tCO ₂ eq)		
	2013	2014	2015
Biomass	−3180.19 to −1690.91	−3191.32 to −1696.83	−3335.47 to −1773.48
Biogas			
−Installed capacity ≤1 MW	−4290.07 to 128.04	−4305.09 to 128.48	−4499.55 to 134.29
−Installed capacity >1–3 MW	−4188.54 to −1237.04	−4203.19 to −1241.37	−4393.06 to −1297.44
−Installed capacity >10 MW	−4684.53 to −2440.38	−4700.93 to −2448.93	−4913.28 to −2559.55
Waste	−706.57 to −178.82	−709.04 to −179.44	−741.07 to −187.55

Table 6. The greenhouse gas (GHG) emission reduction of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) from 2013 to 2015.

Measures/Year	GHG emission reduction (MtCO ₂ eq/Year)		
	2013	2014	2015
The electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste)	8.04	8.65	7.96

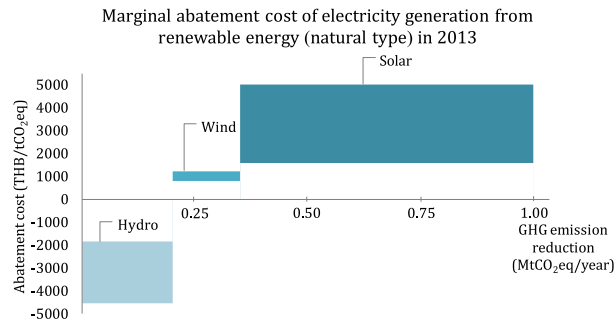


Fig. 1. MAC Curve of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) in 2013.

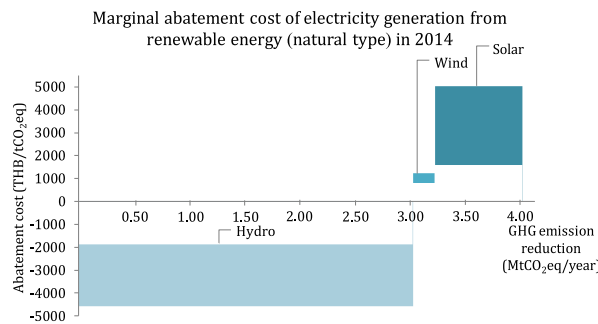


Fig. 2. MAC Curve of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) in 2014.

The greenhouse gas (GHG) emission reduction of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) in Thailand has a publish results in Second Biennial Update Report of Thailand: BUR2) by ONEP [13], The detail can be shown as Table 6.

The results of marginal abatement cost (MAC) of electricity generation from renewable energy (bioenergy type) found that waste has the highest, followed by biomass, biogas >1–3 MW, biogas ≤1 MW and biogas >3 MW, respectively. The marginal abatement cost curve (MAC curve) as illustrated in Figs. 4–6.

5. Conclusion

In this study have estimated the marginal abatement cost (MAC) of Thailand’s electricity generation from renewable energy which consists of (i) natural type (solar energy, wind power, and hydro energy), and (ii) bioenergy type (biomass, biogas, and waste). Estimation of MAC includes 2 main factors are cost and GHG emission which this study the cost factor is electricity generation cost consists of investment, operation, and maintenance cost. The baseline scenario is electricity generation from fossil fuels (natural gas and coal) and policy scenario is electricity generation from renewable energy. The GHG emission reduction from renewable energy had a high reduction and an increasing trend for GHG emission reduction, especially biomass and hydro energy. In addition, GHG emission reduction depends on electricity generation potential. The results of MAC of natural type from various size in 2013–1015 showed that solar energy range from 1576.44 to 5248.32 THB/tCO₂eq, wind power range from 795.93

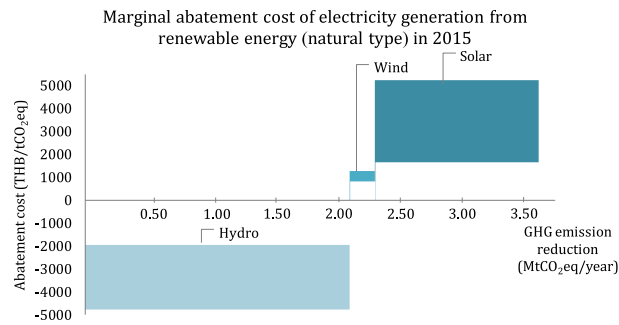


Fig. 3. MAC Curve of electricity generation from renewable energy (natural type; solar energy, wind power, and hydro energy) in 2015.

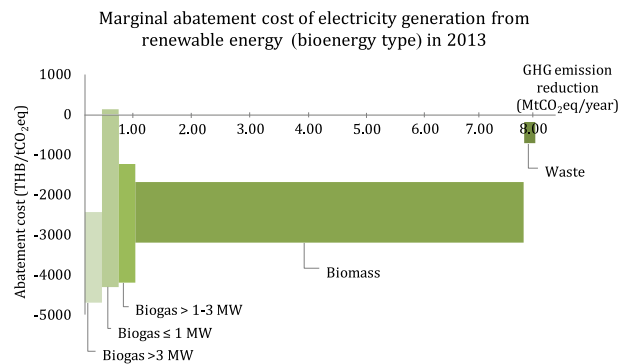


Fig. 4. MAC Curve of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) in 2013.

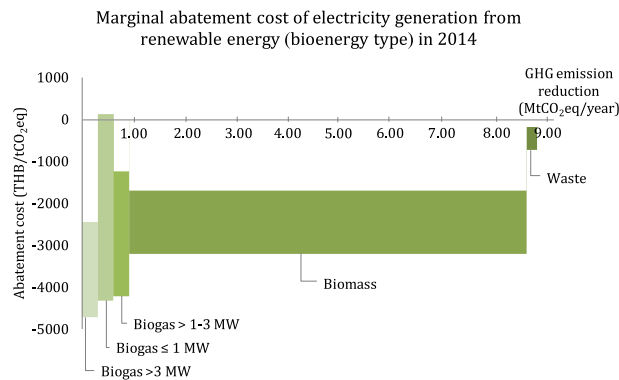


Fig. 5. MAC Curve of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) in 2014.

to 1274.84 THB/tCO₂eq, and hydro energy range from -4780.80 to -1856.02 THB/tCO₂eq. MAC of solar energy has the highest followed by wind power and hydro energy, respectively. For bioenergy type, biomass range from -3335.47 to -1690.91 THB/tCO₂eq, biogas (all size) range from -4913.28 to 134.29 THB/tCO₂eq, and waste range from -741.07 to -178.82 THB/tCO₂eq. MAC of waste has the highest followed by biomass and biogas (all size), respectively. The mainly marginal abatement cost of all type of electricity generation from renewable energy could widely differ range. The very high range of MAC can be explained by plant factor, electricity generation cost, technology, location, and size (in terms of economy of scale).

Marginal abatement cost curve (MAC curve) shows 2 axes that are marginal abatement cost results shown in Y-axis of MAC curve and X-axis shown the greenhouse gas (GHG) emission reduction. Therefore, the considering of measures or policy which is appropriate, it is necessary to consider both axes. In the GHG reduction viewpoint,

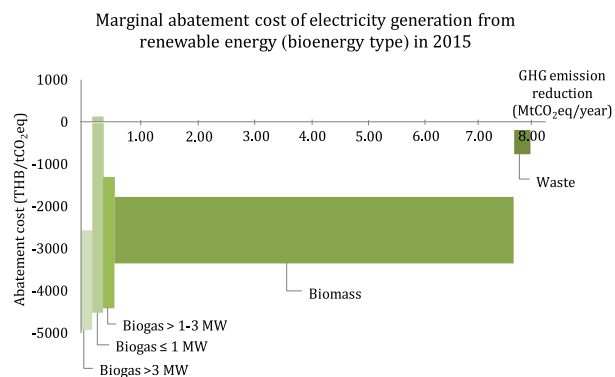


Fig. 6. MAC Curve of electricity generation from renewable energy (bioenergy type; biomass, biogas, and waste) in 2015.

the electricity generation from hydro energy, biomass, biogas (all size) and waste in 2013–2015 can be reducing GHG emission by itself without cost increases. Especially hydro energy and biomass have a high GHG emission reduction. An interesting that is renewable energy in the positive axis. Generally, the government should be support renewable energy that has a positive axis and low abatement cost value as presented in the MAC curve in the first phase. That is wind power and solar energy. If setting support policy for both, it may be effected to increased GHG emissions reduction.

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