Greenhouse Gas Mitigation Analysis from High Energy Efficiency Equipment Replacement in Large Facilities

Det Damrongsak, Wongkot Wongsapai, and Lalita Baibokboon

Abstract—**The marginal abatement costs of energy reduction in designated factory and building are presented. The common energy conservation technologies discussed in this paper are LED, air-conditioner, chiller, motor, boiler and furnace. Results from MAC curve indicate that abatement cost of energy reduction ranges from 2,871.63 to 37,379.24 THB/tCO_2eq, where boiler gives the highest investment cost for the reduction of energy and CO_2 releasing to atmosphere. On the other hand, LED and motor offer low investment cost to reduce energy use and CO_2. Large GHG emission reduction comes from equipment powered by electricity in both factory and building. Results from MAC curve can be used to prioritize which energy conservation measures will reduce the most energy use and CO_2, or which technology should be invested.**

Index Terms—**Marginal abatement costs, energy efficiency, factory, building.**

I. Introduction

Thailand is facing rising energy demand recently. Therefore, Thailand has laid out a national plan called Energy Efficiency Plan (EEP 2015) in order to decrease Energy Intensity (EI) of the country by 30% in 2036. The plan concentrates on energy conservation in many sectors such as energy conservation measure in designated factory and building, subsidization for energy conservation measure, energy conservation in transportation system [1]. Besides energy efficiency plan, Thailand also has high potential on renewable energy due to vast natural resources that can be used to produce energy. Renewable energy technology is relatively expensive in compared with fossil fuel technologies that have been widely used all over the country. Hence, the Thai government put forward the national Alternative Energy Development Plan 2015 (AEDP 2015). This plan sets the target that Thailand must increase the use of alternative energy to 30% of the total energy consumption by 2036 and reduce dependency on fossil fuel and energy imports. Power Development Plan (PDP) and Alternative Energy Development Plan (AEDP) are important plan to promote the use of renewable energy in power generation in Thailand by increasing the proportion of power generation from renewable energy around 15–20% [2] and decreasing natural gas by 30–40% in 2036 [3]. According to the Energy Efficiency Plan, there are some measures related to factory and building that is energy conservation measure in designated factory and building, building code, subsidization for energy conservation measure, promoting the use of LED, promoting research and development of energy conservation, capacity building program, and promoting energy conservation awareness.

The objective of this study is to investigate on the estimation of the marginal abatement costs (MAC) of energy reduction from some technologies used in designated factory and building. The results of this investigation will help the organizations to make decision or formulate policy on energy issues and to be able to prioritize the energy conservation and GHG mitigation measures.

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II. Data and Method

Energy reductions for selected equipment technologies were used to estimate marginal abatement costs in designated factory (DF) and designated building (DB) in Thailand. DF and DB are assigned under the Energy Conservation and Promotion Act B.E. 2535 (A.D. 1992) of Thailand. Energy reduction and its investment for high energy efficiency equipment were from the energy data given by DF and DB to Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy (MOE). Greenhouse gas (GHG) emission reduction of the energy reduction from high energy efficiency equipment were calculated using emission factor from Thailand Greenhouse Gas Management Organization (TGO).

A. Designated Factory and Building

Organizations that use high amount of energy must be regulated by Thailand Energy Conservation Promotion Act (ECP Act). Designated factory and building are organizations that use high amount of energy. By law, designated factory or building must have electrical power meter or total installed transformer with the size at least 1,000 kW or 1,175 kVA, or annual energy consumption at least 20 million MJ. There are total of 8,742 designated factories and buildings in Thailand in 2016. There are 5,747 and 2,995 designated factories and buildings, respectively. Energy data and related information were collected from several types of industries, e.g., paper, water utility, metal, non-metal, garment, food, wood, electricity. For designated buildings, energy data was gathered from hospital, hotel, office building, shopping mall and etc.

B. Energy Reduction and Investment

Thailand faces rising energy demand recently. In response,

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Thailand has put a plan, known as Energy Efficiency Plan (EEP 2015), to reduce the use of energy of the country. The plan concentrates on energy conservation in many sectors, i.e., energy conservation measure in designated factory and building, subsidization for energy conservation measure, energy conservation in transportation system, promoting the use of LED [1]. Energy consumption and energy reduction in designated factories and buildings were provided from the annual energy management report submitted to Department of Alternative Energy Development and Efficiency (DEDE) annually. Energy conservation measures along with their investment were presented in the report [4]. Equipment with high energy savings and energy efficiency potential was used to replace equipment that uses large amount of energy. These selected technologies for this investigation were light emitting diode (LED), air-conditioner, chiller, motor, boiler and furnace. Table I shows energy reduction, CO_2 reduction and investment cost of all mentioned technologies used in designated facilities.

TABLE I: ENERGY REDUCTION, CO_2 REDUCTION AND INVESTMENT COST OF SELECTED TECHNOLOGIES USED IN DESIGNATED FACILITIES

Types of technology	Energy Reduction (kWh)	Energy Reduction (MJ)	CO_2 Reduction (tCO_2eq)	Investment cost (THB)
Electrical energy reduction in designated factory				
- LED	20,554,979	73,997,925	11,642	80,700,395
- Air-conditioner	47,282,408	170,216,669	26,781	194,835,219
- Chiller	656,205,143	2,362,338,514	371,675	4,560,015,444
- Motor	70,170,438	252,613,577	39,745	201,503,579
Electrical energy reduction in designated building				
- LED	75,711,600	272,561,758	42,883	168,362,082
- Air-conditioner	249,067,859	896,644,293	141,072	1,026,326,552
- Chiller	339,105,379	1,220,779,365	192,069	1,334,702,911
- Motor	359,855	1,295,477	204	585,301
Heat energy reduction in designated factory and building				
- Boiler (Factory)	-	111,725,502	9,257	346,007,724
- Furnace (Factory)	-	376,325,597	39,525	1,165,459,643
- Boiler (Building)	-	5,981,491	496	18,524,347

C. Marginal Abatement Costs (MAC)

Marginal abatement costs (MAC) are models and tools for policymaker and governments by using financial and economic data to assess energy cost measures and to evaluate results for a bargaining with emitting sectors and guideline for GHG emission reductions with limited budgets [5]-[7]. Marginal abatement cost curves (MAC Curve) presents the rank of energy measures in the relationship between GHG emission reduction and price or cost which means that “the marginal cost for abating one additional unit of carbon dioxide” [8]. There are several studies with respect to MAC. One of the studies from McKinsey & Company was the global marginal abatement cost curve or MAC curve with respect to energy technology for reducing GHG emission [9]. Jan Abrell *et al*. presented the estimated reduction cost of CO_2 through solar and wind subsidies in Germany and Spain [10]. Jiakuui Chen and Dong Xiang evaluated carbon efficiency and carbon abatement cost of coal-fired power plants in Shanghai [11]. Juan Peng *et al*. estimated the technical efficiency, potential for reduction, and marginal abatement costs of CO_2 emissions of the thermal power sector in China [12].

In this analysis, the MAC equation can be defined by equation (1), in which it is the difference between the power generation cost in policy scenario and baseline scenario divided by the difference between the GHG emission in baseline scenario and policy scenario. Baseline scenario and policy scenario can be described in the next section. The MAC equation can be given as follow:

$$MAC = \frac{C_{PS,y} - C_{BS,y}}{E_{BS,y} - E_{PS,y}} \tag{1}$$

where:

MAC is Marginal abatement costs of power generation from energy efficiency (THB/tCO_2eq)

C_{PS} is power generation cost in policy scenario (THB)

C_{BS} is power generation cost in baseline scenario (THB)

E_{PS} is Greenhouse gas (GHG) emission in policy scenario (tCO_2eq)

E_{BS} is Greenhouse gas (GHG) emission in baseline scenario (tCO_2eq)

y is year

D. Determination of Baseline Scenario and Policy Scenario

Power generation baseline scenario is power generation from the old technological equipment, while the policy scenario is power generation from high energy efficiency equipment (LED, air-conditioner, chiller, motor, boiler, and furnace). To achieve energy saving potential as stated in the national energy efficiency plan, equipment that consumes large amount of energy must be replaced by high energy efficiency equipment. For lighting system, 36 W fluorescent lamps were replaced by 20 W LEDs. For air-conditioning system, old model air-conditioners were replaced by new air-conditioner with EER of 18 (Btu/hr)/W. Chillers were replaced by new chillers with power consumption of 0.6

kW/TR. Motors were changed to high efficiency motors that could reduce power consumption by 1%. Table II shows investment cost per energy saving for equipment replacement in facility.

TABLE II: INVESTMENT COST OF HIGH ENERGY EFFICIENCY EQUIPMENT REPLACEMENT FOR ENERGY SAVING

System	Detail	Investment cost (THB/energy saving)
Lighting	Replaced by LED (20W)	3.93 THB/kWh saving
Air-conditioning	Replaced by air-conditioner with EER of 18 (Btu/hr)/W	4.12 THB/kWh saving
Chiller	Replaced by chiller with power consumption of 0.6 kW/TR	6.95 THB/kWh saving
Motor	Replaced by high efficiency motor	2.87 THB/kWh saving
Boiler	Replaced by high efficiency boiler	3.10 THB/MJ saving
Furnace	Replaced by high efficiency furnace	3.10 THB/MJ saving

III. RESULTS

A. Estimation of Marginal Abatement Costs of Energy Reduction

The estimation of the marginal abatement costs of energy reduction for selected technologies in designated factories and buildings in 2016 are discussed. Table III shows the marginal abatement costs of electrical energy reduction in designated factory and building. Table IV shows the marginal abatement costs of heat energy reduction in designated factory and building.

TABLE III: ESTIMATION OF MARGINAL ABATEMENT COSTS OF ELECTRICAL ENERGY REDUCTION IN DESIGNATED FACTORY AND BUILDING IN 2016

Types of technology in designated factory and building	Marginal abatement costs (THB/tCO_2eq)
Designated factory	
- LED	6,931.63
- Air-conditioner	7,275.19
- Chiller	12,268.84
- Motor	5,069.97
Designated building	
- LED	3,926.08
- Air-conditioner	7,275.19
- Chiller	6,949.07
- Motor	2,871.63

TABLE IV: ESTIMATION OF MARGINAL ABATEMENT COSTS OF HEAT ENERGY REDUCTION IN DESIGNATED FACTORY AND BUILDING IN 2016

Types of technology in designated factory and building	Marginal abatement costs (THB/tCO_2eq)
Boiler (Factory)	37,379.24
Furnace (Factory)	29,486.76
Boiler (Building)	37,379.24

Energy reduction were obtained from technologies, i.e, LED, air-conditioner, chiller, motor, boiler and furnace, that contributed to greater energy savings and also kept on track with the national energy efficiency plan (EEP 2015). Electrical energy reduction ranges from 2,871.63 to 12,268.84 THB/tCO_2eq. While heat energy reduction varies from 29,486.76 to 37,379.24 THB/tCO_2eq. Industrial sector provides a greater energy savings and amount of CO_2 reduction due to large numbers of factories. Boiler has the highest abatement cost of 37,379.24 THB/tCO_2eq. Motor has the lowest abatement cost of 2,871.63 THB/tCO_2eq since motor used in the production process has been frequently used in comparison to other equipment. Hence it reduces greater amount of CO_2 releasing to atmosphere with the lowest investment.

B. The Greenhouse Gas (GHG) Emission Reduction of Energy Reduction

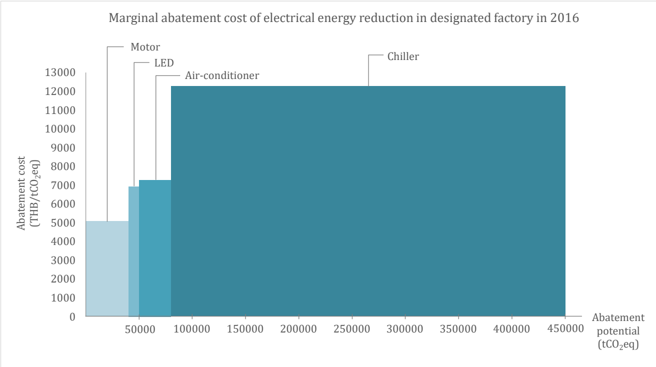
The greenhouse gas (GHG) emission reduction of energy reduction from the use of high energy efficiency technologies in designated factory and building has been presented in the annual energy management report giving to Department of Alternative Energy Development and Efficiency (DEDE) [4]. The details of GHG emission reduction for each technology are shown in Table V. Electrical energy reduction contributes large amount of GHG emission reduction since many high energy efficiency equipment used in facility consumed mostly electricity.

TABLE V: THE GREENHOUSE GAS (GHG) EMISSION REDUCTION OF ENERGY REDUCTION FROM HIGH ENERGY EFFICIENCY EQUIPMENT REPLACEMENT

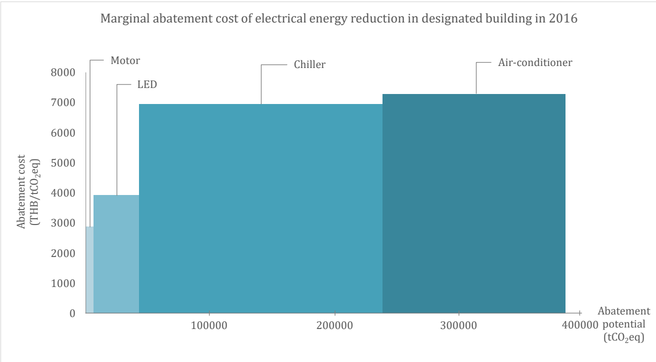
Energy saving measure	GHG emission reduction (tCO_2eq)
Electrical energy reduction in designated factory	449,842
Electrical energy reduction in designated building	376,228
Heat energy reduction in designated factory and building	49,277
Total energy reduction in designated factory and building	875,348

C. Marginal Abatement Cost Curve (MAC Curve) of Energy Reduction

The marginal abatement cost curves (MAC curve) of electrical energy reduction in designated factory and building in Thailand in 2016 are shown in Fig. 1 MAC curve consists of 2 axes. Vertical axis represents marginal abatement costs (THB/tCO_2eq). Horizontal axis represents the greenhouse gas (GHG) emission reduction (tCO_2eq). For factory, it is found that chiller has the highest abatement cost as the high efficiency chiller is very costly. Air-conditioner, LED, and motor have lesser abatement cost, respectively. For building case, air-conditioner has the highest cost as it is quite regular to use split type air-conditioner much more than chiller. Chiller, LED, and motor have lesser cost, respectively. Fig. 2 shows the marginal abatement cost curves (MAC curve) of heat energy reduction in designated factory and building, in which boiler has the highest abatement cost. Fig. 3 shows the marginal abatement cost of all selected technologies for designated facilities. It is found that boiler has the highest abatement cost, followed by furnace, air-conditioning systems, LED, and motor, respectively. It is noticeable from MAC curve that technology using heat energy has high abatement costs in comparison to the low abatement costs from technology using electrical energy. Investment costs on energy equipment often vary for different types of factories. This is why the results show that investment costs on high efficient chillers in factories is higher than those in buildings with respect to the same amount of reduction of energy and CO_2.



(a)



(b)

Fig. 1. MAC Curve of electrical energy reduction in: (a) designated factory and (b) designated building.

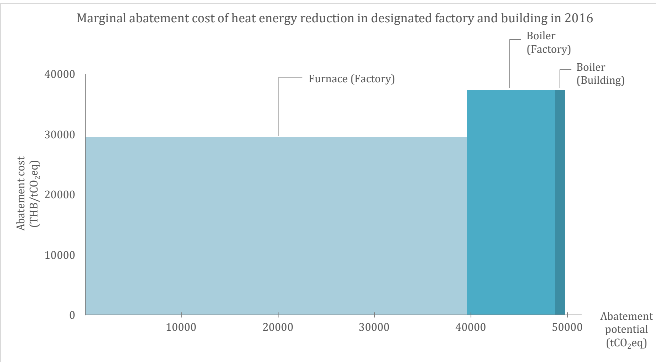


Fig. 2. MAC Curve of heat energy reduction in designated factory and building.

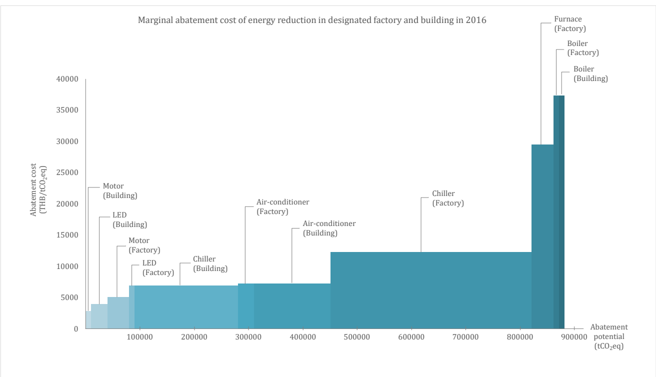


Fig. 3. MAC Curve of total energy reduction in designated factory and building.

IV. Conclusion

The marginal abatement costs (MAC) of energy reduction in designated factory and building are presented. Technologies used in analysis are LED, air-conditioner, chiller, motor, boiler and furnace. Energy data and related information are obtained from Department of Alternative Energy Development and Efficiency. Results from MAC curve show that abatement cost of energy reduction varies from 2,871.63 to 37,379.24 THB/tCO_2eq. The highest investment cost for energy and CO_2 reduction is from boiler, while LED and motor have low investment cost for the reduction of CO_2. Large amount of GHG emission reduction comes from technologies using electrical energy in both designated factory and building. MAC can further be used in energy and CO_2 reduction analysis on other equipment such as air compressor and pump that have high energy consumption in large factories. MAC curve represents the relationship between GHG emission reduction and investment cost on technology. Therefore, it is quite challenge for policymaker and government to prioritize the energy conservation measures for any facility that consumes a large amount of energy. Technology with high investment cost should be supported by the government in terms of capacity building program or subsidy. Furthermore, since there are great numbers of small and medium enterprises (SMEs) in Thailand, MAC can also be employed to analyze the reduction of energy and CO_2 in SMEs as well.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Det Damrongsak and Wongkot Wongsapai conducted the research; Det Damrongsak, Wongkot Wongsapai and Lalita Baibokboon analyzed the data; Det Damrongsak wrote the paper; Det Damrongsak revised the paper; all authors had approved the final version.

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