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CO_2 Reduction Planning for Energy Efficiency Projects in Bangkok Commercial Office Buildings

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Abstract. As a significant contributor to greenhouse gas emissions in the Asia Pacific region, Thailand has pledged to lower its carbon dioxide emissions by 555 million tons by the year 2030. In Bangkok, energy efficiency projects in the large commercial buildings sector are an integral method to reduce emissions and support a lower carbon future. Hence, to support energy efficiency methods, this study develops a methodology to quantify the emissions reduction and cost savings potential to optimize decision-making in CO_2 emissions reduction project planning over the next five years. The results indicate that, among the energy efficiency methods considered for large commercial buildings, AC installations are the most cost-effective method, whereas chiller installations offer the most CO_2 reduction potential. Regarding project planning, results also indicate that with the current goals, additional measures about CO_2 emissions may be required to meet the country's targets.

Keywords: CO_2 emission, Energy efficiency, MACC, Sustainability, Climate change

1. Introduction

1.1. Thailand's CO_2 Emissions

Climate change is a pressing issue that has detrimental impacts on many facets of the world, including energy demand, labor productivity, and public health[1].The gradual increase in global temperatures because of climate change has led to water scarcity, loss of species, increase in extreme weather events, and disease proliferation. CO_2 is the main driver of climate change, as it accounts for almost 80% of greenhouse gas (GHG) emissions. It is widely recognized that to avoid the worst impacts of climate change, the world needs to reduce its CO_2 emissions urgently [2].

From 2010 to 2020, Thailand averaged about 2% of the total Asia Pacific region'sCO_2emissions. In 2020, Thailand reported CO_2emissions of 277 million tons CO_2equivalent (mtCO_2e) with an average annual growth rate of 1% between 2010 and 2020. As part of its commitment to the Paris Agreement, Thailand has pledged a Nationally Determined Contribution (NDC), or emissions reduction, of 555mtCO_2e from 2021 to 2030.

1.2. Energy Efficiency Projects

The Thailand Greenhouse Gas Management Organization (TGO) is the main organization supporting CO_2 emissions reduction initiatives in Thailand. TGO defines eight project types for CO_2 emissions reductions: renewable energy, energy efficiency (EE), waste management, energy from waste management, management in transport sector, forests and green spaces, agriculture, and other methods. Among the eight projects, EE is the most prevalent and accessible form of CO_2 emissions reduction in Thailand and consists of methods to minimize energy waste. EE methods range from large-scale changes such as replacing industrial equipment with more efficient units to small-scale changes such as changing light fixtures to LED and using energy-efficient appliances.

Thailand's Energy Policy and Planning Office (EPPO) forecasts in its Power Development Plan (PDP) that EE projects will result in the highest percentage (57%) of total CO_2 emissions reduction in Thailand by 2030 in accordance with the NDC target. Of this percentage, 52% is EE in end-use cases spanning small commercial and residential, large commercial and residential, and industrial uses.

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The commercial building sector has been identified as an area where significant savings can be made because energy demand and consumption in this sector are rapidly growing. In 2020, the third-largest use of electricity after the industrial (44%) and residential (28%) sectors were the business sector (23%). Within the business sector in the Bangkok Metropolitan Area (BMR), office buildings account for 37% of energy consumption amongst large commercial buildings (LCBs).

Therefore, this study aims to create a framework and modeling analysis to study and quantify CO_2 emissions reduction, electricity savings, and cost savings for EE projects in BMR office buildings for the 2021-2025 period. First, projects for 4 LCB types were evaluated by cost and emissions reduction potential through a Marginal Abatement Cost Curve (MACC). Then, CPLEX optimization software was utilized to quantify the optimal areas to employ three different EE methods in office buildings over a 5-year period.

The remainder of the article is organized as follows. Section 2 presents background research related to the study. Then, the problem is described in Section 3. Section 4 presents the methodology used in the study. Section 5 presents results and discussion. Lastly, Section 6 concludes and discusses the future work directions.

2. Literature Review

2.1. Energy Efficiency Methods

According to the International Energy Agency, EE reduces emissions both directly from fossil fuel combustion and indirectly from electricity generation. Based on the IEA 2018 Efficient World Scenario, if the world were to implement EE in existing technologies fully, energy industry CO_2emissions could be reduced by up to 40% of the total Paris Agreement reduction target. Therefore, EE could be an integral CO_2emissions reduction tool that, when combined with other measures, will help to achieve global climate targets.

Reference[3] assessed the CO_2 reduction potential of energy policies in the Thai LCB sector and found that monetary incentives to support EE projects are the most effective measures to reduce CO_2 emissions, reducing energy demand by 12%. The study also found that LED installations are one of the most effective emissions reducers and that office buildings have the highest reduction potential in the BMR compared to hospitals and hotels.

2.2. Marginal Abatement Cost Curve (MACC)

In practice, the inconsistencies in policy enactment and the heterogeneity of different building types make widespread EE adoption difficult in Thailand. Therefore, MACCs, which standardize EE project parameters on a like-for-like basis, are commonly used by policymakers [4].

MACCs are a decision-making tool widely used to assess and to compare the economic feasibility and CO_2 emissions reduction impact of different reduction strategies[5]. A MACC measures two key metrics: 1) CO_2 reduction and 2) Marginal Abatement Cost (MAC), which is the Net Present Value (NPV) of projects per tCO_2e reduced given in (1). The projects are compared side by side, with the most cost-effective on the left and the least cost-effective on the right.

$$MAC = -NPV / Total\ CO_2\ emissions\ reduction \tag{1}$$

Although there are various ways to construct MACCs, a standard method is inputting project parameters such as duration, upfront capital (CAPEX), operating costs (OPEX), and estimated CO_2reduction into a model calculating the MAC and NPV over time. In addition, MACCs require other information including the local electricity rate and CO_2emissions factors.

MACCs can also include both technology costs and project implementation costs. For example, the study in Colombia used both aforementioned costs to develop MACCs for LCBs, resulting in a CO_2reduction potential of 45,000 tCO_2e per year in office buildings [6].

Other tools can be paired with MACCs as well. For example, MACCs for 30 Chinese provinces were constructed and used a regression analysis to find a negative correlation between EE technology and MAC [7]. Another example is the study utilizing MACCs to investigateCO_2 emissions projects for the building sector in Armenia and Georgia [8].

Note that the EE projects that were studied all resulted in negative costs, meaning that the energy savings are greater than the implementation cost. The results, however, were sensitive to the discount rate; when it was doubled from 7.5% to 15% in the sensitivity analysis, almost all GHG mitigation options turned out to be positive cost options. Therefore, it is useful to test and compare results for different discount rates[8].

Besides academia, MACCs have been widely used by private companies and international institutions such as McKinsey & Company, Bloomberg, and the World Bank to prioritize climate change mitigation options in various countries.

Therefore, the comparisons from the MACC for BMR LCBs can help advise Thailand's energy planning officials on methods to meet the country's NDC agreement.

3. Problem Description

This study focuses on quantifying the effectiveness of EE methods in BMR LCBs, both in terms of cost and CO_2emissions reduction. Also, the research aims to develop an efficient methodology to optimize project planning for future CO_2emissions reduction initiatives in Thailand's buildings. Because of the limited research in this field, most of the available tools are Excel models, requiring manually updating and having no links to a centralized database. Therefore, this study aims to address these gaps by developing tools to standardize EE project comparisons so that they can be fairly assessed for future project development to help meet Thailand's NDC targets.

4. Methodology

4.1. Methodology Outline

First, past LCB project information was collected from public sources, further processed, and compiled into a MACC model. The MACC was used to compare all building types to gain a preliminary understanding of EE cost-effectiveness for each type. The EE methods included were LED, AC, and chiller installation.

Second, office building parameters from the MACC were converted to a per building consumption basis. The parameters were CO_2reduction, electricity savings, cost savings, and MAC. These parameters were placed into CPLEX optimization software, which used multiple objective goal programming to optimize each parameter by priority. The results indicate the project areas to employ the three different EE methods in office buildings over the next five years.

4.2. Data Collection

The Department of Alternative Energy Development and Efficiency (DEDE) and the United Nations Development Program (UNDP) initiated the 2014 Promoting Energy Efficiency in Commercial Buildings (PEECB) project, which focused on LCBs. Various EE methods were employed in 11 different BMR LCB sites, including LED lighting replacement, AC unit optimization, chiller optimization, heater efficiency changes, and building monitoring [9].

The PEECB data [9] was used to develop a MACC for seven LCBs for the LED, AC, and chiller EE methods. The data included previously calculated project electricity savings, CAPEX, cost savings, CO_2 reduction, and payback period. Each project OPEX was then independently estimated for the LED projects based on wattage and bulb cost, and for the remaining projects based on an electricity rate-per-area basis. Other key data that was collected and used for further analysis includes Thailand's annual electricity rates, CO_2 emissions factor, and LCB statistics.

4.3. Data Processing

The PEECB data and OPEX calculations were used as an input to a MACC tool provided by the Western Australia Local Government Association (WALGA). Although the MACC data includes LCBs such as hospitals and hotels, office buildings were chosen to focus on this study due to their relatively high share of electricity consumption. The original PEECB project parameters and the resulting MAC were converted to an electricity consumption basis to standardize comparisons between office locations with different characteristics (Table 1).

Table 1: EE office building project parameters

Project Type	Parameters (on per kWh basis)				
	CO_2 Reduction (tCO_2e)	***Electricity Savings (kWh)***	***Cost Savings (THB)***	***MAC (THB/tCO_2e)***	***CAPEX (THB)***
LED	$3.2x10^{-5}$	$4.0x10^{-3}$	$1.5x10^{-2}$	$1.4x10^{-4}$	$1.2x10^{-2}$
AC	$3.9x10^{-6}$	$6.6x10^{-4}$	$2.8x10^{-3}$	$-8.7x10^{-5}$	$1.7x10^{-2}$
Chiller	$1.3x10^{-4}$	$2.2x10^{-2}$	$8.9x10^{-2}$	$-8.9x10^{-5}$	$6.8x10^{-1}$

CPLEX decision optimization modeling software, which employslinear and constraint programming, was used to designate the office building area to be used in each EE project in a 5-year period(2021-2025). Goal programming was used to weigh four objectives differently based on their priority, with an allowable 5% degradation in objective values with each iteration. Table 2 summarizes the input variable values and objectives in order of importance used to create the linear program for analysis.

Table 2: CPLEX model input variables

Variable	Input
Decision Variable	Area of project work each year
Objectives	Maximize 5-year CO_2 reduction Maximize annual electricity savings Maximize 5-year cost savings Minimize 5-year MAC
Constraints	5-year LCB CO_2 reduction target 5-year LCB cost savings target Annual LCB electricity savings target 5-year EPPO PDP budget BMR office area available

5. Results and Discussion

5.1. MACC Results

Fig. 1 presents the results of the MACC for seven LCBs of different types. Projects are grouped by cost efficiency in ascending order from the left to the right side of the chart.

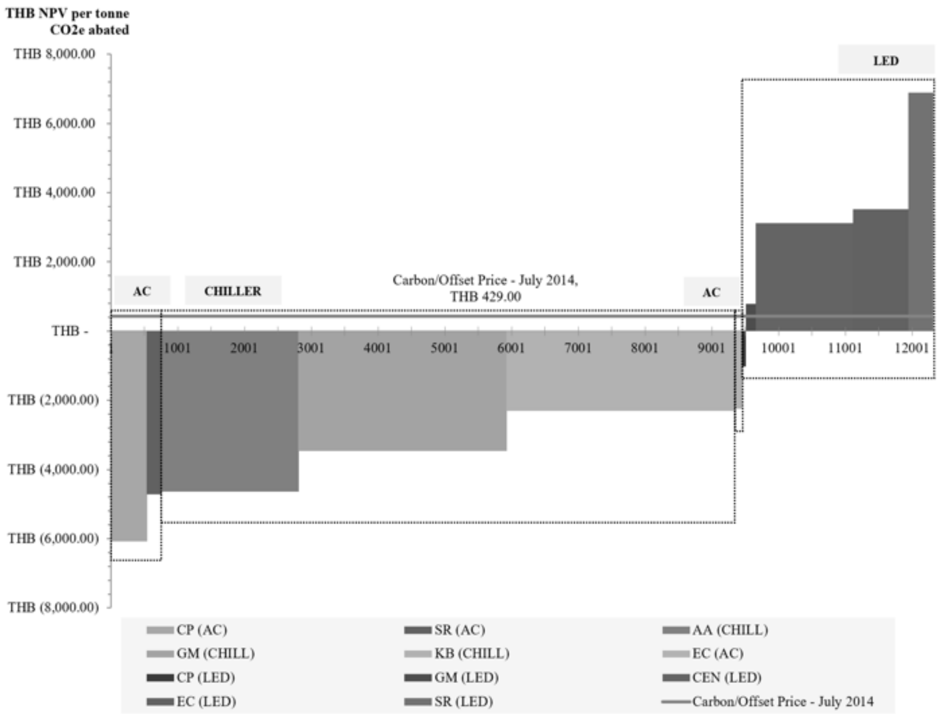

Fig. 1: MACC curve for LCBs in the PEECB project

Two AC projects are clustered toward the left of the curve, indicating that despite their high upfront cost, these projects utilize their capital better to reduce emissions. The negative MAC indicates that the project can generate net cost savings over the project lifetime, lending to its cost-effectiveness. The chiller projects directly to the right of the AC projects offer the highest CO_2 emissions reduction potential than the alternatives, shown by the greater area taken up on the x-axis.

The least cost-effective project is LED installation, which can be attributed to their low-rated bulb life (2.9 years) compared to the average life span of an HVAC unit (15-20 years). Over time for PEECB projects, the lower replacement frequency for the AC and chiller methods lends more savings than LED, assuming that no major operating costs are required during the project life.

As confirmation of the previous research findings (i.e., [3]), LED also offers a CO_2 emissions reduction over AC installation. Note that this applies when we examine only office buildings. Table 1 also indicates that both LED and chiller methods have higher CO_2 reduction potential on an electricity consumption basis. Other information to note is that the MAC, electricity savings, and cost savings in offices are most optimal for chiller replacements. Lastly, CAPEX is the lowest for LED replacements because of the cost of the bulb.

5.2. CPLEX Analysis

Table 3 shows the decision variable results from the CPLEX optimization model for the four different objectives. Note that these values are not per consumption but are reported in their units.

Table 3: CPLEX model output

Project Type	CO_2 Reduction (tCO2e)	Electricity Savings (kWh)	Cost Savings (THB)	MAC (THB/tCO_2e)
LED	$3.2x10^2$	$3.9x10^4$	$1.5x10^5$	$1.3x10^3$
AC	$7.2x10^3$	$1.2x10^6$	$5.1x10^6$	$-1.6x10^5$
Chiller	$4.3x10^1$	$7.3x10^4$	$2.9x10^5$	$-2.9x10^2$
Total	$7.9x10^3$	$1.3x10^6$	$5.5x10^6$	$-1.6x10^5$

The CPLEX model constraints were based on 5-year targets set by EPPO. The model simulated increasing values in electricity savings per year under the assumption that the EPPO PDP forecasts stay constant. There were four iterations of the linear program, with each iteration adding on a constraint for the previous optimal objective value generated. For example, once a maximized value of CO_2 reduction was found in the first iteration, this value was used as a constraint (with acceptable degradation of 5%) in the next iteration for electricity savings.

In comparison to their respective PDP targets, the CO_2 reduction, electricity savings, and cost savings results are insignificant. These targets were set by an assumption of 37% of the total EPPO target for LCBs in accordance with the office building share of electricity consumption. The CO_2 reduction total of $7.9x10^3$ tCO_2e is only 2% of its $3.7x10^5$ tCO_2e target, whereas the totals for electricity and cost savings are negligible compared to their targets of $2.7x10^{10}$ kWh and $1.4x10^9$ THB, respectively. The reasons may come from the incomprehensive PEECB parameters, which may not include all office buildings and should be supplemented with further information to gain a more accurate picture of EE project potential. Otherwise, additional measures other than the EE method may be required to meet the EPPO target values for the LCB sector.

6. Conclusion

6.1. Summary of Findings

Among all LCB building types, AC installations were shown to be the most cost-effective EE method for CO_2emissions reduction. On the other hand, chiller installations offer the most well-rounded solution for both cost-savings and emissions reduction. For office buildings, chiller installations provide the most efficient returns on electricity savings, cost savings, and MAC.

CO_2emissions in office buildings could be mitigated by approximately 7,900 tCO_2ein the next five years, which is approximate 2% of the total reduction target for LCBs. As a LCB building type that consumes over a third of the total electricity generation, it is evident that more measures should be studied to increase the potential CO_2 emissions reduction in this commercial sector by means of potentially combining EE methods or by providing more publicly available data for the study of project parameters in office buildings.

These research results should not be considered definitive but instead as a starting point for further analysis of CO_2 emissions reduction potential in the BMR commercial building sector. Further refinement of the LCB MACC may be needed by modifying assumptions and revising CO_2 reduction potentials based on the adoption rate.

6.2. Opportunities for Further Study

For further research, other types of LCB, including hotels, hospitals, and retail centers, can be compared in the CPLEX program for the different EE project types and different discount rate sensitivities. This will allow a more realistic planning scenario to maximize CO_2 reduction over the next five years. Additionally, dynamic MACC calculations and life cycle costs can be developed and compared with the static MACC from the study to identify potential errors in the assumptions used and gain a more accurate understanding of how the project costs and emissions will evolve over time. Lastly, the tools used in this study can also be adapted for evaluating other projects of interest, such as in the alternative energy sector.

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