Potential for Energy Efficiency Improvements to Reduce Greenhouse Gas Emissions in Thailand's Industrial Estates

Varoon Raksakulkarn, Wongkot Wongsapai*, Sopit Daroon, Chaichan Ritkrerkkrai, Tassawan Jaitiang, Waranya Thepsaskul, Phitsinee Muangjai, and Orapun Chaikwang

***Abstract*—This study aimed to evaluate the potential for reducing greenhouse gas (GHG) emissions through the implementation of energy-efficient measures that involve the replacement of existing machinery and equipment with high-efficiency alternatives. The study's scope encompassed all industrial factories situated within the Industrial Estate Authority of Thailand's (IEAT) industrial estates. The study utilized data from the designated factory's energy management report database, which included information regarding the machinery, equipment, and other relevant data pertinent to the research. The categorization of machinery and equipment systems could be done based on the type of energy consumed, which includes electricity and thermal energy. The potential for increasing energy efficiency could be evaluated for each of these energy systems. The study conducted an initial evaluation based on the available data from the designated factory database with regards to enhancing the efficiency of machinery and equipment. Subsequently, the scale-up concept was applied to evaluate the potential of energy efficiency enhancements for the entire industrial factory. The study findings revealed a total GHG reduction potential of 4.63 $MtCO_2e$, with thermal energy measures accounting for 3.05 $MtCO_2e$ (65.83%) and electricity measures accounting for 1.58 $MtCO_2e$ (34.17%). Among the various measures, the implementation of insulating measures for thermal equipment in the furnace system showcased the most significant potential for GHG reduction, with a potential reduction of 2.26 $MtCO_2e$, accounting for 48.73% of the total GHG reduction potential. Based on these findings, it can be inferred that a reduction of 1 $MtCO_2e$ in GHG emissions could potentially result in a corresponding reduction in energy costs amounting to approximately 8,449–8,889 million baht.**

***Index Terms*—Greenhouse gas emissions, greenhouse gas mitigations, energy efficiency improvements, Thailand's industrial estates, climate action**

I. INTRODUCTION

The industrial sector contributes significantly to Thailand's economy, comprising almost one-third of its GDP and exhibiting higher worker productivity than the agricultural and service sectors [1, 2]. The development of industrial estates is a consequence of the growth of the industrial sector, aiming to support the management, promotion, and development of industries while regulating pollution and addressing environmental concerns such as resource and waste management to mitigate environmental impact. Following Thailand's previous energy efficiency plan in 2015 [3], the country announced its commitment to achieving carbon neutrality or zero net carbon dioxide emissions by 2050 during its participation in the 26th session of the Conference of the Parties (COP 26) to the United Nations Framework Convention on Climate Change (UNFCCC) [4]. The Thailand 4.0 and Industry 4.0 policies of the Thai government prioritize the integration of innovation and advanced technology into the industrial sector to promote collaboration, interdependence, and cost-effective resource management. Environmental protection, including reducing GHG emissions and promoting sustainable resource management, is crucial for the development of industrial estates [5]. Smart industrial estates, utilizing advanced technology and innovation, can improve managerial efficiency and reduce GHG emissions [6]. Thailand's overall GHG emissions by sector (excluding Land Use, Land-Use Change, and Forestry or LULUCF) totaled 354.36 million metric tons of carbon dioxide equivalents ($MtCO_2e$) in 2016, with the energy sector accounting for 71.65% (253.90 $MtCO_2e$). The figure illustrates that the industrial sectors, including the energy industry, manufacturing, and construction, emit 157.78 $MtCO_2e$, accounting for 62.14% of the total GHG emissions from the energy sector [7]. Large industrial factories with significant energy needs and production capacities are typically located in industrial estates, which offer the necessary infrastructure, utilities, and management systems, as well as non-tax and tax incentives [8]. To mitigate energy consumption and GHG emissions and fulfill Thailand's nationally determined contribution (NDC), it is imperative to implement energy efficiency measures within the industrial sector [9]. This study aims to quantify the potential for reducing GHG emissions by improving the energy efficiency of industrial factories located within Thailand's industrial estates. The resulting data can support the country's objective of achieving carbon neutrality.

II. DATA AND METHOD

The GHG reduction potential from energy efficiency improvement measures is conceptualized from the application of significant industrial machinery and equipment data currently used in industrial plants to evaluate the energy efficiency of these facilities. GHG emissions are decreased when heavy machinery and equipment are replaced with high-performance versions.

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Varoon Raksakulkarn is with the Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand.

Wongkot Wongsapai is with the Department of Mechanical Engineering, Faculty of Engineering, Science and Technology Research Institute, Chiang Mai University, Chiang Mai, Thailand.

Sopit Daroon, Chaichan Ritkrerkkrai, Tassawan Jaitiang, Waranya Thepsaskul, Phitsinee Muangjai, and Orapun Chaikwang are with the Energy Technology for Environment Research Center, Chiang Mai University, Chiang Mai, Thailand.

*Correspondence: wongkot@eng.cmu.ac.th (W.W.)

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A. Number of Industrial Factories

The study conducted a thorough examination of 4,946 industrial factories situated in the industrial estates administered by the IEAT, which includes both the IEAT industrial estate and the joint-operating industrial estate [10]. This figure represents 1,120 factories from the list of factories in 2018 [11], or 22.64% of the industrial factories in the industrial estates of the IEAT that were designated under the Energy Conservation Promotion Act B.E. 2535 [12–14]. Table I provides additional details.

TABLE I: NUMBER OF FACTORIES IN INDUSTRIAL ESTATES

Number of factories (places)	IEAT industrial estate	Joint-operating industrial estate	Total
All factories	1,505	3,441	4,946
Designated factories	322	798	1,120

"Legally designated factories" refers to those who are obligated to take legal energy conservation action, with a focus on industrial plants with high energy consumption and the potential to take action on energy conservation. A legally designated factory is one that has received approval from the energy provider to utilize the electric meter or to install a single or a combination of transformers rated at 1,000 kW or 1,175 kVA or more, according to the Royal Decree on Designated Factory B.E. 2540 [15]. A factory that uses electricity from the power supplier's system, steam heat from the power supplier, other consumable power from the power supplier, any other consumable energy from the power supplier or its own, or a combination of 20 million MJ or more of total energy equivalent to electricity is also legally designated. Owners of designated factories must comply with the Ministry of Energy's Notification [16], which mandates that those who set up an energy management operation and submit an annual energy management report that includes information on energy use, the installation or replacement of significant machinery or equipment, and energy conservation.

B. Data

The data of the Department of Alternative Energy Development and Efficiency (DEDE), which currently has the most comprehensive database, was used to compile information pertaining to machinery and equipment, as well as other key data points derived from the annual energy management report database of designated factories for the period spanning 2018-2019. Categorization of machinery and equipment systems can be done based on the type of energy they consume, leading to two distinct groups: those that utilize thermal energy, such as boiler systems and furnace systems, and those that rely on electricity, including lighting systems, split-type air conditioning systems, central air conditioning systems, and motor systems. Table II illustrates the concept of evaluating the potential for enhancing energy efficiency across various systems.

The potential to increase the energy efficiency of significant machinery and equipment can be evaluated using the data contained within the annual energy management report, which is a preliminary assessment based on the information currently available and the assessment guidelines. A number of factories with data and capacities that differ in accordance with energy consumption systems are involved in the optimization of machinery and equipment.

TABLE II: IMPROVING THE ENERGY EFFICIENCY OF INDIVIDUAL MACHINERY AND EQUIPMENT

Type	System	Machinery and equipment
Electricity	Lighting	Replaces the fluorescent (FL) lamp T8 with a light-emitting diode (LED) lamp (20W)
		Replaces the FL lamp T5 with an LED lamp (20W)
		Replaces the mercury-vapor (MV) lamp with an LED lamp (20W)
		Replaces the compact fluorescent (CFL) lamp with an LED lamp (20W)
		Replaces the high-intensity discharge (HID) lamp with an LED lamp (20W)
	Split-type air conditioning (AC)	Replaces the existing one with 18 Btu/W of AC (higher efficiency)
	Chiller	Replaces the existing one with 0.6 kW/TR of chiller (higher efficiency)
	Motor	Replaces the existing one with a higher-efficiency motor
Thermal energy	Boiler	Replaces the existing one with a higher-efficiency boiler
		Insulates steam equipment
	Furnace	Insulates heating equipment

C. Scale-up of Data

The bottom-up methodology, also referred to as the "in-situ energy audit" approach, as utilized by David et al. [17] and Alfonso *et al*. [18], in conjunction with the concept of expanding data, known as "scale-up of data," are employed to evaluate the potential for energy efficiency improvements across all industrial factories situated in industrial estates. As illustrated in Fig. 1, data can be segregated into four distinct levels with the following details:

- Level 1: designated factories in industrial estates with information on machinery and equipment.
- Level 2: designated factories in the IEAT industrial estates reported their energy consumption in 2018.
- Level 3: designated factories in the IEAT industrial estates.
- Level 4: all of the factories in the IEAT industrial estates.

Table III presents instances of data expansion for factory lighting systems located within industrial estates managed by the IEAT. All factories situated within the IEAT industrial estate, including both designated and non-designated factories, undergo the following procedures to expand the preliminary assessable data from the first level to the fourth level:

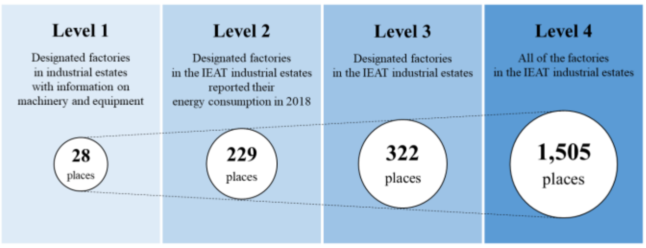

Fig. 1. An example of the level of data needed to evaluate the factory's lighting system's potential in the IEAT industrial estates.

- Arrange the information by industry types because various industries consume energy in different ways.
- Estimate the amount of energy consumption in each system as the number of factories increases, using the rule of three to compare proportions and find the third value from the relationship between two numbers [19]. The direct rule of three describes the process for finding the fourth term d of a proportion, as shown in (1). Given that a, b, and c are known, in words, the solution is to multiply the second and third numbers together and divide the product by the first so that the term d in Eq. (1) becomes Eq. (2).

$$\frac{a}{b} = \frac{c}{d} \tag{1}$$

$$d = \frac{bc}{a} \tag{2}$$

- Calculate the ratio of the improvement in machinery and equipment potential to the energy consumption of each system, then use the ratio to determine the potential in data levels 2-4.
- Calculate the GHG reduction potential from the 4th level of energy saving potential using (3), which is consistent with the methodology of Thailand's Voluntary Emission Reduction Program (T-VER) [20].

$$GHG_i = EC_{saving,i} \times EF_i \tag{3}$$

Where: GHG_i is the amount of GHG reduction potential from energy type *i* ($kgCO_2e$); $EC_{saving,i}$ is the amount of type *i* energy consumption saved (unit); EF_i is the emission factor for energy generation of type *i* ($kgCO_2e$/unit); *i* is the category or type of energy consumption saved.

TABLE III: EXAMPLES OF DATA EXPANSION FOR FACTORY LIGHTING SYSTEMS IN THE IEAT INDUSTRIAL ESTATES

Lighting system	Unit	Level 1	Level 2	Level 3	Level 4
Number of factories	places	28	229	322	1,504
Total electricity consumption	GWh	420.37	4,929.46	6,931.38	32,375.12
Electricity consumption in the lighting system	GWh	13.49	124.62	175.23	818.46
Potential to improve machinery and equipment efficiency	GWh	3.47	31.16	43.81	204.62
The percentage of potential improvement to the system's electricity	%	25.70	25.00	25.00	25.00

III. RESULTS

All factories in Thailand's industrial estates included in this study have the potential to reduce their GHG emissions through energy efficiency improvement measures. In this study, the emission factors of 0.45 $kgCO_2e$/kWh for electricity savings and 2,500 $kgCO_2e$/toe for thermal energy savings were selected [21]. Table IX illustrates the potential reduction in GHG emissions of designated factories within industrial estates managed by the IEAT and joint-operating industrial estates through significant increases in the efficiency of machinery and equipment. This analysis of information from the current designated factory database is preliminary. It can be seen that the designated factories situated in the IEAT-operated industrial estates possess the potential to enhance the energy efficiency of machinery and equipment in regards to electricity consumption by 55.40 GWh and thermal energy consumption by 268.16 TJ.

TABLE IV: THE RESULTS OF THE POTENTIAL ASSESSMENT FOR ENERGY EFFICIENCY IMPROVEMENTS OF SIGNIFICANT MACHINERY AND EQUIPMENT

Type	System	Machinery and equipment	Energy saving potential of all factories			GHG mitigation potential
			Saving (unit/year)	Unit	Costs (million baht)	($ktCO_2e$/year)
Electricity	1) Lighting	Replaces the FL lamp T8 with an LED lamp	150.96	GWh	603.84	67.93
		Replaces the FL lamp T5 with an LED lamp	110.34	GWh	441.36	49.65
		Replaces the MV lamp with an LED lamp	146.43	GWh	585.72	65.89
		Replaces the CFL lamp with an LED lamp	191.77	GWh	767.08	86.30
		Replaces the HID lamp with an LED lamp	105.35	GWh	421.40	47.41
	Subtotal (Lighting)		704.85	GWh	2,819.40	317.18
	2) Split-type AC	Replaces with a higher-efficiency AC	482.91	GWh	1,931.64	217.31
	3) Chiller	Replaces with a higher-efficiency chiller	2,021.41	GWh	8,085.64	909.64
	4) Motor	Replaces with a higher-efficiency motor	313.43	GWh	1,253.72	141.04
Total (Electricity)			3,522.60	GWh	14,090.40	1,585.17
Thermal energy	5) Boiler	Replaces with a higher-efficiency boiler	12,187.40	TJ	6,093.70	721.25
		Insulates steam equipment	1,218.74	TJ	609.37	72.12
	Subtotal (Boiler)		13,406.14	TJ	6,703.07	793.37

Type	System	Machinery and equipment	Energy saving potential of all factories			GHG mitigation potential ($ktCO_2e$/year)
			Saving (unit/year)	Unit	Costs (million baht)	
	6) Furnace	Insulates heating equipment	38,201.56	TJ	19,100.78	2,260.77
Total (Thermal energy)			51,607.70	TJ	25,803.85	3,054.14
Grand total			64,289.06	TJ	39,894.25	4,639.31

Remark: The potential for energy savings is estimated from the cost of electricity (time of use rate): The peak rate is 4.00 baht/kWh [22, 23] and the cost of fuel oil is 0.50 baht/MJ [24].

The designated factories located in the joint-operating industrial estate have the potential to increase the energy efficiency of machinery and equipment by 104.44 GWh for electricity consumption and 247.33 TJ for thermal energy consumption. This study extends the preliminary assessable data from Level 1 to Level 4 for all factories situated in industrial estates, comprising 1,505 factories within the IEAT industrial estates and 3,441 factories within the joint-operating industrial estates. The results showed that there exists a potential to enhance the efficiency of electrical machinery and equipment by 3,522.60 GWh and thermal energy by 51,607.70 TJ, resulting in a total potential reduction of GHG emissions by 4.63 $MtCO_2e$. The study's findings demonstrated that the overall energy cost could be reduced by 39,894.25 million baht, comprising 14,090.40 million baht for electricity and 25,803.85 million baht for thermal energy.

IV. Discussion

The potential reduction in GHG emissions resulting from energy efficiency improvements was first evaluated by utilizing the information presently available in the designated factory database. Furthermore, there exists a limitation in data due to the incompleteness of the Energy Management Report, which fails to encompass all the designated factories. Moreover, certain factories located within industrial estates are not classified as "designated factories" and therefore are not legally required to submit an energy management report, resulting in a lack of information in this section for assessing the potential. Obtaining additional data will enable more precise assessments of the potential for improving energy efficiency. It is recommended that measures for the industrial processes and product use (IPPU) sector, as well as measures for the waste sector, should be considered to evaluate the potential for future GHG emission reductions since these are activities that exist in all factories. Based on the results of previous studies [25–27], insulating measures that focus on heat conservation, particularly those related to fuel and steam, have the highest potential for reducing GHG emissions. Finally, the reduction of 1 $MtCO_2e$ in GHG emissions is expected to result in energy cost savings of approximately 8,449–8,889 million baht, which is in line with other study findings [28, 29].

V. Conclusion

The objective of this study was to assess the potential for reducing GHG emissions from all industrial factories located within Thailand's industrial estates through the implementation of energy efficiency improvement measures. The results showed that a total GHG reduction potential of 4.63 $MtCO_2e$ could be achieved through thermal energy measures of 3.05 $MtCO_2e$ and electricity measures of 1.58 $MtCO_2e$, which represent 65.83% and 34.17% of the total, respectively. Insulating measures implemented in the furnace system to conserve thermal energy exhibited the highest potential for GHG reduction, with a total potential of 2.26 $MtCO_2e$, which accounts for 48.73% of the total GHG reduction potential. Next are the replacement measures for higher-efficiency chillers and boilers, respectively.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Varoon Raksakulkarn reviewed the literature, analyzed the results, and wrote the majority of the manuscript. Wongkot Wongsapai contributed to the article title, provided advice on the results, and modified the manuscript. Sopit Daroon, Chaichan Ritkrerkkrai, and Tassawan Jaitiang provided advice on data and figures. Waranya Thepsaskul, Phitsinee Muangjai, and Orapun Chaikwang joined the discussion and did English editing. All authors have read and approved the final manuscript.

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