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Thailand Roadmap to Nationally Determined Contributions: Can Existing Energy Efficiency be the Potential Measure to Achieve Climate Industrial Sector Target in Thailand?

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Thailand adopted energy management system initiatives in 2010, mandating designated factories to report plant-based energy consumption and conservation data. Validating energy savings from various measures is essential for tracking GHG mitigation performance and predicting future energy trends. Aligning with the 2030 NDC Roadmap, this study proposes three types of energy efficiency measures in large-scale industries: (i) housekeeping, (ii) process improvement, and (iii) machine change equipment. The study also aims to evaluate cumulative savings and GHG mitigation. Our findings indicate that real-world energy efficiency measures resulted in a reduction of 6.27 Mt CO_2 by 2030 which reflect for only 38.00 % of industrial NDC target. However, achieving the target requires an annual average energy saving growth rate of 24.15 %, by using the additional energy in transition measures such as hydrogen and CCUS. Long-term, tailored strategies for specific industrial sectors are essential to pave the way for a sustainable industrial future for the country.

1. Introduction

The increasing greenhouse gas (GHG) emissions from the industrial sector pose a significant challenge to global climate goals, with industries in Thailand emitting more GHGs than any other sector. In 2019, the energy sector contributed 69.96% of Thailand’s GHG emissions, with 36.63% of that from industrial energy use (ONEP, 2022). In response, Thailand has introduced several strategic frameworks aimed at addressing these environmental concerns, including the Energy Efficiency Plan (EEP), the Nationally Determined Contributions (NDC), and Thailand’s Net Zero Roadmap. These initiatives outline ambitious targets for the future, emphasizing the critical need for effective strategies to meet these objectives and support Thailand's commitment to achieving carbon neutrality. However, recent literature reveals significant gaps, Muangjai et al. (2024) highlights that despite progress, current GHG mitigation strategies may fall short of meeting national targets, indicating a need for further research into more effective technologies and approaches. This study aims to forecast greenhouse gas emissions from Thailand's industrial sector under the NDC Roadmap, establishing a business-as-usual scenario for future emission projections. It explores appropriate and feasible technologies for reducing emissions. Additionally, it assesses the potential of hydrogen technology as a means to lower industrial greenhouse gas emissions, highlighting its role in Thailand's journey towards a more sustainable industrial.

2. Energy and Climate Policy in Thailand

Energy and Climate Policy in Thailand encompasses a comprehensive framework aimed at transforming the country's energy and climate change. The Energy Policy focuses on enhancing energy efficiency and promoting

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renewable energy sources to ensure sustainability and reduce dependence on fossil fuels. The encapsulation of these policies and their chronological progression is in Figure 1.

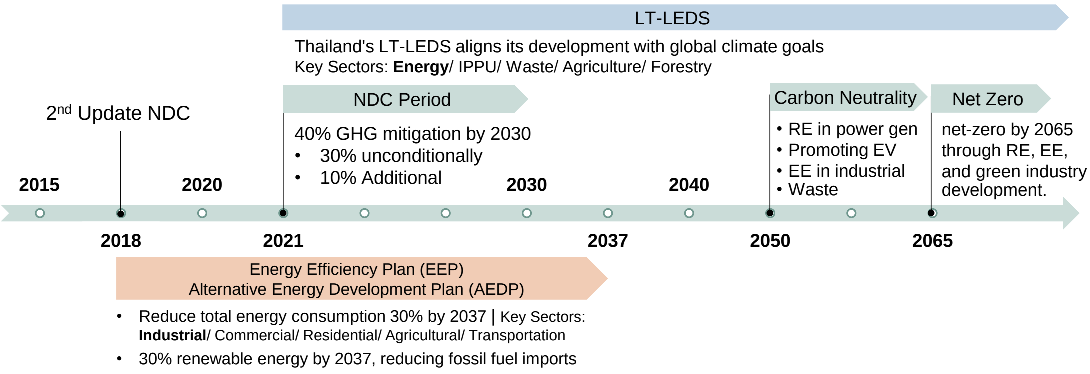

Figure 1: Thailand energy and climate policy timeline

2.1 Energy Policy

Thailand's energy policy is undergoing significant transformation through two key strategic frameworks: the Energy Efficiency Plan (EEP) (DEDE, 2018) and the Alternative Energy Development Plan (AEDP). The EEP, spanning 2018-2037, aims to reduce national energy consumption by 30 % from 2010 levels by enhancing efficiency in industry, residential buildings, and transportation, promoting energy-saving technologies, and implementing standards and incentives. Meanwhile, the AEDP focuses on increasing the share of renewable and alternative energy sources to 30 % by 2037, emphasizing sustainability and leveraging domestic resources for energy production. Together, these plans guide Thailand towards sustainable and diversified energy future.

2.2 Climate Policy

Thailand's approach to tackling climate change revolves around two key strategies: the Nationally Determined Contributions (NDC) and the Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS). The NDC aims to cut greenhouse gas emissions by 30 % from projected levels by 2030, potentially reaching 40 % with sufficient technology and financial backing (UNFCCC, 2022). This involves substantial efforts in energy, transportation, waste management, and industry. Concurrently, the LT-LEDS charts a path for Thailand to achieve carbon neutrality by 2050 and net-zero emissions by 2065, focusing on adopting renewable energy, improving energy efficiency, and fostering green industries. These initiatives underscore Thailand's commitment to global climate efforts and its shift towards a sustainable, low-carbon future.

3. Energy Situation in Thailand

Thailand had the second-largest primary energy supply in Southeast Asia, totaling 5.8 EJ. Indonesia led with 10 EJ, while Malaysia and Vietnam each had 3.8 EJ (IEA, 2022). This comparison highlights Thailand's significant position in the regional energy landscape. Each year, the Department of Alternative Energy Development and Efficiency (DEDE) under the Ministry of Energy collects and compiles energy data. This comprehensive effort encompasses the analysis and dissemination of the nation’s overall energy data, tracking energy situations and leveraging such information for practical applications. This includes the detailed categorization of final energy consumption by both fuel type and economic sector, according to the country's energy accounts and balance. Final energy refers to the form of energy ready for use by consumers and devices, such as machinery or engines, across various economic sectors. This encompasses electricity, the energy contained in diesel fuel, gasoline, and liquefied petroleum gas, among others. The overview of energy consumption patterns in Thailand, including the specific energy use within the industrial sector, is characterized as follows:

3.1 Thailand Final Energy consumption

Over the past 13 years, from 2010 to 2022, an analysis of energy usage by economic sector reveals that the manufacturing and transportation sectors are high energy consumers, accounting for over 70 % of all energy consumption, measured in thousand tons of oil equivalent (ktoe), as depicted in Figure 2. Over the past 12 years, from 2010 to 2021, Thailand's final energy consumption exhibited a general upward trend. However, the COVID-19 pandemic, spanning from 2019 to 2021, caused a noticeable decline in the country's energy consumption. An analysis of Thailand's energy consumption trends during this period reveals that petroleum products dominated energy usage, accounting for 48 % of the total, followed by electricity at 20 %, and coal and its derivatives at 8 %.

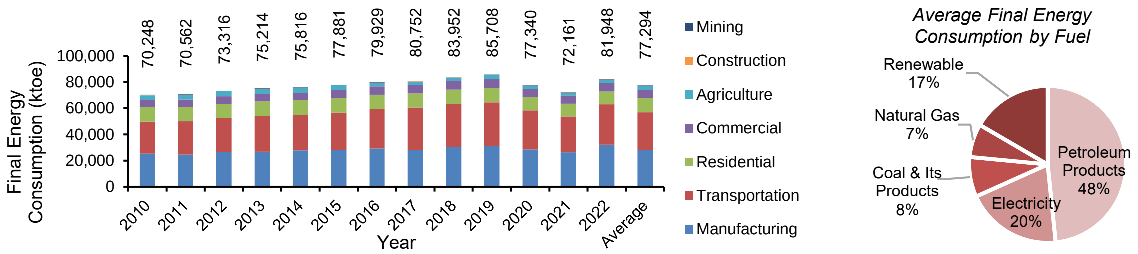

Figure 2: Thailand final energy consumption in the year 2010-2022. (DEDE, 2022)

3.2 Final Energy consumption in manufacturing sector

The energy consumption within Thailand's manufacturing sector from 2010 to 2021, categorized by fuel type: coal & its products, petroleum products, natural gas, and electricity. The graph depicts the progression of the energy mix over a twelve-year period, shown in Figure 3.

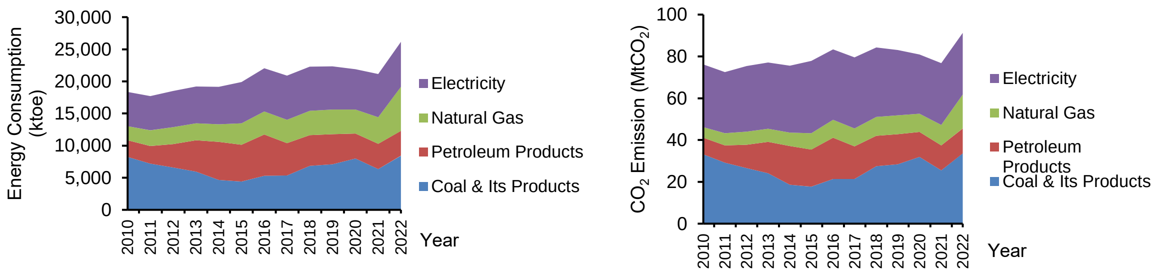

Figure 3: Final Energy Consumption and Associated Emissions in Manufacturing (DEDE, 2022)

3.3 Energy Consumption in Designated Factory

A Designated Factory is defined as an industrial facility that consumes more than 20 million megajoules (MJ) of energy annually or has a transformer capacity exceeding 1,175 kilovolt-amperes (kVA). Factories classified as Designated Factories are required to implement energy management practices and submit annual reports to the government (EPPO, 2007). This process involves conducting an internal audit within the factory, followed by validation through an external audit to ensure accuracy before the report is submitted to the government. After submission, the Department of Alternative Energy Development and Efficiency (DEDE) undertakes a thorough validation and approval process to ensure that the factory meets all energy management and reporting standards (Wongsapai, 2016). Consequently, this data may be delayed by up to two years when compared to the final energy consumption data of the country, as they are derived from different sources. The final energy consumption data of a country are aggregated based on the fuel supplied to and utilized by various sectors across the nation (DEDE, 2020). Food and Beverage, Non-metallic Products, and Chemical sectors account for the highest energy consumption, comprising more than 70 % of the total energy consumption in designated factories. Energy consumption in designated factory, as shown in Figure 4.

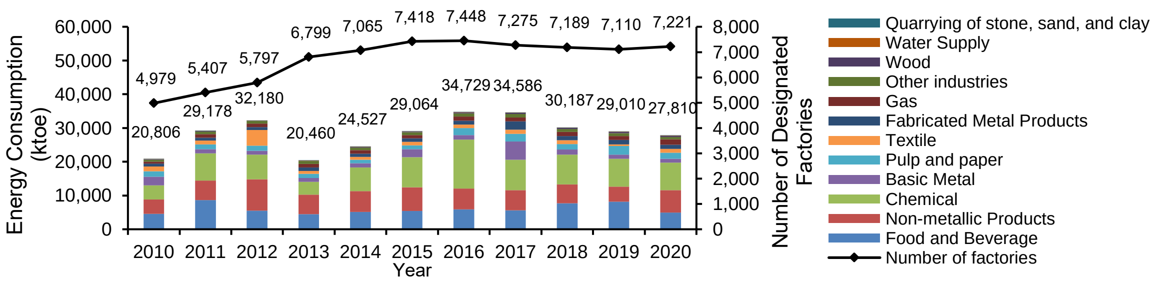

Figure 4: Energy consumption in designated factory by sector, by year (in ktoe)

4. Methodology and scenario assumption

This study comprises two distinct scenarios aimed for GHG mitigation in industrial sector, with each scenario focusing on a different approach to achieve energy efficiency. For clearly identification of equipment pattern in Thai designated factory, Figure 5 illustrates the composition of energy intensive equipment. We found that around 81 % of total number of equipment are electricity based, e.g. (i) motor, (ii) chiller and air conditioner, while the remaining proportion are from thermal energy which the major players are boiler and furnace.

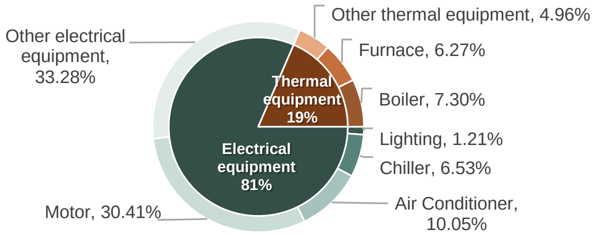

Figure 5: Proportion of Equipment unit in designated factory in 2020

4.1 Scenario 1: Business as usual (BAU)

This scenario focuses on GHG mitigation through energy efficiency improvement in designated factory. Energy efficiency is a key approach to low-carbon, sustainable energy transition, offering wide-ranging benefits at lower costs (Dhar et al., 2018). However, this scenario considers the cumulative energy savings resulting from the implementation of new energy efficiency measures in normal pattern of Thai designated factories by using fixed Thailand's 2015 emission factors (Daroon et al., 2023). Calculate the GHG mitigation by multiplying the activity data (cumulative energy efficiency improvement) by the emission factor (Hashim et al., 2022). This scenario assumes replacement of the new equipment after end of life only. Equation 1 presents the cumulative energy efficiency improvement under BAU. All parameters are in energy physical value. This equation comprises the savings across different years and types of energy efficiency measures, providing a comprehensive assessment of total energy savings from housekeeping, process improvement, and machine change measure.

$$\sum_{t=1}^{n} EC = \sum_{t=1}^{n} EC_{HK,i,j,t} + \sum_{t=1}^{n} EC_{PI,i,j,t} + \sum_{t=1}^{n} EC_{MC,i,j,t} \quad (1)$$

- $\sum_{t=1}^{n} EC$ is cumulative energy efficiency improvement under BAU through various measures in specified sectors and equipment types over a period of n years.
- $\sum_{t=1}^{n} EC_{HK,i,j,t}$ is savings from housekeeping measures for equipment i in sector j in year t. housekeeping measures typically involve one-time savings implemented in a specific year.
- $\sum_{t=1}^{n} EC_{PI,i,j,t}$ is cumulative savings from process improvement measures for equipment i in sector j in years t.
- $\sum_{t=1}^{n} EC_{MC,i,j,t}$ is cumulative savings from machine change measures for equipment i in sector j in years t.

4.2 Scenario 2: Replace with higher energy efficiency equipment

This scenario focuses on upgrading the existing equipment to higher energy efficiency equipment with immediate effect with the assumption presented in table 2, The analysis is based on current usage data of the factory's machinery. Replacing the existing machinery with more efficient equipment is expected to result in energy savings and reductions in greenhouse gas emissions, with two sub-scenarios, as follows:

- Scenario 2.1: Electricity efficiency scenario: Replace existing equipment with new, high-efficiency models.
- Scenario 2.2: Thermal energy efficiency scenario: Upgrading to high-efficiency thermal equipment.

Table 2: Assumptions for high-efficiency equipment replacement

Equipment	Assumption
Lighting	Replacement of fluorescent (T8) with LED, leading to a 50 % decrease in power consumption
Air Conditioner	Replacement of existing air conditioners to high-efficiency units rated at 22.5 BTU/hr-W ((EGAT), 2023)
Chiller	Replacement of existing chiller with a high-efficiency chiller rated at 0.6 kW/TR
Motor	Replacement of existing motor with a high-efficiency motor (3 % efficiency improvement)
Boiler	Replacement of existing boiler to a high-efficiency boiler (achieving 82 % efficiency)
Furnace	Replacement with a high-efficiency furnace (5 % efficiency improvement)

Scenario 1 evaluates the GHG mitigation from current operations, tracking energy savings from ongoing measures. It assesses the incremental increase in reductions over time. Scenario 2 enhances these efforts by accelerating the replacement of existing machinery with higher efficiency models, further boosting GHG mitigation based on the factory's current machinery data. Both approaches contribute to achieving the NDC targets for GHG mitigation.

5. Results

The energy savings and GHG mitigation evaluation results from both scenarios are as follows:

5.1 Scenario 1: Business as usual (BAU)

Based on the past data of energy efficiency measures in designated factories from 2016 to 2020, cumulative energy savings are projected until 2030. By using the 5 % average growth rate, which is taken from the normal pattern of energy efficiency in Thailand, including regular maintenance. It was found that savings would be 4,139 GWh in electricity and 29,211 TJ in thermal energy and the GHG emissions could be reduced by 3.65 $MtCO_2$, as shown in Figure 6.

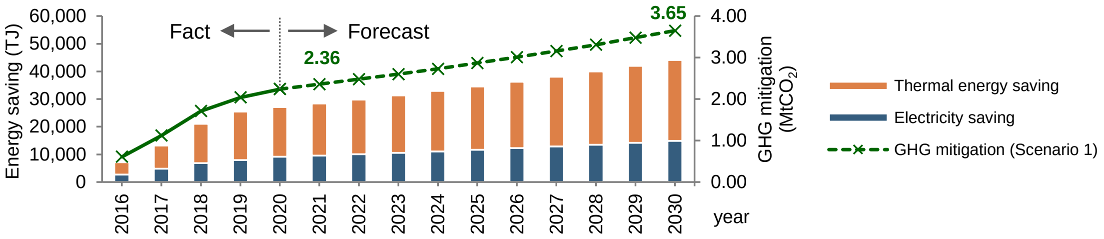

Figure 6: Energy saving and GHG mitigation from scenario 1

5.2 Scenario 2: Replace with higher energy efficiency equipment

Apart from scenario 1, more immediate replacements have been treated in scenario 2. We found that the additional energy savings would be 4,128 GWh in electricity and 9,124 TJ in thermal energy, respectively while the GHG emissions would have the additional reduction by 2.62 Mt CO_2, as shown in Table 3.

Table 3: Additional energy saving and GHG mitigation in the year 2030

Equipment	Energy savings	Unit	GHG mitigation (tCO_2)	GHG mitigation (tCO_2/unit of equip.)
• Lighting	26	GWh	13,760	0.05
• Air Conditioner	1,480	GWh	771,731	27.66
• Chiller	1,555	GWh	810,717	251.93
• Motor	1,068	GWh	556,733	17.80
Total of electrical equipment	4,128	GWh	2,152,940	
• Boiler	423	TJ	21,835	3.84
• Furnace	8,701	TJ	449,570	215.11
Total of thermal equipment	9,124	TJ	471,405	
Total of all equipment	23,986	TJ	2,624,346	

5.3 Comparison with NDC target

From our two scenarios evaluation, we compare the energy efficiency improvement results with the NDC target, as illustrated in Figure 7. The total of 6.27 Mt CO_2 reduction from both scenarios has been estimated which is only 38.00 % achievement compared with the 16.50 Mt CO_2 in industrial NDC target. This can be concluded that Thailand required the additional 10.23 Mt CO_2 afford to achieve this targe by 2030.The results can also imply that the NDC cannot achieved solely by energy efficiency improvement measure but more clean energy measures such as hydrogen application substitute in thermal energy consumption in boiler or furnace including power generation or carbon capture utilization and storage (CCUS) should be considered and implemented. However, due to the very high investment of capital and operation expenditures (CAPEX and OPEX) and the complexity in each manufacturing sub-sector which require different size, type, and specific technologies, more subsidization programmes from the government should be initiated, such as soft loans, direct subsidy, or tax incentives. Those programmes have to be tailored to each specific requirement and milestone.

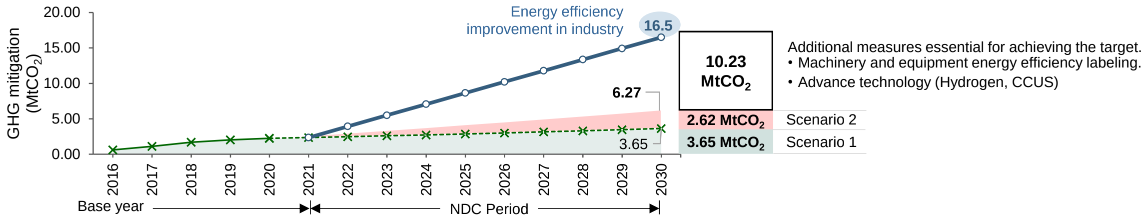

Figure 7: GHG mitigation potential compared with the NDC target.

6. Conclusions

From the total of 6,161 designated factories in Thailand which have to report the annual energy consumption and energy savings by law. This paper estimates the GHG mitigation potential through energy efficiency improvement measures with two scenarios; i.e. (i) business as usual which results in 3.65 Mt CO_2 reduction and (ii) replacing with higher energy efficiency equipment which results in an additional of 2.62 Mt CO_2 reduction. The total of 6.27 Mt CO_2 reduction from both scenarios can achieve only 38.00 % of the industrial sector NDC target. More robust and high impact actions such as the energy efficiency labelling for machinery and equipment, as well as the integration of advanced technologies such as hydrogen utilization in thermal use and CCUS should be considered. These additional measures are critical to achieving the targeted GHG reductions to pave the way for a sustainable industrial future for the country.

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