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Technology Roadmap for Achieving Carbon Neutrality of Thai Industrial Estate: The Case of Map Ta Put Area

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Climate change is the forefront of global agenda in recent years with the goal of achieving carbon neutrality or net zero emission. Consequently, Thailand has expressed her intention, with strong collaboration from all economic sectors, to achieve Carbon Neutrality and Net zero GHG by 2050 and 2065, respectively. Industrial Estate Authority of Thailand (IEAT), a public enterprise that plays a significant role to enhance competitiveness with technology and innovation along with being environmentally friendly for Thai industry, has ambitious target for greenhouse gas (GHG) mitigation, especially in estate infrastructure. This paper illustrates the starting point to achieving the IEAT GHG mitigation goals by establishing a technology roadmap for achieving carbon neutrality in the largest industrial estate of the country, namely the Map Ta Put. By adopting appropriate GHG mitigation technologies, e.g. energy efficiency, renewable energy, waste management, electrical vehicles, from the year 2023 to 2050, with considering the equipment lifetime for reduction pathway, we found that Map Ta Put industrial estate can reduce GHG emission by 28.85 % of BAU in 2050. Energy efficiency measures have the highest potential to reduce GHG emission at 22.62 %. Although Map Ta Put industrial estate area can deploy the high-efficiency technology, it cannot achieve the carbon neutrality target. Therefore, carbon offsetting by forestry or carbon credit is one of the major alternative options for this estate to achieve the target. Estimation of the abatement cost per unit of GHG mitigation also prioritized in this study. The cost for achieving net zero emissions is higher than the investment for carbon neutrality by 4.67 %.

1. Introduction

In recent years, climate change and net-zero emissions have become the forefront of the world's agenda. The 2015 Paris Agreement established a global framework to keep global warming to well below 2 °C, and pursuing efforts to limit it to 1.5 °C, compared to the pre-industrial level (UNFCCC,2015) with the cooperation of many countries trying to minimize their environmental impact. Thailand has had longstanding commitment for clean energy since 2010 (Wongsapai et al., 2022) and now committed to submit a 20% greenhouse gas (GHG) reduction below baseline level by 2030 through Intentionally Determined National Contributions (INDCs) (ONEP, 2022). Subsequently, Thailand announced an more ambitious target of a 40% GHG reduction by 2030 during the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow, United Kingdom.
Industrial Estate Authority of Thailand (IEAT) aims to be "regional leader of integrated industrial estate development with sustainable innovation", focusing on development and provision of integrated public utilities for entrepreneurs in industrial estates and ports with innovations and technologies. It is to upgrade the competitiveness of entrepreneurs and the country, especially in strategically targeted industries in accordance

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with the 13th National Economic and Social Development Plan under the consideration of economy, social and environment balance to achieve sustainable development. Thailand's participation in COP26 and its commitment to achieving net-zero CO2 by 2050, in line with Thailand 4.0 and Industry 4.0, which emphasize advanced technologies and innovation in the industrial sector. While IEAT also develop a master plan for smart industrial estate and port development. This plan, referred to as IEAT4.0, will focus on eco-industry, digital technology investments to enhance service quality, data collection, analysis, and information dissemination to stakeholders. To reach this target, IEAT should establish a technology roadmap outlining the path towards carbon neutrality. The Map Ta Put industrial estate area is the largest one in the kingdom, representing a wide range of activities. It presents opportunities to evaluate GHG emission and explore their potential for reduction across various dimensions. This is the starting point of opportunity for IEAT to develop a technology roadmap, which can then be extended using the methodology to develop roadmap for all areas of IEAT. Notably, this study is conducted by a government-owned company that provides a model demonstration for private sector agencies, serving as a case study for a technology roadmap.

2. Methodology

This research aims to study technology roadmap for achieving carbon neutrality of Map Tu Put industrial estate. It is analyzed toward carbon neutral target including short-term (2023 – 2027), middle-term (2028 – 2037), and long-term plan (2038 – 2050), that is in accordance with the national policies and Ministry of Industry policy. Notably, this study focuses on activities carried out by industrial estate developer, specifically the Industrial Estate Authority of Thailand (IEAT), which implied that the activities of factories in the industrial estate are not included due to the confidentiality of data. The centralized infrastructures are considered, consisting of of (i) freshwater supply and wastewater management, (ii) lighting, air conditioning and office appliances of the estate office buildings, (iii) estate's street lighting,

2.1 Carbon Footprint of Organization (CFO)

Carbon Footprint of Organization (CFO) methodology is adopted to determine greenhouse gas (GHG) emission. GHG-emitting sources of Map Ta Put industrial estate are investigated, consisting of three scopes. The first is direct emission (Scope 1) from various activities such as stationary combustion, mobile combustion, septic tank, chemical fertilizer, refrigerant, etc. The second is energy indirect emission (Scope 2) comprising of electricity consumption from air-conditioning system, lighting system, motor system. The third is other indirect emission (Scope 3) such as purchased goods and services, downstream leased assets, and fuel and energy related activities. The majority of these emissions depend on GUSCO company, which has been contracted by Map Ta Put industrial estate to develop and manage the facilities in all areas of industrial estate. The responsible activity of such company is defined as scope 3. The CFO can be determined as Eq(1)

$$CFO_{i,j}=A_{i,j}\times EF_{i,j} \quad (1)$$

When $CFO_{i,j}$ is amount of GHG emission for activity i, in scope j, $A_{i,j}$ is activity data of activity i, in scope j and $EF_{i,j}$ is emission factor of activity i, in scope j that based on Thai National LCI Database, Ecoinvent 2.2 and IPCC Vol.2 (TGO,2022).

2.2 The forecast of Greenhouse Gas Emission

The GHG emission from 2018 - 2022 is investigated in accordance with the mentioned emitting sources. Then, the future GHG emission from 2023 – 2050 is forecasted by the previous investigation data of GHG emission along with the raw water production data that is forecasted to average 0.5 % growth rate per year, as suggested by the experts from IEAT. The estimation of GHG emission is analyzed by linear regression method and applied as Business-as-usual (BAU). For the future electricity consumption in scope 2, it is determined in accordance with Grid Emission Factor (GEF) that Electricity Generating Authority of Thailand (EGAT) forecasted in the Power Development Plan 2018 – 2037 (PDP2018) (EPPO, 2022). The GEF has estimated to decline by 2.23 % per year since Thailand expect to generate more electricity from renewable energy in the future.

2.3 Greenhouse Gas Mitigation Technology

The GHG mitigation technology for Map Ta Put industrial estate is analyzed by collecting the existing technology (Wongsapai, 2017). Energy Efficiency Plan 2018 – 2037 (EEP2018) and Alternative Energy Development Plan 2018 – 2037 (AEDP2018) measures are involved in deployment of energy efficiency activities and renewable energy activities. Regarding EEP2018, the energy efficiency activity is the deployment of high-efficiency equipment which consists of three systems, i.e., air-conditioning system, lighting system, and motor system. The equipment lifetime for reduction pathway is considered. Electric vehicles (EVs) are also investigated the mitigation potential to replace the traditional vehicles. AEDP2018 measure is the deployment of renewable

energy activities, i.e., the installation of Solar PV rooftop which depends on various factors such as rooftop area, technology efficiency, installation area, etc. Moreover, the estimation of future GHG reduction potential by GHG mitigation technology is analyzed by the reduction ratio from the technology data of Map Ta Put industrial estate. The amount of GHG reduction can be determined as Eq(2)

$$GR_{i,j,y} = \sum CFO_{i,j,y} \times RD_{i,j} \quad (2)$$

When $GR_{i,j}$ is the amount of GHG reduction of activity i, in scope j, year y and $RD_{i,j}$ is the GHG reduction ratio of activity i, in scope j.

2.4 Energy Efficiency Activities

In Table 1, the information about the current status of electrical devices is presented which can be used to investigate the potential for reducing GHG emissions in accordance with EEP2018. The main energy efficiency involves replacing existing electrical devices with high-efficiency ones. Three devices are particularly focused on reduction potential. The first device is the fluorescent bulbs, which has been replaced with LEDs that can reduce electricity consumption by 50 % and have a lifetime of 50,000 h. The second device is the air-conditioner, which has been replaced with a 20 BTU/W EER and has a lifetime of 15 y. The third device is the low-efficiency motor, which has been replaced with a high-efficiency motor that can reduce electricity consumption by 1 % and has a lifetime of 15 y (Damrongsak et al., 2020). Then, the potential pf GHG reduction is calculated, resulting present in Table 2. For light bulbs, Map Ta Put industrial has completely replaced all areas with LED lighting since 2021, resulting in a reduction in GHG emission that cannot be further decreased. Although lighting system is high-efficiency technology, it should be replaced in the end of its lifetime.

Table 1: The information of electrical devices.

Scope	Area/Parameter	Air conditioner	Lighting	Motor
Scope 2	Quantity	167	2,975	30
	Average lifetime in 2022 (y)	10.66	1.93	10.00
	Efficiency indicator	12 BTU/W	5 – 400 W	0.75 – 30 W
Scope 3	Quantity	23	-	131
	Average lifetime in 2022 (y)	3.96	-	12.16
	Efficiency indicator	10 BTU/W	5 – 100 W	0.75 – 15 W

Table 2: The potential of GHG reduction in 2050

Scope	Area/Parameter	Air conditioner	Lighting	Motor	Total
GHG reduction potential in 2050 (tCO_2eq)					
Scope 2	Office	281 (22.68 %)	-	-	281
	Streetlight	-	-	-	-
	Raw water production system	-	-	41 (10.00 %)	41
Scope 3	GUSCO's office	25 (39.35 %)	-	-	25
	Tap water production	9 (37.63 %)	-	17 (11.34 %)	26
	Wastewater treatment system		-	18 (9.11 %)	18
	Total	314 (23.76 %)	-	76 (10.03 %)	390

2.5 Renewable Energy Activities

Although Map Ta Put industrial estate has already installed a 130 kW solar PV system on the office rooftop, there are 30 staff residences where the potential for GHG reduction can be further enhanced. According to 2022-surveyed data, the rooftop area of each staff residence is 100 m^2, but only 60 % of this area has been installed with solar panels. Assuming a solar PV efficiency of 20 % and a solar energy potential of 160 W/m^2 (Jaitiang et al, 2022), a 288 kW solar PV system can be deployed by 2050, which could reduce GHG emission by 24.35 tCO_2eq.

2.6 Electric Vehicles

The measure is to replace internal combustion engine (ICE) vehicles with electric vehicles (EVs) for transportation services across all industrial estate activities. The focus is on four types of vehicles: cars, light trucks, vans, and trucks. By switching cars, light trucks, and vans to EVs, GHG emission can be decreased by 68.91 %, while switching trucks to EVs can reduce emissions by 79.23 % (Suttakul et al., 2022). The details are demonstrated in Table 3.

Table 3: The GHG emission of each vehicle types in 2050 and its reduction potential.

Scope	Parameters	Car	Light truck	Van	Truck	Total
Scope 1	Quantity	1	11	3	4	19
	Fuel type	Gasohol 95	Diesel	Diesel	Diesel	
	Average lifetime in 2022 (years)	6.00	7.27	6.00	24.50	
	GHG emission in 2050 (tCO_2eq)	1.84	17.18	4.80	17.07	40.88
	(%GHG emission by vehicle types)	(4.50 %)	(42.02 %)	(11.74 %)	(41.74 %)	
	GHG reduction potential in 2050 (tCO_2eq)	1.27	11.51	3.31	13.52	29.61

3. Results

3.1 Greenhouse Gas Emission

From the study, it was found that Map Ta Put industrial estate generally had study visited by other organizations leading the high energy consumption in meeting room. During the period of 2018 – 2020, the meeting room has been renovated, which resulted in GHG emission of 1,714 tCO_2eq in 2018 and an increase to 2,091 tCO_2eq in 2020. In 2021, due to the higher use of air-conditioner and lights as it was used as COVID-19 vaccination site, therefore, the GHG emission increased to 3,223 tCO_2eq. However, the situation returned to normal in 2022, the room has already been renovated and there were study visits, resulting in 2,157 tCO_2eq of GHG emission.
The investigation into GHG-emitting sources shows that majority of GHG emission came from scope 2, which includes energy consumption in raw water production, office, and lighting system, accounting for 50 – 60 % of total emissions. In terms of scope 3, the total GHG emissions were 2,157 tCO_2eq in 2022, accounting for 34 % of total emissions that the emission was generated from GUSCO's activities.
When considering the future GHG emissions, the forecast revealed a BAU growth rate of 3.74 % in the first five years, primarily resulting from higher electricity consumption in scope 2, whereas the growth rate of medium-term plan and long-term plan is 1.55 % and 0.004 % per year, respectively. As a result, BAU accounts for 3,005 tCO_2eq of GHG emissions in 2050. Scope 2 represents the majority of emission at 65.49 %, followed by scope 3 and scope 1 at 32.43 % and 2.08 %, respectively.

3.2 Greenhouse Gas Reduction Potential by GHG mitigation technology

The analysis of GHG reduction potential by GHG mitigation technologies in Map Ta Put industrial estate must be consistent with emitting sources. The reduction pathways, which depend on the technology lifetime are demonstrated in Figure 1. The short-term plan and medium-term plan can decrease GHG emission by 14.20 % and 26.45 % compared to BAU, respectively. Furthermore, the long-term plan is projected to achieve a reduction of 28.85 % compared with BAU in the end of 2050. Among the three categories of measures, energy efficiency activities serve as the majority measure, capable of reducing emission by 22.62 % compared to BAU. Notably, the air-conditioning system is identified as the major emission contributing equipment, presenting the highest emissions and the greatest potential for reduction. A 19 of EVs can reduce GHG emissions by 0.97 % in 2050, with the highest reduction demonstrated in truck. Additionally, renewable energy activities as solar PV rooftop technology can reduce GHG emissions by 0.81 % compared to BAU. When energy demand declines, the energy acquisition in scope 3 also decreases as well, resulting in a 4.45 % reduction in GHG emissions compared to BAU. Although Map Ta Put industrial estate area can deploy the GHG mitigation technology, it cannot achieve the carbon neutrality target. Therefore, carbon offsetting by forestry or carbon credit is one of the major alternative options for this estate to achieve the target.

3.3 Technology Roadmap for achieving Carbon Neutrality

Regarding the objective, this study aims to develop a technology roadmap for achieving carbon neutrality target. The results obtained for the Map Ta Put industrial estate indicate that it cannot achieve these targets on its own. Carbon offsetting is considered to be the appropriate alternative.
Sustainable forestation has the potential to capture GHG emissions, which is dependent on the number of trees planted, assuming as average of 31.50 $kgCO_2eq$/tree. If Map Ta Put industrial estate is to achieve its carbon neutrality target with further sustainable forestation as part of the roadmap, a total of 32,000 trees should be planted between 2003 to 2050, and the offsetting measures must be certified by 2050. The results demonstrate that forestry can decrease GHG emissions to 1,130 tCO_2eq by 2050. It is important to note that only forestry cannot bring the industrial estate to carbon neutrality. The offsetting of the remaining GHG emission through carbon credit is crucial to achieve this goal. The detail of roadmap is shown as alternative 1 in Figure 2.

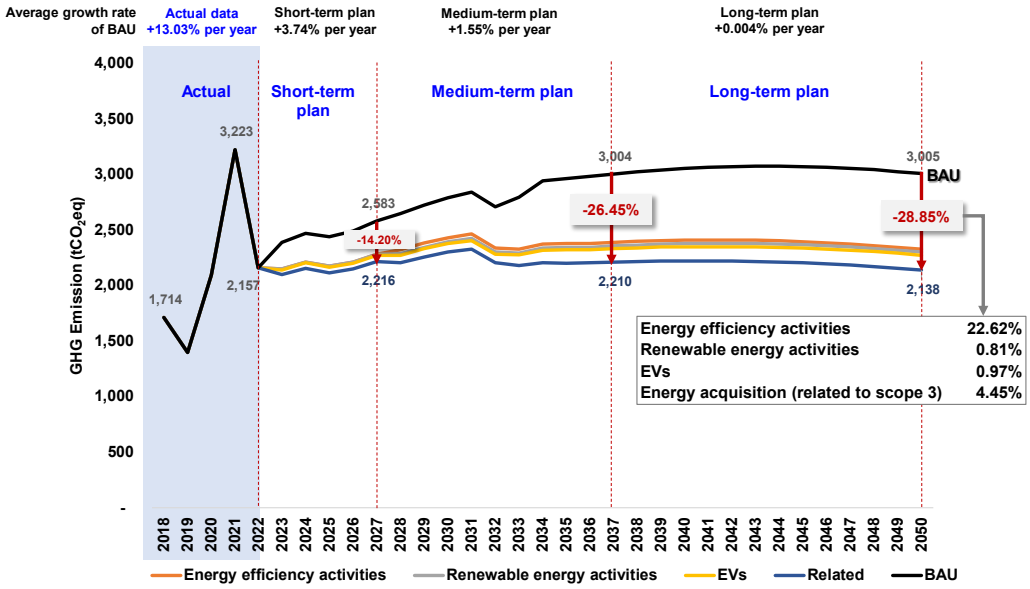

Figure 1: Technology roadmap of Map Ta Put industrial estate.

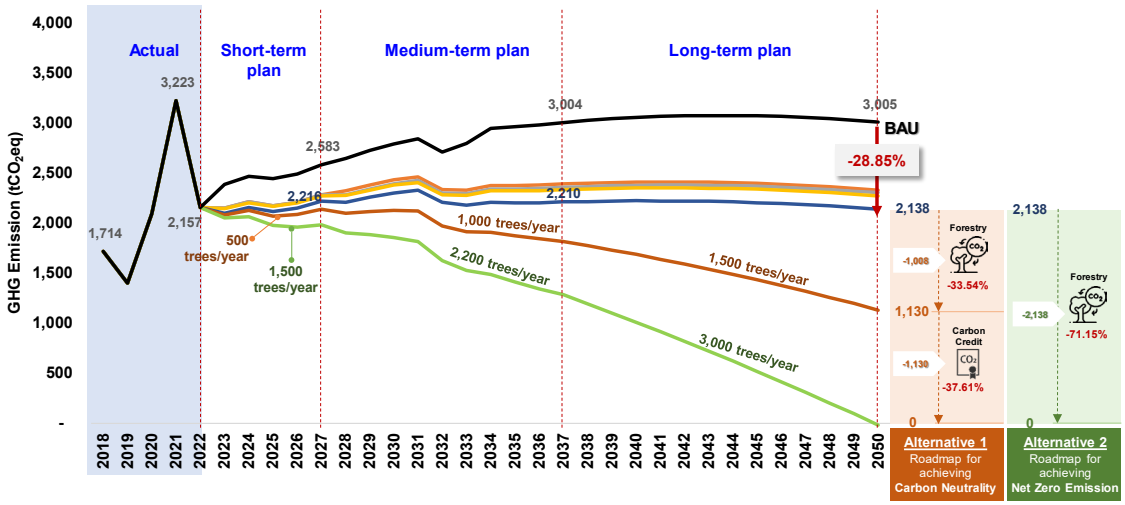

Figure 2: Technology roadmap for achieving Carbon Neutrality and Net Zero Emission of Map Ta Put industrial estate.

When investigating the technology roadmap to achieve the Net Zero Emission target, it is found that industrial estate should further plant a total of 68,500 trees, resulting in a 71.15 % offset of total GHG emissions. The detail of roadmap is shown as alternative 2 in Figure 2.

To achieve carbon neutrality, carbon offsetting by forestry or carbon credit is one of the major alternative options for Map Ta Put industrial estate area. Estimation of the abatement cost per unit of GHG mitigation is also prioritized in this study. The standard cost of equipment, as determined by Budget Bureau (BB, 2022) is referred to calculate cost of GHG mitigation. The estimating for carbon credit price is based on the maximum price in Thailand market (TGO, 2023), with the potential for future increases.

The cost range for energy efficiency of the air-conditioning system is 2.23 – 3.10 THB/BTU, while the lighting system range from 4 – 25 THB/W, and the motor system ranges from 2,167 – 8,800 THB/kW. The cost of solar PV rooftop is 30,000 THB/kW. For EVs, the cost range from 1.19 – 2.70 THB/unit. In Table 4, the results indicate that carbon neutrality can be achieved by investing 1,707.21 THB/kgCO_2eq, resulting in a total cost of 82.16 MTHB. Among the various options, electric vehicles have the highest cost at 1,301.69 THBkgCO_2eq, while carbon credits have the lowest cost at 0.11 THB/kgCO_2eq. The estimating for carbon credits is based on the maximum price in Thailand market (TGO, 2023), with the potential for future increases. For achieving net zero

emissions, the investment at 1,707.10 THB/kgCO_2eq. To achieve net zero emissions, an investment of 1,707.10 THB/kgCO_2eq is required. This would result in a total cost of 85.99 MTHB. The cost for achieving net zero emissions is higher than the investment for carbon neutrality by 4.67 %.

Table 4: The abatement cost per unit of GHG mitigation to achieve target.

Measure	Cost (THB/kg CO_2eq)	
	Carbon Neutrality	Net Zero Emission
Energy efficiency activities	47.08	47.08
Renewable energy activity	354.89	354.89
Electric vehicles	1,301.69	1,301.69
Forestry	3.44	3.44
Carbon credit	0.11	
Total abatement cost (THB/kgCO2eq)	1,707.21	1,707.10
Total Cost (THB)	82,158,739	85,992,966

4. Conclusions

The results of this study illustrate the future of Map Ta Put industrial estate area for achieving carbo neutrality, aiding in the preparing of measures and the budgeting for investment. It can serve as a guideline for developing an appropriate technology roadmap for IEAT. Therefore, the technology roadmap should be accelerated to study and establish the roadmap across all areas of IEAT including the private industrial estate which has around 40 estates around the Kingdom. Subsequently, the deployment of the action plan should be applied which includes a timeline, budget allocation and any risk assessment with technology implementation.

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References

Budget Bureau (BB), 2022, List of Standard Equipment Price in 2022, Bangkok, Thailand.

Damrongsak D., Wongsapai W., Baibokboon L., 2020, Greenhouse Gas Mitigation Analysis from High Energy Efficiency Equipment Replacement in Large Facilities, International Journal of Environmental Science and Development, 11, 74 – 78.

Energy Policy and Planning Office (EPPO), 2022, Power Development Plan 2018 – 2037 (PDP2018), Ministry of Energy. Bangkok, Thailand

Jaitiang T., Vorayos N., Vorayos N., 2022, The Energy and Environmental Eficiency Assessment of Energy System: A Case of Thailand's Industry, Proceedings of 2022 12th International Conference on Power, Energy and Electrical Engineering 25 – 27 Feb 2022, Shiga, Japan.

Office of Natural Resources and Environmental Policy and Planning Thailand (ONEP), 2017, Thailand's Nationally Determined Contribution Roadmap on Mitigation 2021-2030, Bangkok, Thailand.

Suttakul, P, Wongsapai, W, Fongsamootr, T., Mona, Y, Poolsawat, K., 2022, Total cost of ownership of internal combustion engine and electric vehicles: A real-world comparison for the case of Thailand, Energy Reports, 8, 545-553.

TGO, 2022, Emission Factor for CFO, Thailand Greenhouse Gas Management Organization (TGO) <thaicarbonlabel.tgo.or.th/tools/files.php?mod=YjNKbllXNXBlbUYwYVc5dVgyVnRhWE56YVc5dQ&type=WDBaSlRFVlQ&files=TXc9PQ> accessed 20.03.2023

TGO, 2023, Carbon Credit Price from T-VER, Thailand Greenhouse Gas Management Organization (TGO) < carbonmarket.tgo.or.th/index.php?lang=TH&mod=Y2hhcnQ=&action=bGlzdA==> accessed 20.03.2023

United Nations Framework Convention on Climate Change (UNFCCC), 2015, The Paris Agreement, United Nation, Paris, France.

Wongsapai W., Bunchuaidee R., Wayuparb N., Ritkrerkkrai C., 2017, Policy-based Greenhouse Gas Mitigation Tracking and Institutional Framework Development under Thailand's NAMAs in Energy Sector, Chemical Engineering Transactions, 56, 295 – 300.

Wongsapai, W., Ritkrerkkrai, C., Pongthanaisawan, J. 2022, Integrated model for energy and CO_2 emissions analysis from Thailand's long-term low carbon energy efficiency and renewable energy plan, Energy Procedia, 100, 492-495.