



# Pathways to Industrial Decarbonization in Thailand Toward Net-Zero 2050

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## ABSTRACT

This study develops model-based pathways for achieving net-zero greenhouse gas emissions in Thailand's industrial sector, integrating policy foresight with quantitative energy system modeling. Using the low emission analysis platform (LEAP) framework, nine industrial subsectors were analyzed under three transition scenarios—path of challenge, visionary goal, and balancing growth—to assess the techno-economic feasibility of decarbonization through 2065. The model incorporates structural transformation, technology diffusion, and policy enforcement parameters to simulate future energy demand and emission trajectories. Results highlight that policy enforcement and the pace of low-carbon technology adoption are the dominant determinants of industrial emission outcomes. Under the visionary goal scenario, which aligns with current national policy direction, Thailand could reach net-zero emissions by 2065; however, this requires an accelerated GHG reduction rate and early deployment of high-impact technologies such as hydrogen and carbon capture, utilization, and storage (CCUS). The Balancing Growth scenario, emphasizing rapid industrial restructuring and early technology commercialization, demonstrates a potential to achieve net-zero before 2050, contingent on industrial emissions peaking between 2025 and 2030. Conversely, the path of challenge scenario—characterized by delayed technology uptake and limited policy intervention—shows that the net-zero target becomes unattainable, with cumulative emissions exceeding the allowable carbon budget by over 30 MtCO<sub>2e</sub>. The findings underscore the need for coherent long-term industrial and energy policies that simultaneously promote innovation, strengthen institutional mechanisms such as the forthcoming climate change act, and incentivize early commercialization of emerging technologies. Integrating policy ambition with targeted technology acceleration is essential for Thailand's industrial sector to align with national and global net-zero trajectories.

**Keywords:** Industrial Decarbonization, Thailand, Net-Zero 2050

**JEL Classifications:** Q41, Q47, Q48

## 1. INTRODUCTION

The rapid advancement of technology and the ambitious global targets to reduce greenhouse gas (GHG) emissions toward net-zero are driving a fundamental energy transition and industrial restructuring across many countries. Thailand stands out as one of the nations actively engaging in both energy and industrial transitions. However, the country faces several critical challenges in achieving this transformation. These include trade pressures associated with product footprint requirements, international mechanisms such as the carbon border adjustment mechanism (CBAM), the relocation of digital and AI-based industries, and

the urgent need for Thai industries to adapt and survive in an increasingly green energy-driven landscape.

This research aims to identify technological solutions for GHG mitigation within Thailand's industrial sector, focusing on feasible decarbonization pathways under multiple future scenarios. The study considers various contextual factors, such as economic feasibility, policy support mechanisms, and potential socio-economic and environmental impacts.

Previous studies have examined Thailand's journey toward net-zero emissions and the macroeconomic implications of such

transitions (Rajbhandari et al., 2024; Wangjiraniran et al., 2025), providing a broad perspective on national-level GHG reduction strategies. Meanwhile, international studies—such as the IEA’s Energy Technology Perspectives (IEA, 2024) and analyses of industrial transitions in Europe (CISL, 2019)—have explored sector-specific decarbonization pathways. However, research specific to Thailand’s individual industrial subsectors remains limited, with only a few examples in industries such as cement (Jaiboon et al., 2021; Sairatanathongkham and Wangjiraniran, 2017), petrochemical (Kanchanapiya et al., 2015), textile (Jaitiang et al., 2020; Dechasiri et al., 2013) and food processing (Iamchamnan et al., 2025). This study therefore seeks to bridge that research gap by conducting a comprehensive analysis of nine key industrial subsectors in Thailand. The focus is on assessing changes in economic and industrial structures, as well as identifying emerging trends that could shape decarbonization strategies and technological solutions for each subsector.

The research employs a scenario-based analytical framework to explore Thailand’s industrial energy use and transition pathways. Using a foresight process, combined with the low emissions analysis platform (LEAP) model—an energy accounting and simulation tool—the study quantitatively projects future industrial energy consumption by subsector. Structural changes and long-term growth trends within the industrial sector are also incorporated. Furthermore, the study applies multi-criteria analysis (MCA) to evaluate alternative technologies, taking into account factors such as technological readiness, policy environment, and cross-cutting economic, social, and environmental impacts.

## 2. SNAPSHOT OF CURRENT THAILAND INDUSTRIES

The 2022 data, used as the baseline year in the model, illustrates the structure of Thailand’s industrial sector in Figure 1. In terms of value added, fabricated metals—which include the automotive, electronics, machinery, and related industries—account for approximately 40%. This is followed by the food and chemical industries, each contributing around 19-20%. Other industries together contribute only about 20% of total industrial value added.

In terms of energy consumption, the non-metallic industry—which includes cement, glass, and ceramics—records the highest share at around 29%, close to the food industry at 27%, followed by chemicals at 18%. Other industries each consume <10% of total industrial energy. GHG emissions in the industrial sector (considering only direct emissions as defined in the IPCC national inventory) show a similar pattern to energy use, with the non-metallic industry standing out at over 50% of total emissions. This is followed by chemicals at 17%, and food and paper industries at around 9%, while the remainder collectively account for <20%.

These data highlight the critical role of industrial structure in shaping both energy demand and GHG emissions. The non-metallic industry is highly energy- and emissions-intensive, posing a major challenge for GHG mitigation. By contrast, fabricated metals and emerging industries, which have relatively

low emissions intensity, present challenges in terms of scaling up their role in the industrial transition.

## 3. METHODOLOGY FOR SCENARIO DEVELOPMENT

### 3.1. Scenario Building Concept

Scenario building was employed to analyze the possible pathways to achieve carbon neutrality in the energy sector. Scenario building is a method used to determine the feasibility of the future on issues of interest, suitable for policy and strategic planning. Initially, it starts with a look at the relevant qualitative future. This methodology is based on the brainstorming of experts from all sectors, e.g., public, private, and academic. The steps of scenario building are presented as a diagram in Figure 2 (Pongthanasawan et al., 2023).

First, the focal issues were identified. Relevant driving forces or drivers to the focal issue, such as social drivers, technological drivers, economic drivers, environmental drivers, and political drivers, were analyzed using STEEP analysis. Then, the critical uncertainties were identified and ranked regarding their importance and uncertainty. Then the most important and highest uncertainty drivers would be selected to examine their interactions with each other using scenario logic. At the end, the scenarios would be named, and all driving forces in each scenario would be characterized to reflect the characteristics of the scenarios.

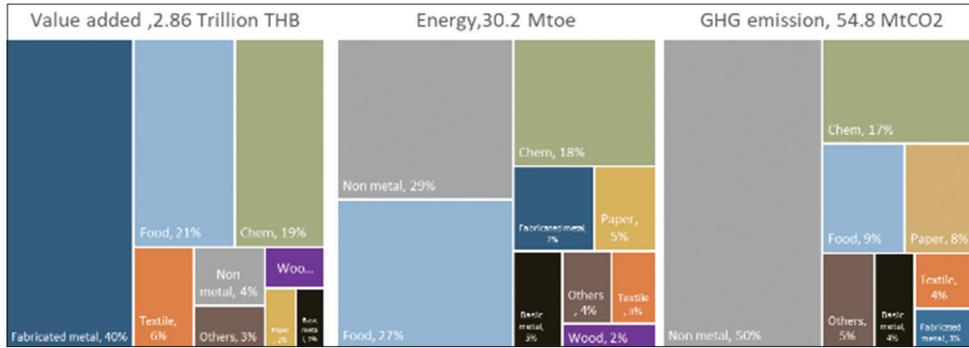
### 3.2. Driving Factors and Critical Uncertainty

The analysis of driving factors to achieve net-zero emission in industrial sector is based on the STEEP analysis, which investigates how external factors—social, technological, economical environmental, and political factors—affect the energy market and GHG emissions in the industrial sector. The analysis was made through a brainstorming workshop with experts from the public, private and academic sectors<sup>1</sup>. The driving factors were assessed for their impact on net-zero emission, as shown in Figure 3, which can be summarized as follows:

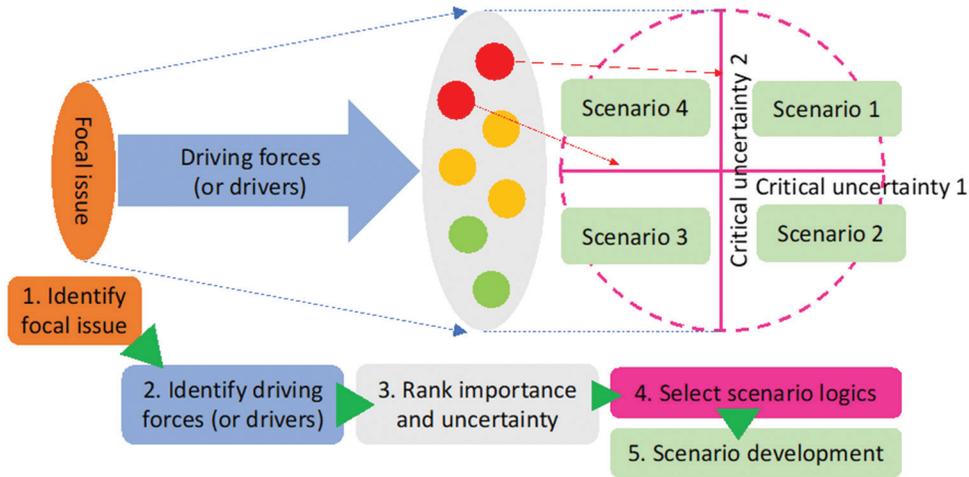
- Political factors: The Climate Act (DCCE, 2025), which is currently in the process of being enacted, has become one of the most prominent policy factors influencing the industrial sector. While the overall direction of the Act is relatively clear—aiming to require industrial operators to reduce GHG emissions under specified frameworks—it remains uncertain which industrial groups will fall under the regulation and within what timeframe the enforcement will take effect. The Act is designed to align with Thailand’s national net-zero emissions target. In parallel, other relevant policy drivers include the clean electricity certification scheme to support emerging industries and data centers, as well as investment promotion measures by the board of investment (BOI). However, these latter factors are currently assessed to have a comparatively limited influence on the industrial sector’s progress toward achieving net-zero emissions.
- Technological factors: Energy storage and recycling technologies are viewed as key enablers for achieving the

<sup>1</sup> Data collection during the focus group on “Thailand energy outlook to net-zero emission 2065” on April 4, 2025, Bangkok

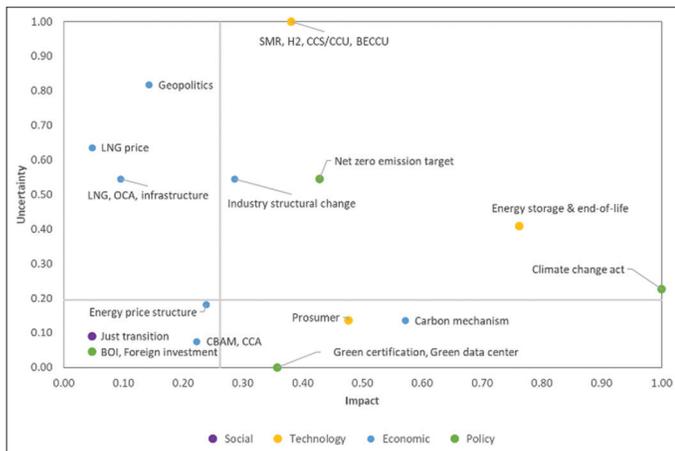
**Figure 1:** Economic value, energy and greenhouse gas emission for Thailand industries in 2022



**Figure 2:** Scenario building methodology



**Figure 3:** Driving factors and critical uncertainties affecting net-zero emission in industrial sector (1 = most influencing factor, 0 = least influencing factor)



net-zero emissions target. For energy storage, according to IPCC GHG emission accounting, the factor primarily impacts the power generation sector directly, but it also indirectly affects industrial energy demand through the consumption of electricity. Meanwhile, recycling and a circular economy contribute to more efficient raw material management, which similarly has indirect effects on energy efficiency. Moreover, the use of renewable energy and prosumer-based systems such

as solar, bioenergy, and waste-to-energy has already reached commercial deployment, though the remaining potential for expansion appears to be limited. Similarly, carbon capture technologies—including hydrogen, carbon capture and storage (CCS) and bioenergy with carbon capture and storage (BECCS)—still face significant uncertainty and require further development in both business models and market mechanisms. Nevertheless, the forthcoming Climate Act could serve as a critical policy instrument to accelerate the commercialization and market adoption of these emerging technologies.

- Economic factors: Carbon mechanisms such as emissions trading systems (ETS) and carbon taxes are key economic factors that must be highlighted, as they have a direct influence on industrial operations and investment decisions. Likewise, structural changes within the industrial sector will significantly impact the overall energy mix and energy efficiency. In contrast, other factors—such as geopolitical dynamics, energy prices and pricing structures, and trade agreements including CBAM—are currently considered to have a relatively limited effect on the achievement of net-zero emission targets.
- Social factors: Social factors may not serve as primary drivers directly influencing the achievement of net-zero targets, but rather as outcomes arising from structural transformations. In particular, issues related to a just transition are expected to emerge due to shifts in the labor skill landscape and changes in required expertise across industries.

- Environmental factors: Environmental factors are embedded across all the aforementioned dimensions, particularly through the overarching goal of reducing GHG emissions to achieve net-zero. This is driven by legal mechanisms and carbon policies, which in turn promote the development and deployment of emerging technologies. Other environmental issues—such as air pollution and wastewater management—are already governed by existing regulatory frameworks and therefore are not explicitly represented in this map.

### 3.3. Scenario Definition and Storyline

From the analysis of critical uncertainties in the previous section—which include the Climate Change Act, energy storage and carbon capture technologies, including industrial structural reform—three possible scenarios can be illustrated as follows:

- Path of challenge reflects a conservative environmental context under structural transformation constraints. These include the slow adaptation of an economy and industries reliant on fossil fuels, delays in enacting climate legislation, and regulations that do not facilitate competition or investment in green businesses and energy. New investments continue to flow into fossil-based industrial infrastructure, while investments in smart grids, batteries, and renewable energy progress only gradually. As a result, green energy development is confined to currently cost-effective technologies, while the deployment of emerging technologies is further delayed.
- Visionary goal represents a scenario aligned with official policy frameworks and strategic plans targeting net-zero emissions by 2065. Incumbent industry actors are expected to play a pivotal role in facilitating the energy transition; while emerging industrial structures exhibit organic growth and legacy industries experience continued decline. Nevertheless, as current development plans extend only to 2037, achieving net-zero by 2065 remains subject to significant challenges, risks, and uncertainties. Achieving the target will require sustained policy interventions and accelerated technological innovation. In particular, carbon capture is projected to become indispensable in the long term as a critical component for achieving net-zero by 2065.
- Balancing growth represents a scenario in which policies prioritize the green economy as the primary driver of long-term economic development. The net-zero by 2065 target is leveraged to stimulate economic growth, with the Climate Change Act being actively enforced, leading to a rapid structural transformation toward environmentally friendly industries. Energy storage technologies play a critical role in enabling the integration of variable renewable energy into the power system. Carbon capture technologies are expected to address the remaining residual emissions; however, their deployment may not be urgently required given the high level of uncertainty surrounding their maturity and cost-effectiveness.

## 4. METHODOLOGY FOR ENERGY MODELLING

### 4.1. Energy Account Model

In an energy accounting framework, as illustrated in Figure 4 (Wangjiraniran et al., 2022), the analytical process begins with

the assessment of final energy demand within the demand analysis module. For the industrial sector, energy demand is estimated based on key driving parameters such as economic expansion, industrial output, technological advancement, and energy efficiency—all of which significantly influence energy consumption patterns. The characterization of industrial energy demand across various sub-sectors provides the foundation for subsequent GHG emission analysis, as energy use in production processes directly correlates with emissions intensity depending on the fuel mix and process efficiency. The model structure categorizes the industrial sector into nine subsectors, consisting of food processing, textile, wood, paper, chemical, non-metallic, basic metal, fabricated metal, and others, following the classification of the Thailand Standard Industrial Classification (TSIC). Input data were obtained from the Department of Alternative Energy Development and Efficiency (DEDE), using year of 2022 as the base year, and projected to the year of 2065 consistent with Thailand's first official net-zero emission target<sup>2</sup>. It further allows for the assessment of potential adjustments in response to future changes in policies or targets.

The results from the demand module serve as the intermediate inputs for energy transformation and supply-side analysis. These components consider technological and operational factors such as energy conversion efficiency, production capacity, fuel utilization ratios, and trade flows (imports and exports). While the demand module captures direct energy consumption and associated emissions within industrial activities, the supply-side analysis is essential for quantifying indirect emissions that arise from upstream energy production particularly electricity generation and fuel refining processes required to meet industrial energy demand.

Through the integration of demand and supply-side analyses, the model enables a comprehensive understanding of the industrial sector's total energy-related GHG emissions, capturing both direct process emissions and indirect emissions embedded in the energy supply chain. This holistic approach ensures that mitigation strategies address not only end-use efficiency improvements but also the decarbonization of upstream energy supply systems.

In this study, the energy accounting model was constructed using the LEAP program as a tool (SEI, 2025). LEAP is a software designed to assist quantitative analysis to project a comprehensive picture of energy demand and supply. Moreover, it can modify mathematical equations and be used at different levels of energy data, from data by sector to more detailed data at the end-user level. With its ability to facilitate the collection of technological and numerical data relating to greenhouse gas emissions and environmental impact, LEAP can assess the impact of greenhouse gas emissions and other environmental impacts caused by the energy sector.

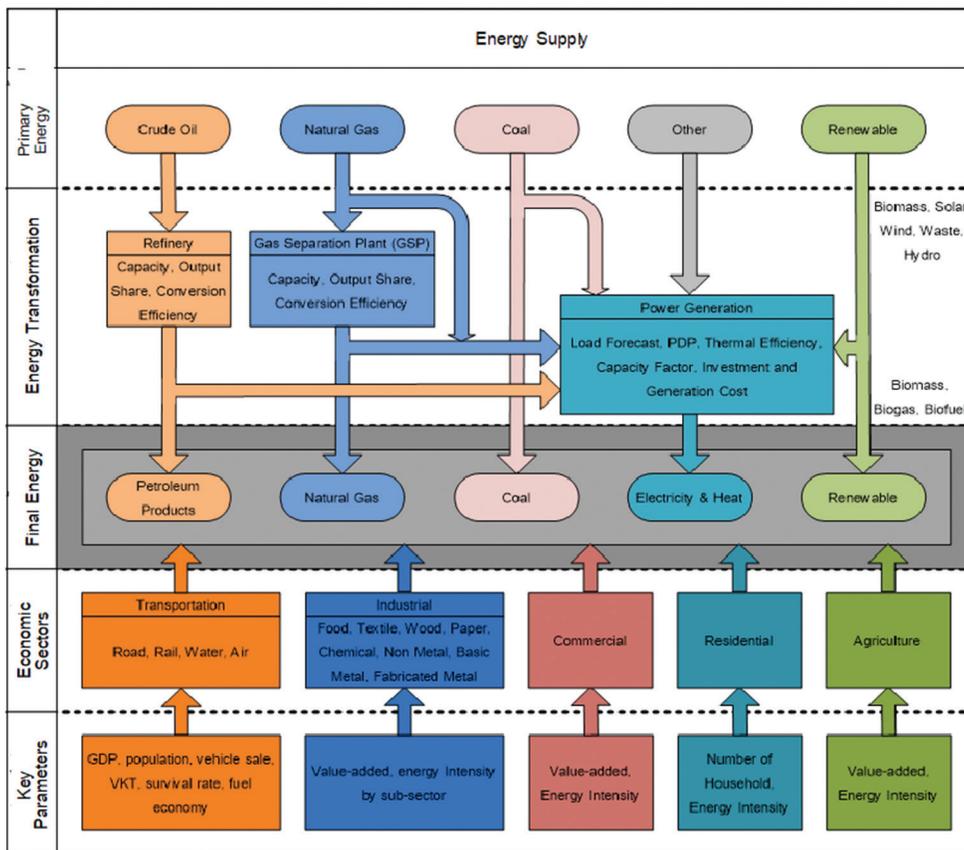
### 4.2. Key Assumptions

#### 4.2.1. Economic growth

The macroeconomic growth assumptions for Thailand under the Visionary Goal and Balancing Growth scenarios indicate a gradual

2 This study was completed prior to the formation of Thailand's new government. In late September 2025, the national net-zero emission target was revised from 2065 to 2050.

Figure 4: Structure of Thailand’s energy system



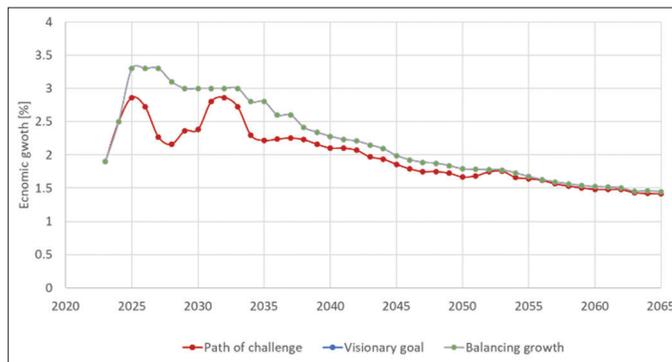
recovery from COVID-19 in the short term. For 2024, the real GDP growth rate of 2.5% reported by NESDC (NESDC, 2024) is applied. From 2025 to 2037, projections from NESDC, prepared for the draft Power Development Plan 2024 (EPPO, 2024), are adopted, with annual growth expected in the range of 2.4-3.2%, gradually decelerating as the economic base expands. Beyond this period, projections from the Network for Greening the Financial System (NGFS, 2025), which assess long-term economic growth across countries while accounting for the impacts of the transition toward net-zero emissions, are used. In the long term (2037-2065), Thailand’s economy is assumed to grow at approximately 1.5-2% per year.

For the path of challenge scenario, a more conservative perspective is taken regarding Thailand’s long-term economic growth. Based on expert interviews, the growth assumptions under this scenario are moderated relative to those of Visionary Goal and Balancing Growth. In certain periods, however, special events may temporarily stimulate GDP, such as the opening of airport expansions in 2032 and new investment cycles across various industries after 2050. The assumptions for Thailand’s GDP growth are summarized in Figure 5.

4.2.2. Industrial structure reform

Structural transformations in the economic and industrial sectors constitute the key driver directly impacting energy demand and GHG emissions. Previous studies (Wangjiraniran et al., 2011) on economic restructuring have highlighted significant improvements in energy efficiency driven by the transition toward a service-based economy and low energy-intensive, high value-added industries.

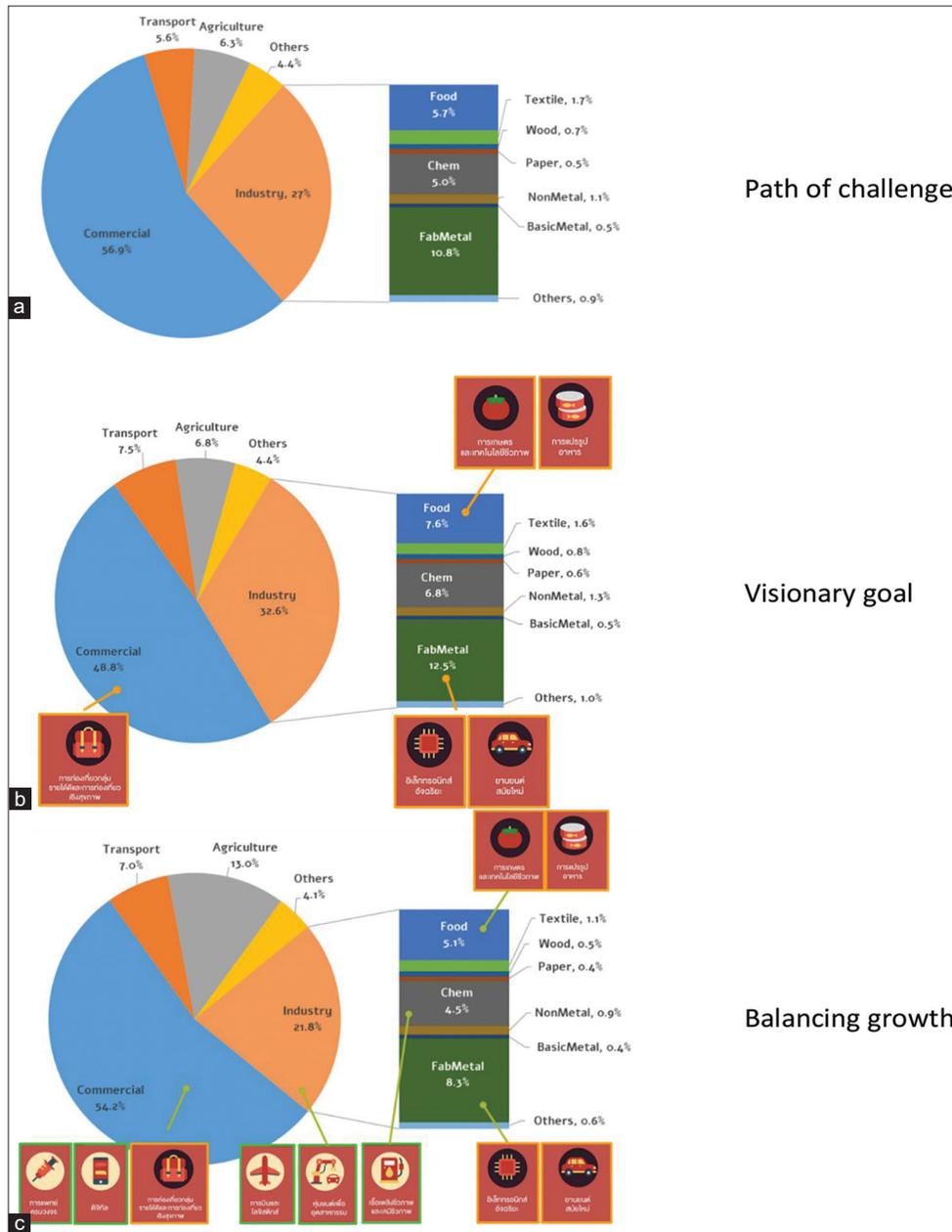
Figure 5: Assumption on long-term economic growth



The assumptions informing these transformations are specified as follows:

- The path of challenge is based on the assumption that there will be no changes in the economic and industrial structure from the present, as shown in Figure 6a. The data references the Office of the National Economic and Social Development Council (NESDC). By the year 2065, the service sector will have the highest share of economic value at 56.9%, followed by the industrial sector at 27%, with the remaining share coming from transportation, agriculture, and others (construction and mining), respectively. Regarding the value added in the industrial sector, the metal products industry will have the highest share at 10.8% of the entire economy, followed by the food industry at 5.7%, and the chemical industry at 5%.

Figure 6: (a-c) Assumption on share of economic and industrial value



- The visionary goal is based on the assumption that economic and industrial structures transition toward an industry-driven economy, following the methodology for setting assumptions from the Thailand Development Research Institute (TDRI) as illustrated in Figure 6b. By 2065, the service sector remains the largest contributor to economic value at 48.8%, although this represents a decline compared to the path of challenge scenario. The industrial sector follows at 32.6%, with an increasing share particularly in food-related industries (agriculture and biotechnology, processed food), chemicals (biochemical), electronics, and modern automotive. In contrast, metals, non-metals, paper, and textiles see a declining share. The remainder is accounted for by transportation, agriculture, and other sectors (construction and mining), respectively.
- The balancing growth is based on the assumption that economic and industrial structures evolve toward a mixed

economy, driven by the service, industrial, and agricultural sectors as illustrated in Figure 6c. The agricultural sector is expected to register the largest increase in its share of economic value, following the methodology from TDRI. By 2065, the service sector remains the largest contributor at 52.2%, driven by new economic activities such as digital services, integrated healthcare, and health-oriented tourism. The industrial sector follows at 21.8%, reflecting a significant decline, while agriculture’s share rises to 13%. Within the industrial sector, emphasis is placed on high-value, low-energy-intensive industries such as metal products, chemicals, and food and agricultural products, supported by new industries including robotics for manufacturing, aviation and logistics, biofuels, and biochemical production. Conversely, energy-intensive industries such as non-metals and steel experience a decline in their economic

role. The remainder is accounted for by transportation, agriculture, and other sectors (construction and mining), respectively.

### 4.2.3. Technology adoption

The analysis of technology adoption in the industrial sector referred to a framework for prioritizing technologies to identify the most suitable options, as developed by (Wangjiraniran et al., 2023). The assessment considers regulatory readiness, economic feasibility, and participation in the value chain. It also incorporates potential economic, social, and environmental impacts.

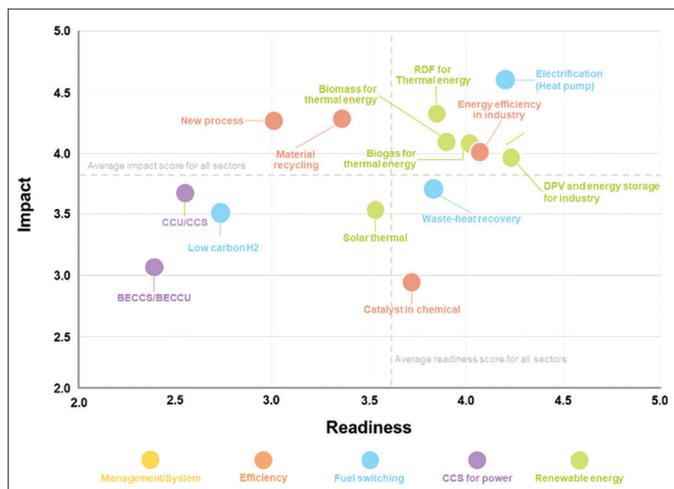
For this study, the data were further refined based on expert inputs collected from November 2024 to April 2025 to capture recent developments. The results are presented in Figure 7. In this round of expert consultation, significant changes have been observed compared to the previous study, particularly the markedly increased role of electrification. Emerging technologies that remain high-cost and are still under development—such as hydrogen, CCS/CCUS, and BECCS—are now assessed to have greater readiness and potential to generate impact. Renewable energy technologies continue to be recognized as important, with further market expansion still required.

The following presents the assumptions for each scenario, based on the technology prioritization framework described above. The details are as follows:

1. **Electrification:** In the current baseline, the Thai industrial sector accounts for approximately 23% of total electricity consumption (DEDE, 2022), with sectoral shares varying across subsectors. Future projections indicate a pronounced trend toward electrification, driven primarily by increased adoption of electric machinery in production processes, particularly within fabricated metals, including the automotive, electronics, and machinery manufacturing industries. Additional electricity demand is expected from the deployment of heat pumps for thermal applications in low- to medium-temperature operations (70-90°C) (Zuberi et al., 2022), notably in the food processing, chemical, and textile sectors. For sectors requiring high-temperature processes, such as the basic metal and steel industries, electric arc furnace technology is identified as a key enabler of electrification (Juntueng et al., 2020; Sopapan et al., 2025). These trends are incorporated into the model to capture sector-specific shifts in electricity demand and associated GHG emissions. Assumption of electrification by sub-sector industries is summarized in Figure 8.

The installation of distributed photovoltaics (DPV) is another measure that can help reduce electricity demand from the grid. DPV may not directly affect direct GHG emissions accounting from industrial energy consumption, it indirectly impacts the national GHG inventory by lowering electricity consumption in the industrial sector. Currently, industrial plants in Thailand are increasingly adopting DPV for self-consumption as prosumers, a trend accelerated by rapidly declining DPV costs. According to the previous study (Tongsopit et al., 2024), the assumptions for rooftop DPV installations in industries are illustrated in Figure 9.

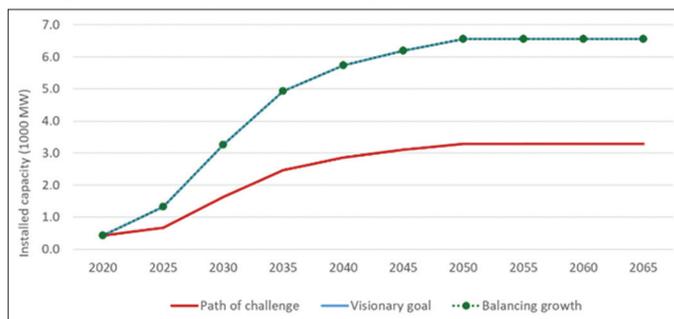
**Figure 7:** Prioritization of energy technology adoption for industrial sector



**Figure 8:** Assumption on electrification by sub-sector industries

% Electrification	2022	2065		
		Path of challenge	Visionary goal	Balancing growth
FabMetal	71%	84%	97%	97%
BasicMetal	44%	66%	74%	76%
Others	9%	33%	58%	75%
Textile	39%	50%	59%	74%
Wood	34%	67%	67%	60%
Food	25%	35%	33%	50%
Paper	15%	35%	56%	50%
Chem	22%	26%	25%	40%
NonMetal	7%	8%	8%	13%

**Figure 9:** Assumption on DPV deployment for industrial sector



2. **Renewable energy:** Currently, renewable energy accounts for approximately 18% of total energy consumption in Thailand’s industrial sector (DEDE, 2022). The majority consists of biomass derived from agricultural residues, such as rice husks, bagasse, and wood waste, or processed into fuels such as wood chips and refuse-derived fuel (RDF) (Itsarathorn et al., 2022). Most of this biomass is used as a substitute for fossil fuels in the food and wood-processing industries. Its use in other industries is limited; for example, the cement industry only partially replaces coal due to thermal properties that may not fully match those of fossil fuels. A key factor in utilizing biomass energy is the availability and potential of feedstock. Accordingly, the assumptions in this study are primarily based on the biomass potential figures reported in research by (Churdchoo, 2022), which account for

feedstock availability, allocation between power generation and industrial use, economic feasibility, and other relevant factors.

For future assumption development, it is evident that beyond the food industry, Thailand has significant potential to increase the use of bio-based renewable energy. This could take the form of torrefied biomass (Onsree et al., 2020; (Bampenrat et al., 2023), which possesses properties more comparable to fossil fuels, particularly for applications in the cement and paper industries. Meanwhile, the chemical industry is expected to increasingly integrate energy use with feedstock production through biorefinery. Assumption of renewable energy adoption by sub-sector industries is summarized in Figure 10.

3. Hydrogen and carbon capture technologies: Hydrogen energy and carbon capture technologies have been receiving increasing attention, despite not yet achieving commercial cost-effectiveness. For hydrogen, the primary target sectors are hard-to-abate industries, such as chemicals, basic metal and non-metallic industries, which require high-temperature applications exceeding 100°C (Deloitte, 2023) as substitutes for fossil fuels. A previous study (Nakapreecha et al., 2023) on hydrogen use in Thailand’s industrial sector identified potential applications both through blending in the natural gas pipeline system and through direct thermal use. The most economically viable options involve substituting hydrogen for fuel oil and LPG. The Hydrogen Thailand club has further estimated that hydrogen demand for industrial heat applications could account for approximately 4-19% of total industrial thermal energy consumption.

In this study, assumptions were set for the use of low-carbon hydrogen for thermal applications in the industrial sector, with commercial deployment starting in 2030 (EPPO, 2024). The focus is on the chemical, steel, and non-metal industries, as illustrated in Figure 11.

The deployment of CCS/CCU technologies in the industrial sector is increasingly being discussed in terms of feasibility. Previously, commercial viability was considered to be limited primarily to applications in enhanced oil recovery (PTTEP, 2024). However, their potential use in highly energy- and GHG-intensive industries has gained more attention. Notably, in the cement industry, carbon dioxide (CO<sub>2</sub>) can be captured and utilized in methanol production or concrete curing processes, while in the steel industry, captured CO<sub>2</sub> can be applied in ethanol production. The chemical industry represents another sector with significant potential, wherein captured CO<sub>2</sub> can be utilized as a feedstock in production processes, including the synthesis of alternative fuels and various chemical products (Misila et al., 2024). According to the previous study (Srinongsaeng et al., 2025), CCS/CCU deployment could reduce Thailand’s GHG emissions by approximately 25.7% under the best-case scenario.

However, the assumptions regarding CCS/CCU deployment are not only contingent upon the aforementioned utilization pathways, but also dependent on the residual use of fossil fuels that remain after substitution through electrification and renewable energy.

Accordingly, within the model development process, residual fossil fuel consumption and associated industrial GHG emissions are calculated, after which CCS is applied.

The model assumes differentiated timelines for the earliest commercial deployment of CCS/CCU across scenarios, reflecting varying policy, technological, and industrial readiness conditions. In the Balancing Growth scenario, deployment is assumed to commence as early as 2035, representing the most accelerated pathway. The Visionary Growth scenario adopts a more gradual trajectory, with commercial-scale CCS/CCU expected by 2040 (ONEP, 2023). In contrast, the path of challenge scenario reflects the slowest progress, delaying deployment until 2045. The corresponding results of the CCS/CCU assessment, with GHG emissions incorporated as intermediate inputs to the model, are presented in Figure 12.

## 5. RESULTS AND DISCUSSION

### 5.1. Decoupling of Industrial Activities, Energy and GHG Emissions

The results of the analysis of overall economic growth, industrial value added, energy demand, and direct GHG emissions in the industrial sector are presented in Figure 13.

Summary is as follows:

- In the path of challenge scenario, which is based on a conservative perspective, energy consumption continues to

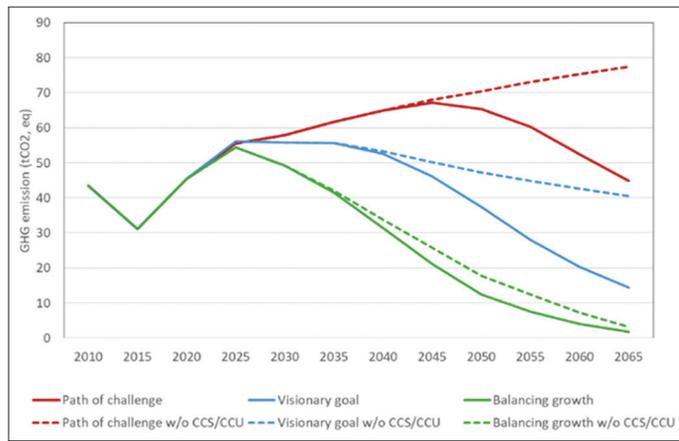
Figure 10: Assumption of share of bioenergy and refuse-derived fuels in 2065

% Renewable	2022	2065		
		Path of challenge	Visionary goal	Balancing growth
Food	53%	51%	47%	47%
NonMetal	4%	18%	18%	52%
Wood	65%	32%	33%	40%
Paper	4%	29%	33%	49%
Chem	10%	19%	17%	27%
Textile	2%	2%	2%	25%
BasicMetal	0%	6%	6%	7%
FabMetal	0%	0%	0%	0%
Others	3%	0%	0%	0%

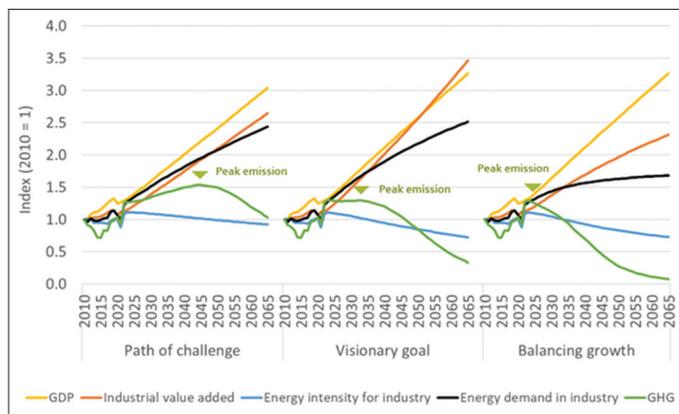
Figure 11: Assumption of hydrogen (H<sub>2</sub>) share in heat application for Thailand industry in 2065

% H2	2065		
	Path of challenge	Visionary goal	Balancing growth
Chem	14%	14%	19%
BasicMetal	8%	9%	15%
NonMetal	4%	4%	6%

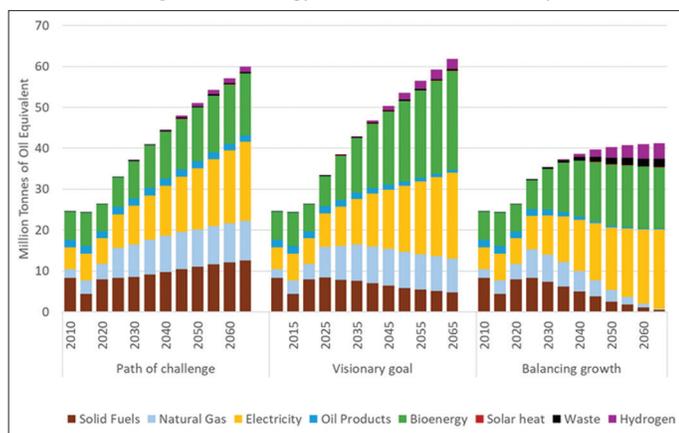
**Figure 12:** Assumption of carbon capture and storage/carbon capture and utilization adoption with intermediate result of greenhouse gas emissions



**Figure 13:** Decoupling of industrial value, energy and greenhouse gas emissions



**Figure 14:** Energy mix in Thailand industry



grow in line with overall economic and industrial expansion. Delays in the energy transition result in a peak in emissions around 2040-2045, making it highly unlikely to achieve the net-zero 2065 target.

- In the visionary goal scenario, simulated based on official plans, a decoupling between energy consumption and industrial growth begins to emerge. Peak emissions shift earlier, occurring around 2030-2035. However, long-term projections still highlight significant challenges. Achieving

net-zero by 2065 is contingent upon a critical condition: following the energy planning horizon, after 2037, industrial sector GHG emissions must decline at a markedly accelerated rate.

- In the balancing growth scenario, which emphasizes structural transformation, a clear decoupling is observed: energy consumption remains nearly constant while the economy and industrial value added continue to grow, particularly after 2035. Peak emissions occur within the near term, around 2025-2030, with the most rapid GHG reductions projected between 2030 and 2045. Beyond this period, achieving net-zero emissions becomes relatively straightforward.

### 5.2. Energy Mix in Industry Sector

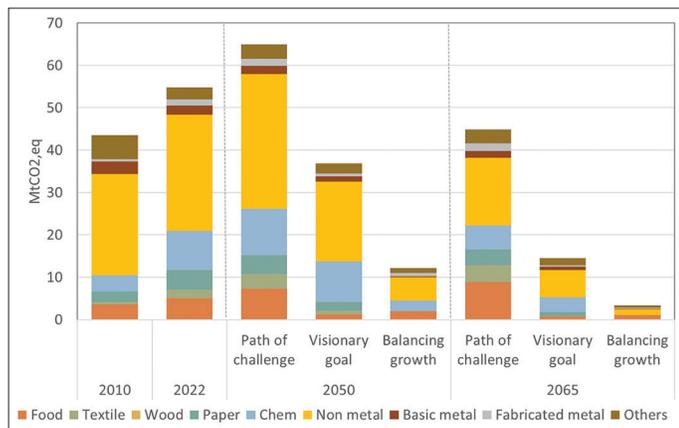
The results of the energy mix for the industrial sector are presented in Figure 14. Summary is as follows:

- In the path of challenge scenario, energy demand continues to show an upward trend throughout the study period, leading to an overall increase in demand for all types of energy, except for oil, which is projected to decline. The share of electricity and renewable energy is expected to gradually rise from 44% in 2022 to 58% in 2065, replacing coal and natural gas. Hydrogen energy begins to be utilized after 2040, but its share remains limited, as it is expected to be used primarily in hard-to-abate industries such as chemicals, steel, and cement.
- In the visionary goal scenario, energy demand in the industrial sector continues to rise steadily and is overall higher than in the path of challenge scenario. This is driven by a more optimistic outlook on the macro economy. Moreover, the industrial sector is expected to serve as a key growth engine for Thailand’s economy, leading to a sustained increase in industrial energy demand. Electricity and renewable energy play an increasingly important role in achieving the net-zero emission target, with their combined share reaching 74% by 2065. Coal and natural gas consumption shows a continuous decline but remains in use, while hydrogen maintains a limited role, serving as an alternative only in certain industrial subsectors.
- In the balancing growth scenario, industrial energy demand clearly reaches a saturation point around 2030. This results partly from economic growth being driven more by the service and agricultural sectors than by industry, and partly from continued improvements in energy efficiency. With energy demand stabilizing over the long term, electricity and renewable energy together become the dominant sources, accounting for over 88% of total energy consumption by 2065. Similarly, hydrogen use increases to 9% by 2065. In this scenario, fossil fuel consumption is minimal, making up <2% of total energy use.

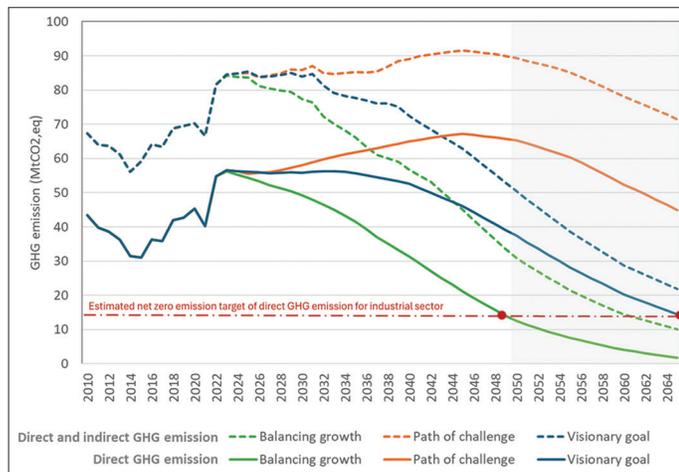
### 5.3. GHG Emissions in Industry Sector

The results of the GHG emissions for the industrial sector are presented in Figure 15 for direct emissions by sub-sector industries and Figure 16 for direct and indirect GHG emissions allocated to energy demand in industry. It must be noted that the analysis of GHG emissions in the industrial sector in relation to the net-zero emission target may not be directly comparable, as industrial energy use represents only a part of the national inventory under category

**Figure 15:** Direct greenhouse gas emissions by sub-sector industries



**Figure 16:** Direct and indirect greenhouse gas emissions by scenarios



1A2: Manufacturing industries and construction. Therefore, the GHG emission target for industrial energy use is based on the guideline from the Office of Natural Resources and Environmental Policy and Planning (ONEP), which specifies that GHG emissions from industrial energy consumption should not exceed 13.8 MtCO<sub>2</sub>e, excluding the CCS/CCU (ONEP, 2023), in order to achieve the net-zero emission target. Summary of the result is as follows:

- In the path of challenge scenario, GHG emissions in 2065 remain at a relatively high level. Although they decline compared to 2022, they are still far from reaching the net-zero emission target. The non-metal, basic metal, and chemical industries continue to record high levels of GHG emissions, not including indirect emissions from electricity use, which would further widen the gap. Without structural transformation and with a continued conservative approach toward supporting renewable and low-carbon energy alternatives, the path of challenge scenario will remain significantly distant from the net-zero goal.
- The visionary goal scenario is considered to remain on track toward achieving net-zero emissions by 2065. However, this depends on several key conditions—most notably, the period after 2037, which marks the end of the current energy planning horizon. Beyond this point, no official policies have yet been announced, and existing hydrogen and CCS/CCU roadmaps remain at the research stage. Furthermore, when indirect emissions reallocated back to the demand side are taken into

account, the risks increase even further. A major risk factor lies in the success of reducing GHG emissions within the power generation sector. The visionary goal scenario would not be able to achieve its target if the timeline for reaching net-zero emissions were accelerated.

- The Balancing Growth scenario represents another pathway capable of achieving the net-zero target by 2065, with the potential to reach net-zero emissions even earlier—before 2050—for direct emissions. Efforts to reduce GHG emissions through industrial restructuring, efficiency improvements, and greater use of renewable energy also help minimize the need for CCS/CCU technologies, which remain costly and face readiness challenges. A key condition in this scenario is that the peak emission point must occur within the period 2025-2030.

## 6. CONCLUSION

The study presents model-based pathways toward achieving net-zero GHG emissions in Thailand’s industrial sector, emphasizing the sequencing and prioritization of mitigation technologies based on readiness levels, and multi-dimensional impacts across economic, social, and environmental domains. The modelling framework integrates technology adoption dynamics with policy and macroeconomic drivers, providing a quantitative basis for assessing long-term decarbonization feasibility under alternative transition scenarios.

- Assessment of transition parameters indicates that policy enforcement and technological adoption remain the primary determinants of emission trajectories. The climate change, and Thailand’s net-zero target commitment define a major policy shift affecting investment behavior and cost learning curves. On the technology side, advanced low-carbon fuels (such as hydrogen) and carbon capture and utilization (CCS/CCU) emerge as critical variables for bridging residual emissions in hard-to-abate sectors, including non-metallic minerals, chemicals, and basic metals, jointly accounting for more than 71% of direct industrial GHG emissions. Complementary measures such as advanced nuclear (i.e., small modular reactor) and energy storage technologies (battery energy storage, grid-scale energy storage) are modelled as enablers for system-wide electrification and indirect emission mitigation.
- Model simulations under the Visionary pathway suggest that net-zero emissions can be achieved by 2065, assuming an accelerated learning rate and early deployment of high-impact technologies. However, this requires a GHG reduction rate significantly higher than the levels proposed in the draft national energy plan guideline, necessitating early-scale deployment of high-uncertainty, high-impact technologies—particularly hydrogen and CCS/CCUS. Under this accelerated transition, net-zero emissions could be achieved by 2065, contingent upon timely investment, policy enforcement, and infrastructure readiness
- The Balancing Growth pathway yields an earlier net-zero achievement (before 2050) under assumptions of early peak emissions (2025-2030) and rapid industrial restructuring. This pathway requires a shift in industrial value added parameters toward high value-added and resource-efficient industries, along with accelerated process electrification rates and

commercial-scale deployment of H<sub>2</sub> and CCS technologies by 2030. The model indicates that delaying these conditions by even 5 years would increase cumulative emissions by more than 15%, making the 2050 target unattainable.

- In contrast, the path of challenge scenario assumes conservative adoption curves and status-quo industrial structural parameters, leading to slower penetration of green technologies. The absence of early-stage commercialization of hydrogen and CCS/CCUS technologies results in persistent residual emissions. The model outputs show that under these constraints, net-zero by 2065 is not achievable, with cumulative industrial emissions exceeding the allowable carbon budget by more than 30 MtCO<sub>2e</sub>, compared to the Visionary scenario in 2065.

## 7. AUTHOR'S CONTRIBUTION

Weerin Wangjiraniran: Conceptualization, formal analysis, methodology, writing - original draft. Nitida Nakapreecha: data curation, project administration, funding acquisition, writing - reviewing and editing. Jakapong Pongthanasawan: Investigation, validation, writing - reviewing and editing

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