

## LMDI Decomposition of CO<sub>2</sub> Emissions from Thailand's Electricity Generation Sector (2014–2023)

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### Abstract

This study analyzes the driving forces of carbon dioxide (CO<sub>2</sub>) emissions from Thailand's electricity generation sector during 2014–2023 using the additive Logarithmic Mean Divisia Index (LMDI) method. Electricity generation accounts for the largest share of Thailand's energy-related CO<sub>2</sub> emissions and is central to achieving national climate targets under the Nationally Determined Contributions (NDC) and long-term carbon neutrality and net-zero goals. An additive LMDI framework based on an extended Kaya identity decomposes changes in total CO<sub>2</sub> emissions into five components: activity, structural, fuel mix, thermal efficiency, and emission factor effects. The analysis uses annual electricity generation data from the Global Change Data Lab, energy consumption data from Thailand's Energy Balance compiled by the Department of Alternative Energy Development and Efficiency (DEDE), and default emission factors from the 2006 IPCC Guidelines. In addition, scenario-based projections are developed to assess emission pathways consistent with Thailand's 2030 NDC target, 2050 carbon neutrality, and a 2065 net-zero greenhouse gas emissions goal. The results show that total CO<sub>2</sub> emissions from the electricity sector declined by approximately 10.02 Mt CO<sub>2</sub> during 2014–2023. Improvements in thermal efficiency and structural changes in the generation mix were the main drivers of emission reductions, while shifts in fuel mix from coal toward natural gas and renewable energy provided additional mitigation effects. However, rising electricity demand, captured by the activity effect, partially offset these gains. Scenario analysis suggests that pathways featuring accelerated renewable energy deployment and earlier coal phase-out are more consistent with Thailand's higher-ambition NDC targets and long-term decarbonization goals. The findings provide quantitative evidence on the relative importance of demand growth, efficiency improvement, and structural change, offering policy-relevant insights for electricity-sector decarbonization in Thailand.

**Keywords:** CO<sub>2</sub> emissions; electricity generation; energy transition; fuel mix; LMDI decomposition; Thailand

### 1. Introduction

Electricity generation plays a central role in modern economic systems by supporting industrial activity, urban development, and household welfare. In many emerging economies, growth in electricity demand is closely linked to economic expansion, resulting in increased energy consumption and greenhouse gas emissions. Thailand is no exception. Despite recent progress in energy-efficiency improvements and renewable

energy deployment, the electricity generation sector remains the largest single source of carbon dioxide (CO<sub>2</sub>) emissions within the national energy system, largely due to continued reliance on fossil fuels, particularly natural gas and coal.

Over the past decade, Thailand's electricity demand has grown steadily in response to economic development, urbanization, and rising living standards. Although the share of renewable electricity has increased, fossil-fuel-based

generation continues to dominate the power mix. Natural gas remains the primary generation fuel, while coal and lignite still contribute a substantial share, particularly in baseload generation. As a result, the electricity sector occupies a critical position in Thailand's national climate strategy, representing both a major challenge and a key opportunity for achieving carbon neutrality and long-term decarbonization goals.

Thailand's climate and energy policies are framed by its international commitments under the Paris Agreement and domestic planning instruments. The country's Second Updated Nationally Determined Contribution (NDC) sets a target to reduce greenhouse gas emissions by 30 percent below business-as-usual levels by 2030, or up to 40 percent with international support, alongside long-term goals of achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065<sup>1</sup>. These objectives are operationalized through the Power Development Plan (PDP), the Alternative Energy Development Plan (AEDP), and the Energy Efficiency Plan (EEP), which collectively emphasize renewable energy expansion, energy-efficiency improvement, gradual coal phase-down, and modernization of the electricity system. However, translating these policy ambitions into effective emission reductions requires a clear understanding of the underlying drivers of changes in CO<sub>2</sub> emissions in the electricity sector.

Decomposition analysis provides a systematic approach for identifying the factors that drive changes in energy-related CO<sub>2</sub> emissions. Among available methods, the Logarithmic Mean Divisia Index (LMDI) approach is widely applied due to its theoretical consistency, perfect decomposition without residual terms, and flexibility in incorporating structural and technological variables. Previous LMDI-based studies on Thailand's power and energy sectors have demonstrated that economic activity and electricity demand growth

are major contributors to increases in emissions, while improvements in efficiency and gradual shifts in fuel structure have partially offset these effects. Nevertheless, most existing research relies on long historical periods, aggregate sectoral data, and standard decomposition frameworks, offering limited insight into recent structural changes and their policy relevance under Thailand's current decarbonization agenda.

This study addresses these limitations by applying an extended additive LMDI framework to analyze changes in CO<sub>2</sub> emissions in Thailand's electricity generation sector over the period 2014–2023. This period is deliberately selected as it represents a critical phase of policy and structural transition in the Thai power sector, characterized by successive revisions of the Power Development Plan, accelerated renewable energy deployment, gradual coal phase-down, and the formulation of key national climate commitments, including the Second Updated Nationally Determined Contribution and the Long-Term Low Greenhouse Gas Emission Development Strategy. By decomposing total emission changes into activity, structural, fuel mix, thermal efficiency, and emission factor effects, the analysis provides a detailed assessment of how technological progress, fuel substitution, and changes in electricity generation structure have influenced emission trends during this period. In addition, scenario-based analysis aligned with Thailand's national climate targets is developed to examine possible implications of alternative electricity demand trajectories and decarbonization pathways for the 2030 NDC target, 2050 carbon neutrality, and the 2065 net-zero greenhouse gas emissions goal.

## 2. Literature Review

The Logarithmic Mean Divisia Index (LMDI) is a widely used index decomposition method for analyzing changes in energy consumption and

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<sup>1</sup> According to Thailand's Second Updated Nationally Determined Contribution (NDC), the projected business-as-usual (BAU) greenhouse gas emissions in 2030 are approximately 555 Mt CO<sub>2</sub>eq (economy-wide, excluding LULUCF). Thailand commits to reducing emissions by 30% below the BAU level by 2030, or up to 40% with international support. Building on this near-term mitigation target, Thailand's Revised Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) defines carbon neutrality by 2050 as achieving net-zero carbon dioxide (CO<sub>2</sub>) emissions through balancing residual CO<sub>2</sub> emissions with removals or offsets, while net-zero greenhouse gas emissions by 2065 refer to minimizing anthropogenic emissions of all greenhouse gases and fully balancing remaining emissions with removals (UNFCCC, 2022).

CO<sub>2</sub> emissions. It enables total emission changes to be systematically attributed to multiple driving factors—including activity, structural change, energy/thermal efficiency, fuel mix, and emission factors—without residual terms. Owing to its theoretical consistency, path independence, and flexibility in incorporating technological and structural variables, LMDI has been extensively applied to the power sector, where electricity demand, generation structure, and technology evolve simultaneously (Chontanawat *et al.*, 2020; Mai *et al.*, 2020).

Previous LMDI-based studies in the energy and industrial sectors consistently identify activity or output growth as the dominant driver of emission increases, while improvements in efficiency, fuel switching, and renewable energy deployment partially offset this effect. High-resolution decomposition analyses further emphasize the importance of accounting for technology-specific efficiency and structural change when assessing emission dynamics, particularly in emerging economies undergoing energy transitions (Shrestha *et al.*, 2009).

In the context of Thailand, LMDI and related decomposition methods have been applied to analyze CO<sub>2</sub> emissions from the electricity and broader energy sectors. Existing studies consistently find that economic growth and rising electricity demand are primary drivers of emission increases, whereas improvements in efficiency and gradual changes in fuel structure provide limited mitigation, resulting mainly in relative rather than absolute decoupling between economic growth and emissions (Muangthai *et al.*, 2014; Chen *et al.*, 2025). However, most studies rely on long historical periods, aggregated sectoral data, and standard decomposition frameworks, offering limited insight into recent technology-driven structural changes under Thailand's current decarbonization agenda.

This study advances the literature by focusing on the recent period 2014–2023 and applying an expanded LMDI framework with higher-resolution, technology-level data disaggregated by generation technology, fuel type, and producer category. This approach enables a more detailed assessment of how efficiency improvements, structural changes, and fuel substitution have

shaped recent CO<sub>2</sub> emission trends in Thailand's electricity sector.

### 3. Methodology and Data

#### 3.1 Logarithmic Mean Divisia Index (LMDI) Method

The additive Logarithmic Mean Divisia Index (LMDI) is employed in this study as the principal method for decomposing changes in CO<sub>2</sub> emissions within Thailand's electricity sector. LMDI is widely recognized for its ability to provide perfect decomposition, ensuring that all changes in emissions are fully attributed to defined contributing factors without residual terms. This mathematical robustness allows researchers and policymakers to precisely quantify the influence of diverse drivers such as emission factors, energy efficiency, fuel mix, structural shifts, and overall activity levels across multiple time periods.

The decomposition in this study is based on an extended Kaya-type identity, articulated as:

$$C = \sum_i C_i = \sum_i G_{tot} \times \frac{G_{th}}{G_{tot}} \times \frac{G_i}{G_{th}} \times \frac{F_i}{G_i} \times \frac{C_i}{F_i} \dots (1)$$

Where:

$G_{tot}$ : total electricity generation from all sources;  
 $G_{th}$ : total electricity generation from all thermal (fossil-based) fuels;  
 $G_i$ : total electricity generation from fuel  $i$ ;  
 $F_i$ : fuel consumption of type  $i$ ; and  
 $C_i$ : CO<sub>2</sub> emissions from fuel  $i$ .

The LMDI method utilizes both multiplicative and additive decomposition formulas to capture the impact of each key factor. The total change in CO<sub>2</sub> emissions over any given period, such as from 2014 to 2023, can be expressed as:

$$\Delta C_{tot} = C^t - C^0 \dots \dots \dots (2)$$

$$\Delta C_{tot} = \Delta C_{act} + \Delta C_{str} + \Delta C_{mix} + \Delta C_{eff} + \Delta C_{ef} (3)$$

**Table 1:** Formulation of the LMDI Approach.

| Identity              | $C = \sum_i C_i = \sum_i G_{tot} \times \frac{G_{th}}{G_{tot}} \times \frac{G_i}{G_{th}} \times \frac{F_i}{G_i} \times \frac{C_i}{F_i}$                                                                |                                                                                                                                                       |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Division              | Multiplicative decomposition                                                                                                                                                                           | Additive decomposition                                                                                                                                |
|                       | $D$                                                                                                                                                                                                    | $\Delta C$                                                                                                                                            |
| Effect of each factor | $D_{act} = \exp \left( \sum_i \frac{(C_i^t - C_i^0)/(\ln C_i^t - \ln C_i^0)}{(C^t - C^0)/(\ln C^t - \ln C^0)} \ln \left( \frac{G_{tot}^t}{G_{tot}^0} \right) \right)$                                  | $\Delta C_{act} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_{tot}^t}{G_{tot}^0} \right)$                                  |
|                       | $D_{str} = \exp \left( \sum_i \frac{(C_i^t - C_i^0)/(\ln C_i^t - \ln C_i^0)}{(C^t - C^0)/(\ln C^t - \ln C^0)} \ln \left( \frac{G_{th}^t}{G_{th}^0} \times \frac{G_{tot}^0}{G_{tot}^t} \right) \right)$ | $\Delta C_{str} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_{th}^t}{G_{th}^0} \times \frac{G_{tot}^0}{G_{tot}^t} \right)$ |
|                       | $D_{mix} = \exp \left( \sum_i \frac{(C_i^t - C_i^0)/(\ln C_i^t - \ln C_i^0)}{(C^t - C^0)/(\ln C^t - \ln C^0)} \ln \left( \frac{G_i^t}{G_{th}^t} \times \frac{G_{th}^0}{G_i^0} \right) \right)$         | $\Delta C_{mix} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_i^t}{G_{th}^t} \times \frac{G_{th}^0}{G_i^0} \right)$         |
|                       | $D_{eff} = \exp \left( \sum_i \frac{(C_i^t - C_i^0)/(\ln C_i^t - \ln C_i^0)}{(C^t - C^0)/(\ln C^t - \ln C^0)} \ln \left( \frac{F_i^t}{G_i^t} \times \frac{G_i^0}{F_i^0} \right) \right)$               | $\Delta C_{eff} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{F_i^t}{G_i^t} \times \frac{G_i^0}{F_i^0} \right)$               |
|                       | $D_{ef} = \exp \left( \sum_i \frac{(C_i^t - C_i^0)/(\ln C_i^t - \ln C_i^0)}{(C^t - C^0)/(\ln C^t - \ln C^0)} \ln \left( \frac{C_i^t}{F_i^t} \times \frac{F_i^0}{C_i^0} \right) \right)$                | $\Delta C_{ef} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{C_i^t}{F_i^t} \times \frac{F_i^0}{C_i^0} \right)$                |

**Source:** Formulation of the Logarithmic Mean Divisia Index (LMDI) method adapted from Ang *et al.* (1998) and Ang (2004, 2005).

Each component term represents a specific driving factor of CO<sub>2</sub> emission change, defined as:

$$\Delta C_{act} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_{tot}^t}{G_{tot}^0} \right) \dots \dots \dots (4)$$

$$\Delta C_{str} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_{th}^t}{G_{th}^0} \times \frac{G_{tot}^0}{G_{tot}^t} \right) \dots \dots \dots (5)$$

$$\Delta C_{mix} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{G_i^t}{G_{th}^t} \times \frac{G_{th}^0}{G_i^0} \right) \dots \dots \dots (6)$$

$$\Delta C_{eff} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{F_i^t}{G_i^t} \times \frac{G_i^0}{F_i^0} \right) \dots \dots \dots (7)$$

$$\Delta C_{ef} = \sum_i \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln \left( \frac{C_i^t}{F_i^t} \times \frac{F_i^0}{C_i^0} \right) \dots \dots \dots (8)$$

Definitions of Effects:

$\Delta C_{act}$  (Activity Effect) measures the effect of changes in total electricity generation ( $G_{tot}$ ) between the two periods.

$\Delta C_{str}$  (Structural Effect) indicates the impact of changes in the proportion of total thermal generation within overall electricity generation ( $G_{th}/G_{tot}$ ).

$\Delta C_{mix}$  (Fuel Mix Effect) reflects the impact of changes in the share of electricity generated from each fuel  $i$  in total thermal generation ( $G_i/G_{th}$ ).

$\Delta C_{eff}$  (Thermal Efficiency Effect) captures the change in CO<sub>2</sub> emissions due to variations in the efficiency of converting fuel energy into electricity ( $F_i/G_i$ ).

$\Delta C_{ef}$  (Emission Factor Effect) represents the change in CO<sub>2</sub> emissions resulting from variations in the emission factor of fuel ( $C_i/F_i$ ).

In the context of Thailand's electricity sector, LMDI enables the clear separation of the effects of technology upgrades, shifts in energy mix—such as increased adoption of renewables or switching from coal to natural gas—changes in sector structure, and rising or falling electricity demand. Moreover, the additive form of LMDI permits direct quantification of each factor's contribution to total emission changes, enhancing transparency in scenario analysis and policy evaluation.

While LMDI offers mathematical precision and analytic clarity, some limitations should be acknowledged. Notably, incomplete or missing data may affect the accuracy of factor attribution, and impacts from unmeasured influences—such as abrupt policy changes or behavioral shifts—may not be captured fully. Appropriate zero-value handling techniques and sensitivity checks are recommended to strengthen confidence in results.

### 3.2 Data

This section describes and summarizes the key datasets, sources, and classification methods used for the LMDI decomposition analysis of CO<sub>2</sub> emissions within Thailand's electricity sector from 2014 to 2023.

#### 3.2.1 Energy Consumption Data and Trends

Primary energy consumption data were obtained from Thailand's Energy Balance published by the Department of Alternative Energy Development and Efficiency (DEDE). The data are originally reported in thousand tons of oil equivalent (KTOE) and were converted to petajoules (PJ) using the standard conversion factor (1 KTOE = 0.041868 PJ) to ensure analytical consistency and compatibility with the default 2006 IPCC carbon emission factors expressed in tonnes of CO<sub>2</sub> per terajoule (t CO<sub>2</sub>/TJ). All energy use variables employed in the LMDI calculations were therefore harmonized in PJ.

Thermal energy inputs to electricity generation include bituminous coal, briquettes and other coal, lignite (Mae Moh), high-speed diesel, fuel oil, and natural gas in various forms. Consistent

with the LMDI framework, these fuels were aggregated into three categories:

- (i) Coal Products: bituminous coal, briquettes/other coal, lignite (Mae Moh);
- (ii) Oil Products: high-speed diesel (HSD), fuel oil;
- (iii) Natural Gas: natural gas, methane, pipeline gas, LNG.

As summarized in **Fig. 1**, Thailand's energy consumption structure has changed substantially over the past decade. The share of coal declined from 22.42% in 2014 to 13.53% in 2023, indicating a gradual move away from coal as a primary energy source. Natural gas remained the dominant fuel throughout the period, accounting for approximately 55–67% of total energy consumption throughout the period and continuing to play a central role in thermal power generation. In contrast, the share of renewable energy increased markedly, rising from 11.93% in 2014 to 30.74% in 2023, reflecting sustained expansion of low-carbon energy sources. Correspondingly, the overall share of thermal (fossil-based) fuels decreased from 88.07% to 69.26% (**Fig. 1**), highlighting a gradual but steady rebalancing of Thailand's energy mix toward diversification and decarbonization.

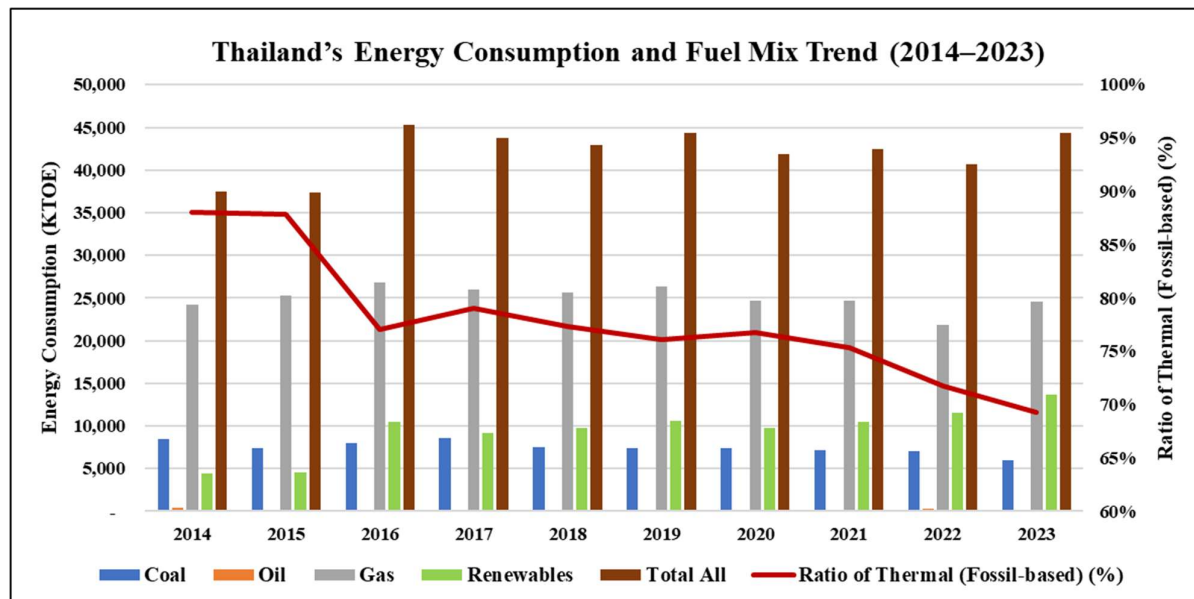


**Fig. 1:** Thailand's Energy Consumption and Fuel Mix Trend (2014–2023).

### 3.2.2 Electricity Generation and Fuel Mix Evolution

Electricity generation data were obtained from the Global Change Data Lab (GCDL), which reports national annual figures in terawatt-hours (TWh). For consistency in analysis and to ensure compatibility with the 2006 IPCC default carbon emission factors ( $\text{t CO}_2/\text{TJ}$ ), all electricity generation values were converted to petajoules (PJ) using the conversion factor  $1 \text{ TWh} = 3.6 \text{ PJ}$ . This harmonization allows direct comparison with energy consumption data and enables coherent calculation of efficiency and fuel mix effects within the LMDI decomposition framework.

Consistent with the categorization of energy consumption, electricity generation from thermal power fuels is grouped into three main categories: coal products, oil products, and natural gas. This classification supports clear trend analysis of Thailand's evolving generation mix and facilitates sectoral  $\text{CO}_2$  emission calculations.

As illustrated in **Fig. 2**, Thailand's electricity generation experienced notable shifts in fuel composition and volume over the period 2014–2023. Total electricity generation increased from approximately 173.76 TWh in 2014 to 190.49 TWh in 2023, reflecting steady growth in electricity demand. Fossil-fuel-based (thermal) generation—comprising coal, oil, and natural gas—remained

the backbone of the generation portfolio but exhibited a declining share, decreasing from 91.82% of total generation in 2014 to 84.37% in 2023.

Coal-fired generation declined from 37.57 TWh (21.62%) in 2014 to 30.43 TWh (15.97%) in 2023, indicating a gradual phase-down consistent with Thailand's decarbonization efforts. Oil-based generation accounted for a very small share of total output and declined further from 0.96% to 0.47% over the study period. Natural gas continued to serve as the dominant generation fuel, maintaining a share of approximately 63–72% throughout the period and increasing slightly to 67.93% in 2023.

Renewable electricity generation increased substantially, rising from 14.21 TWh (8.18%) in 2014 to 29.77 TWh (15.63%) in 2023. Among renewable sources, bioenergy consistently accounted for the largest share, followed by hydropower, solar, and wind. This expansion reflects Thailand's continued deployment of renewable energy capacity and the influence of national policy incentives.

Overall, the combination of steady growth in electricity generation and evolving fuel mix highlights a gradual transition toward a cleaner power generation structure. These trends are critical for modeling  $\text{CO}_2$  emission trajectories and assessing the impacts of energy transition policies within the LMDI framework.

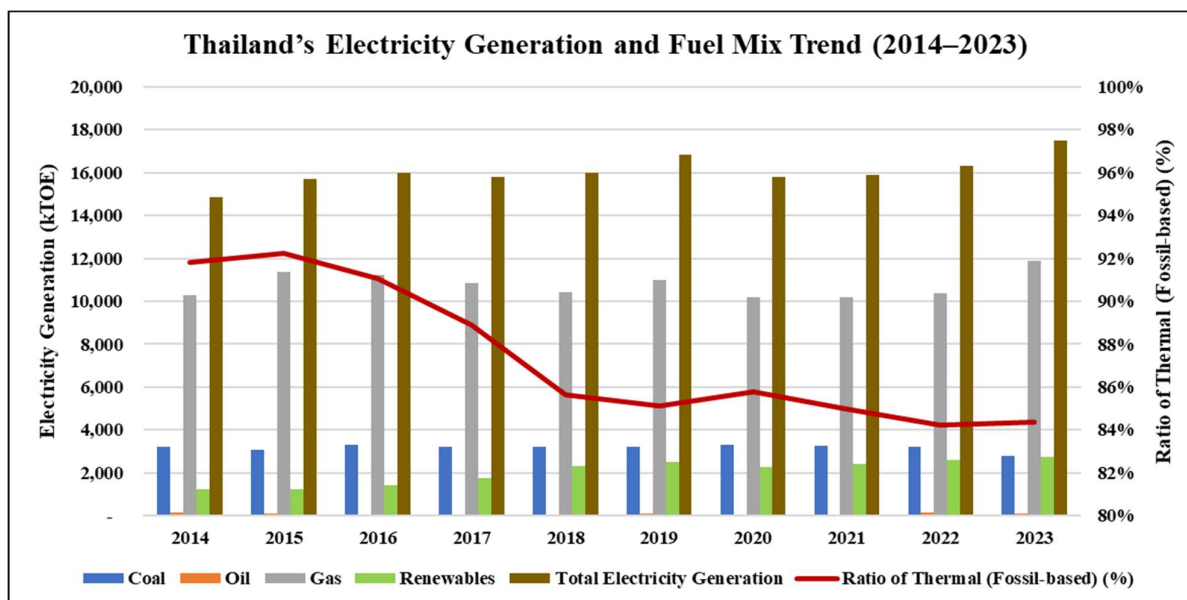


**Fig. 2:** Thailand's Electricity Generation and Fuel Mix Trend (2014–2023).

Electricity imports are excluded from the LMDI decomposition analysis and treated separately from domestic electricity generation. Although imported electricity is included in Thailand's national energy balance as part of total electricity supply, it does not generate direct CO<sub>2</sub> emissions within the domestic electricity generation sector and is predominantly sourced from hydropower in neighboring countries. This exclusion ensures that the decomposition results accurately reflect changes in Thailand's domestic fuel mix, thermal efficiency, and generation structure driven by national energy and climate policies.

### 3.2.3 Carbon Emission Factors

In this study, the effect of CO<sub>2</sub> emission factors was held constant over the entire period from 2014 to 2023. This approach is based on the adoption of default carbon emission factors from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2: Energy, Table 2.2), as summarized in **Table 2**. These standardized values (t CO<sub>2</sub>/TJ) are assigned to primary fuels used in stationary combustion—such as coal, oil, and natural gas—within the energy industry.

**Table 2:** Carbon Emission Factors.

| Fuel                    | CO <sub>2</sub> (Default Emission Factor) |
|-------------------------|-------------------------------------------|
|                         | t CO <sub>2</sub> / TJ                    |
| <b>Coal</b>             |                                           |
| Bituminous              | 96.1                                      |
| Briquettes & other coal | 97.5                                      |
| Lignite                 | 101.0                                     |
| <b>Oil</b>              |                                           |
| High-Speed Diesel       | 74.1                                      |
| Fuel Oil                | 77.4                                      |
| <b>Natural Gas</b>      | <b>56.1</b>                               |

In the IPCC framework, *stationary combustion* refers to the burning of fuels in fixed installations—such as power plants, industrial boilers, and electricity generation facilities—that do not involve mobile sources. This category is therefore most relevant for analyzing emissions from Thailand's electricity sector.

According to the IPCC 2006 Guidelines, these emission factors are default fixed values and

remain constant over time. As a result, carbon intensity per unit of energy input does not vary throughout the study period. Consequently, the CO<sub>2</sub> emission factor effect does not contribute to changes in total CO<sub>2</sub> emissions from Thailand's electricity generation sector during 2014–2023. All observed changes in total CO<sub>2</sub> emissions in this analysis arise from other influencing factors—including the thermal efficiency effect, fuel mix effect, structural effect, and activity effect—rather than from variations in emission factors.

### 3.3 Scenario Design and Assumptions

This study develops a set of stylized scenarios to examine possible future CO<sub>2</sub> emission pathways in Thailand's electricity sector that are consistent with national mitigation milestones for 2030, 2050, and 2065. The scenarios are designed as policy-consistent but methodologically controlled experiments, allowing the effects of changes in electricity demand (activity), generation structure and fuel mix, and technology-related efficiency improvements to be assessed within the LMDI decomposition framework. Therefore, these scenarios should be interpreted as analytical scenarios rather than definitive forecasts or predictions of Thailand's future electricity system.

Scenario assumptions are primarily derived from Thailand's Second Updated Nationally Determined Contribution (NDC 2.0), the Long-Term Low Emission Development Strategy (LT-LEDS, 2022), and the draft Power Development Plan (PDP 2024–2037). Rather than forecasting outcomes, the scenarios represent alternative, internally consistent pathways constructed to isolate key emission drivers relevant to power-sector decarbonization.

#### 3.3.1 Scenario Drivers and Analytical Link to LMDI

Across all scenarios, three core drivers are varied in line with the LMDI decomposition structure:

1) *Electricity demand growth (activity effect)*, reflecting alternative assumptions regarding economic growth, energy efficiency improvements, and demand-side management;

2) *Generation mixes and fuel composition (structural and fuel-mix effects)*, capturing shifts from coal and natural gas toward renewable and other low-carbon electricity generation technologies;

3) *Thermal efficiency and low-carbon technology deployment (thermal efficiency effect)*, including improvements in fossil-fuel power plant performance and the gradual introduction of CCUS, hydrogen, and other low-emission options in later periods.

Emission factors are held constant across all scenarios, consistent with the use of default emission factors from the IPCC (2006) Guidelines, thereby ensuring analytical consistency within the LMDI framework.

### 3.3.2 BAU Definition, NDC Targets, and Scenario Specifications

#### 1) Business-as-Usual (BAU) Definition

Thailand's Second Updated Nationally Determined Contribution (NDC 2.0, 2022) specifies an economy-wide business-as-usual (BAU) greenhouse gas emission level of approximately 555 Mt CO<sub>2e</sub> in 2030, but it does not provide sector-specific emission baselines or detailed annual emission trajectories. In this study, the BAU emissions pathway for the electricity generation sector is constructed based on projected electricity demand, generation mix assumptions, and fuel-specific emission factors consistent with the Draft Power Development Plan (PDP 2024–2037), the Alternative Energy Development Plan (AEDP), and observed historical electricity generation trends.

The resulting electricity-sector BAU represents a policy-consistent reference pathway, rather than a no-policy counterfactual. It serves as the baseline against which the 30% and 40% emission reduction targets under Thailand's NDC are operationalized in the scenario analysis.

#### 2) NDC Targets and Policy Benchmarks

Under Thailand's NDC 2.0 (2022), the country commits to reducing greenhouse gas emissions by 30% below the BAU level by 2030 on an unconditional basis, achievable through domestic mitigation measures.

In addition, Thailand has announced an enhanced ambition to reduce emissions by 40% below BAU by 2030. This 40% target is operationalized as comprising two components: (i) a 33.3% reduction from BAU (unconditional), achievable through national policies and domestic resources; and (ii) a 6.7% reduction

from BAU (conditional), contingent upon enhanced international support in finance, technology, and capacity building. Accordingly, the overall 40% reduction target is driven primarily by domestic mitigation efforts, supplemented by a smaller conditional component dependent on international assistance.

In this study, the analysis focuses on two mitigation benchmarks: a 30% unconditional reduction target (hereafter referred to as NDC 30) and the domestic component of the 40% reduction target, corresponding to a 33.3% reduction from BAU (hereafter referred to as NDC 40 Unconditional). For consistency with Thailand's national implementation framework, the term NDC 40 (Unconditional) is used exclusively to denote the domestic mitigation component of the overall 40% ambition.

Based on the constructed BAU pathway, electricity-sector CO<sub>2</sub> emissions in 2030 are projected at 120.0 Mt CO<sub>2</sub>, which serves as the reference level for operationalizing the mitigation targets. Accordingly, NDC 30 corresponds to an emission level of 84.0 Mt CO<sub>2</sub>, while NDC 40 (Unconditional) corresponds to 67.7 Mt CO<sub>2</sub>.

To ensure methodological consistency in the LMDI decomposition analysis, the BAU pathway is extended to 2050 and 2065. In 2050, BAU electricity-sector emissions are projected at 73.60 Mt CO<sub>2</sub>, implying corresponding emission levels of 51.52 Mt CO<sub>2</sub> under NDC 30 and 41.52 Mt CO<sub>2</sub> under NDC 40 (Unconditional). By 2065, Thailand's net-zero greenhouse gas emissions objective implies near-zero electricity-sector emissions under deep decarbonization pathways.

*Note:* Thailand submitted its Third Updated Nationally Determined Contribution (NDC 3.0) on 4 November 2025, committing to reduce net greenhouse gas emissions to 152 Mt CO<sub>2eq</sub> by 2035 (a 47% reduction relative to 2019 levels). As the scenario framework and analytical design of this study were finalized prior to the release of NDC 3.0, all scenario benchmarks remain anchored to NDC 2.0 and contemporaneous energy planning assumptions in order to maintain analytical consistency.

#### 3) Scenario Design and Specifications

▪ *Scenario 1 (PDP-aligned pathway):* Follows the electricity demand trajectory, efficiency improvements, and generation mix evolution

specified in the Draft Power Development Plan (PDP) 2024. It represents a moderate and policy-consistent decarbonization pathway under relatively high electricity demand assumptions.

▪ *Scenario 1A (Accelerated renewable deployment and coal phase-down)*: Adopts the same electricity demand and efficiency assumptions as Scenario 1 but assumes a more rapid reduction in coal-fired power generation and a higher penetration of renewable electricity from 2024 onward. This scenario isolates the effect of a more ambitious supply-side decarbonization strategy under high-demand conditions.

▪ *Scenario 2 (Lower-demand pathway)*: Assumes a reduced electricity demand growth rate based on historical trends observed during 2014–2023, with an estimated compound annual growth rate (CAGR) of approximately 1.8% per year. For the projection period, electricity demand growth is fixed at this rate, while the generation mix structure remains consistent with Scenario 1. This scenario isolates the role

of the activity effect in driving changes in electricity-sector CO<sub>2</sub> emissions.

▪ *Scenario 2A (Lower demand with enhanced renewable deployment)*: Combines the reduced demand growth assumption of Scenario 2 with moderately higher renewable energy shares and an accelerated coal phase-down. This scenario represents a conservative yet more mitigation-oriented decarbonization pathway that integrates both demand-side moderation and strengthened supply-side transformation.

## 4. Results and Discussion

### 4.1 Historical CO<sub>2</sub> Emissions from the Electricity Generation Sector (2014–2023)

As shown in **Table 3** and **Fig. 3**, total CO<sub>2</sub> emissions from Thailand's electricity generation sector exhibited a fluctuating but overall declining trend, decreasing from 92.93 Mt CO<sub>2</sub> in 2014 to 82.91 Mt CO<sub>2</sub> in 2023.

**Table 3:** Thailand's CO<sub>2</sub> Emissions from Electricity Generation Sector (Mt CO<sub>2</sub>) (2014–2023).

| CO <sub>2</sub> emission (Mt CO <sub>2</sub> ) | 2014         | 2015         | 2016         | 2017         | 2018         | 2019         | 2020         | 2021         | 2022         | 2023         |
|------------------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| <b>Coal</b>                                    | <b>34.72</b> | <b>30.61</b> | <b>33.11</b> | <b>35.17</b> | <b>30.82</b> | <b>30.26</b> | <b>30.28</b> | <b>29.52</b> | <b>29.11</b> | <b>24.80</b> |
| Bituminous                                     | 16.42        | 10.75        | 13.65        | 15.46        | 13.39        | 12.84        | 13.27        | 11.80        | 11.88        | 9.19         |
| Briquettes & other coal                        | 0.48         | 4.68         | 2.27         | 3.06         | 2.59         | 3.01         | 3.16         | 2.81         | 2.92         | 2.26         |
| Lignite (Mae Moh)                              | 17.83        | 15.17        | 17.19        | 16.65        | 14.84        | 14.42        | 13.85        | 14.92        | 14.31        | 13.35        |
| <b>Oil</b>                                     | <b>1.23</b>  | <b>0.67</b>  | <b>0.35</b>  | <b>0.20</b>  | <b>0.16</b>  | <b>0.19</b>  | <b>0.17</b>  | <b>0.48</b>  | <b>0.94</b>  | <b>0.51</b>  |
| High-Speed Diesel                              | 0.06         | 0.07         | 0.10         | 0.12         | 0.11         | 0.11         | 0.08         | 0.18         | 0.86         | 0.50         |
| Fuel Oil                                       | 1.18         | 0.60         | 0.24         | 0.08         | 0.05         | 0.08         | 0.09         | 0.30         | 0.08         | 0.01         |
| <b>Gas</b>                                     | <b>56.97</b> | <b>59.35</b> | <b>62.97</b> | <b>60.98</b> | <b>60.16</b> | <b>62.01</b> | <b>58.10</b> | <b>58.09</b> | <b>51.22</b> | <b>57.60</b> |
| <b>Total</b>                                   | <b>92.93</b> | <b>90.62</b> | <b>96.42</b> | <b>96.36</b> | <b>91.14</b> | <b>92.45</b> | <b>88.55</b> | <b>88.09</b> | <b>81.27</b> | <b>82.91</b> |

The emission trajectory is broadly divided into three distinct phases. During the first phase (2014–2017), emissions increased and reached a peak of 96.42 Mt CO<sub>2</sub> in 2016, reflecting strong growth in electricity demand and continued reliance on fossil-fuel-based generation, particularly natural gas and coal. In the second phase (2017–2019), emissions declined gradually, coinciding with expanded renewable energy deployment and observable improvements in generation efficiency. The third phase (2019–2023) captures the combined effects of the COVID-19 pandemic and subsequent economic recovery, with emissions declining sharply during 2020–2022 before rebounding modestly in 2023.

Throughout the study period, natural gas remained the dominant contributor to CO<sub>2</sub> emissions from the electricity sector, accounting for approximately 61–69% of total emissions. In contrast, coal-related emissions declined both in absolute terms and as a share of total emissions. Oil-based emissions remained negligible, reflecting the limited role of oil in electricity generation. Overall, the historical trend suggests a gradual decoupling of electricity-sector emissions from electricity demand growth, although fossil fuels continue to dominate the generation mix, as illustrated by the fuel-specific emission shares in **Fig. 4**.

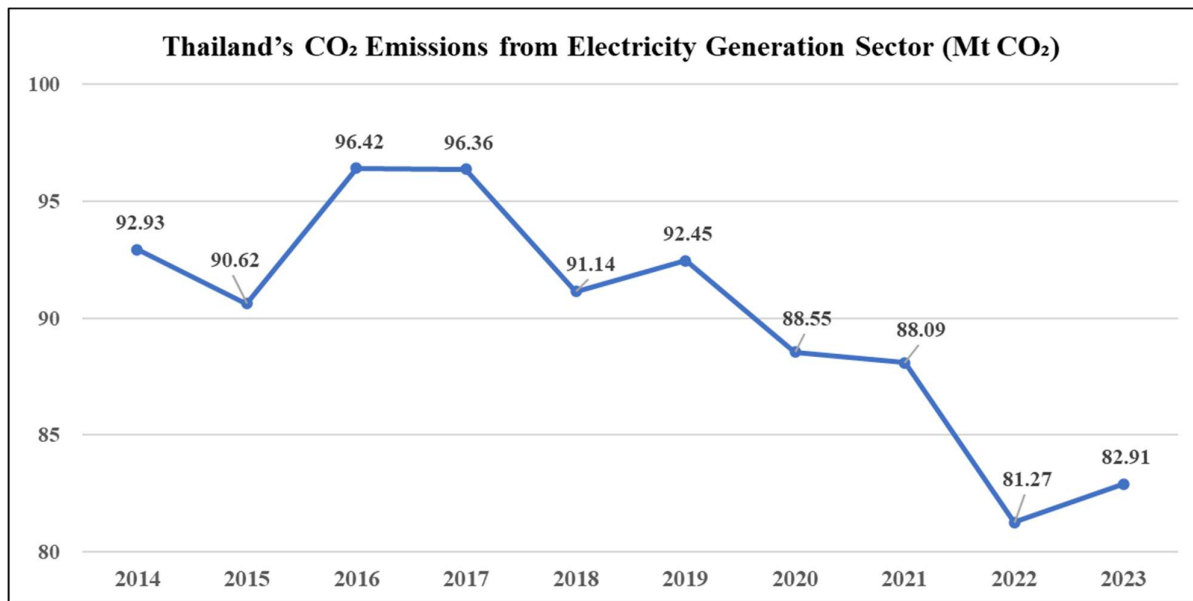


Fig. 3: Thailand's CO<sub>2</sub> Emissions from Electricity Generation Sector (Mt CO<sub>2</sub>).

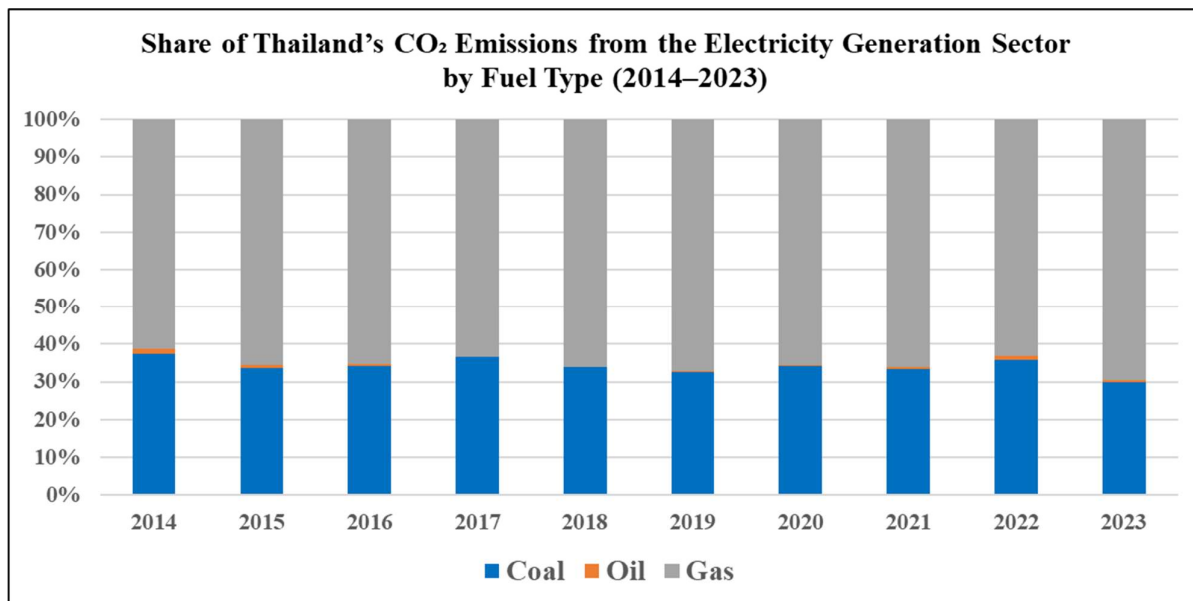


Fig. 4: Share of Thailand's CO<sub>2</sub> Emissions from the Electricity Generation Sector by Fuel Type (2014–2023).

## 4.2 LMDI Decomposition Results and Analysis

### 4.2.1 Historical Decomposition (2014–2023)

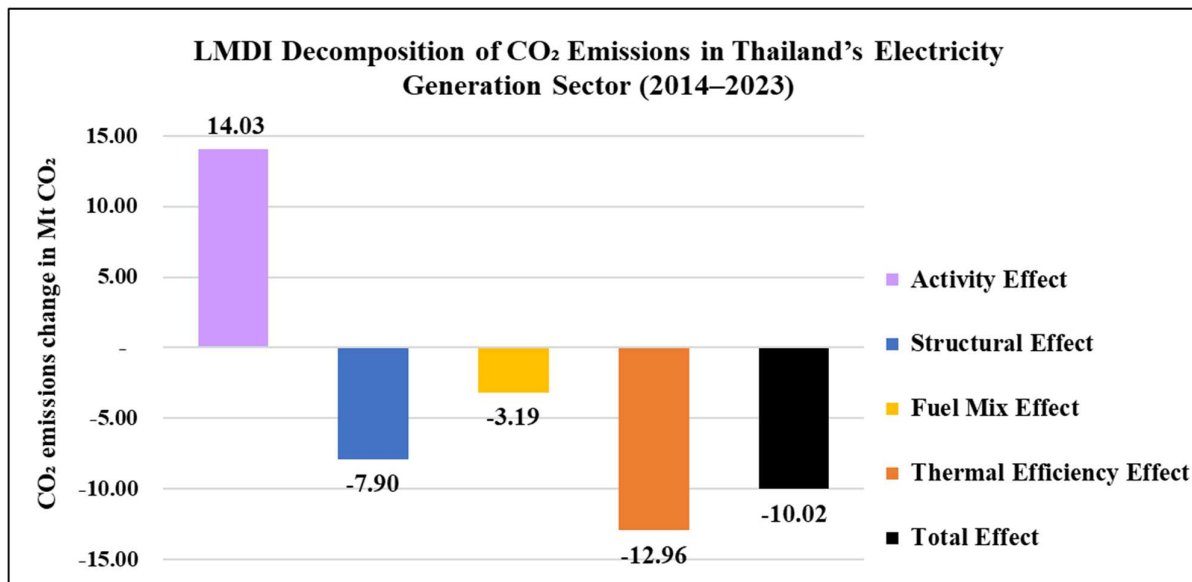
Table 4 and Fig. 5 present the additive LMDI decomposition results for changes in CO<sub>2</sub> emissions from Thailand's electricity generation sector over the period 2014–2023. Over this decade, total CO<sub>2</sub> emissions declined by approximately 10.02 Mt CO<sub>2</sub>, indicating a net reduction despite continued growth in electricity generation.

The decomposition results indicate that this overall decline resulted from the interaction of opposing effects. The activity effect ( $\Delta C_{act}$ ) was the dominant positive driver, contributing a cumulative increase of +14.03 Mt CO<sub>2</sub>. This reflects rising electricity demand associated with economic expansion, population growth, urbanization, and increasing electricity consumption across residential, commercial, and industrial sectors. As electricity generation expanded to meet this growing demand, upward pressure on emissions persisted throughout the study period.

**Table 4:** LMDI Decomposition of CO<sub>2</sub> Emissions Change in Mt CO<sub>2</sub> (2014–2023).

| Period           | $\Delta C_{act}$ | $\Delta C_{str}$ | $\Delta C_{mix}$ | $\Delta C_{eff}$ | $\Delta C_{ef}$ | $\Delta C_{tot}$ |
|------------------|------------------|------------------|------------------|------------------|-----------------|------------------|
| 2014-2015        | 5.00             | 0.41             | -1.93            | -5.78            | -               | -2.31            |
| 2015-2016        | 1.65             | -1.19            | 0.95             | 4.39             | -               | 5.80             |
| 2016-2017        | -1.09            | -2.32            | -0.04            | 3.39             | -               | -0.06            |
| 2017-2018        | 0.93             | -3.49            | 0.47             | -3.12            | -               | -5.21            |
| 2018-2019        | 4.73             | -0.54            | -0.67            | -2.21            | -               | 1.31             |
| 2019-2020        | -5.52            | 0.69             | 0.97             | -0.04            | -               | -3.90            |
| 2020-2021        | 0.52             | -0.82            | -0.05            | -0.11            | -               | -0.46            |
| 2021-2022        | 2.07             | -0.78            | -0.28            | -7.83            | -               | -6.82            |
| 2022-2023        | 5.75             | 0.16             | -2.62            | -1.65            | -               | 1.64             |
| <b>2014–2023</b> | <b>14.03</b>     | <b>-7.90</b>     | <b>-3.19</b>     | <b>-12.96</b>    | <b>-</b>        | <b>-10.02</b>    |

Note: Positive (negative) values indicate emission increases (reductions).  $\Delta C_{tot}$  is decomposed into activity, structural, fuel-mix, efficiency, and emission-factor effects (Mt CO<sub>2</sub>).

**Fig. 5:** LMDI Decomposition of CO<sub>2</sub> Emissions in Thailand's Electricity Generation Sector (2014–2023).

Note: Positive (negative) values indicate emission increases (reductions).  $\Delta C_{tot}$  is decomposed into activity, structural, fuel-mix, efficiency, and emission-factor effects (Mt CO<sub>2</sub>).

In contrast, several factors contributed substantially to emission reductions. The thermal efficiency effect ( $\Delta C_{eff}$ ) was the most significant mitigating factor, reducing emissions by -12.96 Mt CO<sub>2</sub>, indicating improvements in power generation efficiency, particularly within thermal power plants. The structural effect ( $\Delta C_{str}$ ), amounting to -7.90 Mt CO<sub>2</sub>, reflects gradual changes in the composition of the electricity supply system, including a declining share of high-carbon generation technologies and an increasing contribution from lower-carbon and non-fossil electricity sources. In addition,

the fuel-mix effect ( $\Delta C_{mix}$ ) contributed a reduction of -3.19 Mt CO<sub>2</sub>, capturing shifts toward cleaner fossil fuels, such as greater reliance on natural gas relative to coal and oil.

The emission-factor effect ( $\Delta C_{ef}$ ) remained zero throughout the study period, as constant default emission factors from the IPCC Guidelines were applied. Overall, the results suggest that improvements in generation efficiency and structural changes played a key role in mitigating CO<sub>2</sub> emissions, although these gains were partially offset by sustained growth in electricity demand.

#### 4.2.2 Relationship between Decomposition Effects and Key Variables

##### 1) Activity Effect ( $\Delta C_{act}$ )

The activity effect ( $\Delta C_{act}$ ) captures the impact of changes in total electricity generation on CO<sub>2</sub> emissions. Over the period 2014–2023,  $\Delta C_{act}$  was the dominant upward driver of emissions, contributing a cumulative increase of +14.03 Mt CO<sub>2</sub>.

As illustrated in **Fig. 6**,  $\Delta C_{act}$  closely tracks variations in total electricity generation. Periods of increasing electricity output—such as 2014–2015, 2018–2019, and 2022–2023—are associated with positive  $\Delta C_{act}$  values, indicating emission increases driven by expanding electricity demand. In contrast, during the COVID-19 shock in 2019–2020, electricity generation declined sharply, resulting in a negative  $\Delta C_{act}$ .

Overall, this relationship confirms that growth in electricity demand remains a key constraint on emission reduction. Higher levels of electricity generation continue to translate directly into higher CO<sub>2</sub> emissions in a power system that is still dominated by fossil fuels.

##### 2) Structural Effect ( $\Delta C_{str}$ )

The structural effect ( $\Delta C_{str}$ ) captures changes in the composition of electricity generation between fossil-based and non-fossil sources. Over the period 2014–2023,  $\Delta C_{str}$  contributed a cumulative reduction of -7.90 Mt CO<sub>2</sub>, making it one of the most significant drivers of emission mitigation.

As illustrated in **Fig. 7**, a clear inverse relationship is observed between  $\Delta C_{str}$  and the share of fossil-based electricity generation, which declined from 91.82% in 2014 to 84.37% in 2023. Years characterized by larger reductions in the fossil share correspond to more negative  $\Delta C_{str}$  values, indicating that shifts toward non-fossil electricity generation directly reduced CO<sub>2</sub> emissions.

This relationship highlights structural decarbonization—driven by the gradual expansion of renewable energy and imported hydropower—as a central mechanism for emission mitigation in Thailand’s power sector.

##### 3) Fuel Mix Effect ( $\Delta C_{mix}$ )

The fuel mix effect ( $\Delta C_{mix}$ ) reflects changes in the composition of fuels used within thermal electricity generation. Over the study period,  $\Delta C_{mix}$  contributed to a cumulative emission reduction of -3.19 Mt CO<sub>2</sub>.

As shown in **Fig. 8**,  $\Delta C_{mix}$  is negatively associated with the share of coal-fired generation. The decline in coal’s share from 23.6% in 2014 to 18.9% in 2023, together with increased reliance on natural gas, reduced the average emission intensity of thermal power generation. In contrast, temporary increases in coal use—such as during 2015–2016 and 2019–2020—coincide with positive  $\Delta C_{mix}$  values.

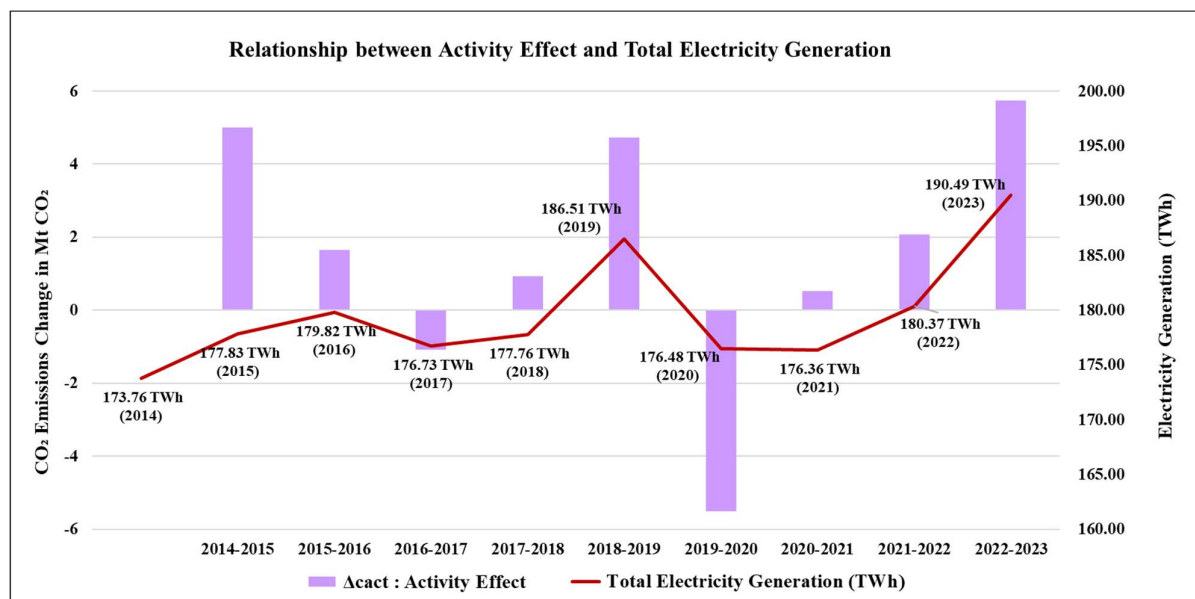


**Fig. 6:** Relationship between Activity Effect and Total Electricity Generation (2014–2023).

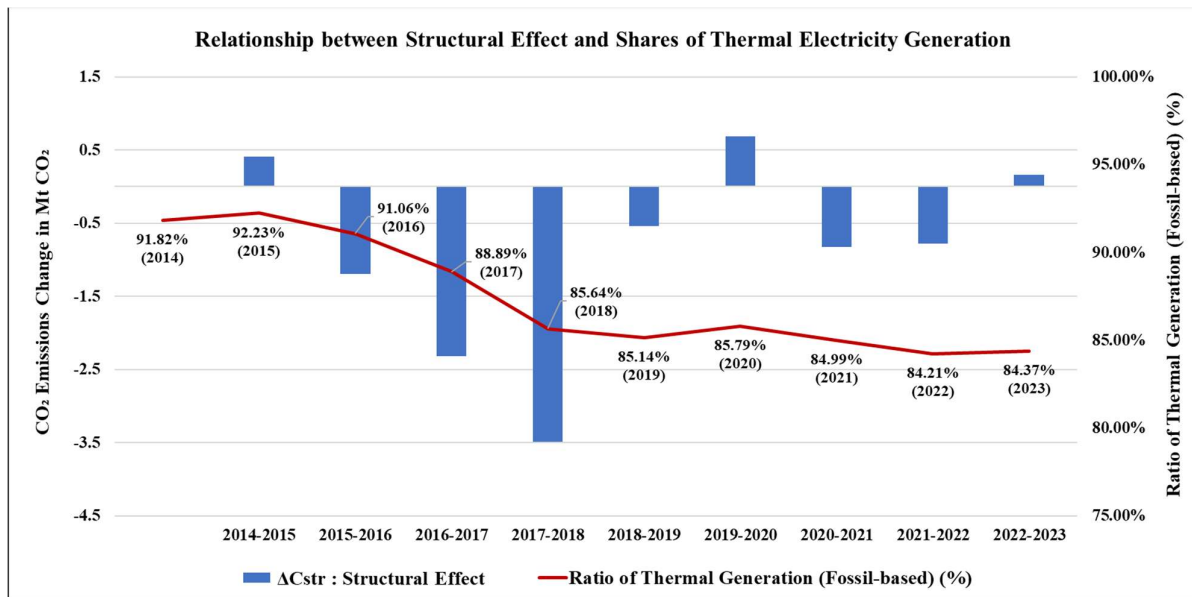


Fig. 7: Relationship between Structural Effect and Shares of Thermal (Fossil-based) Electricity Generation (2014–2023).

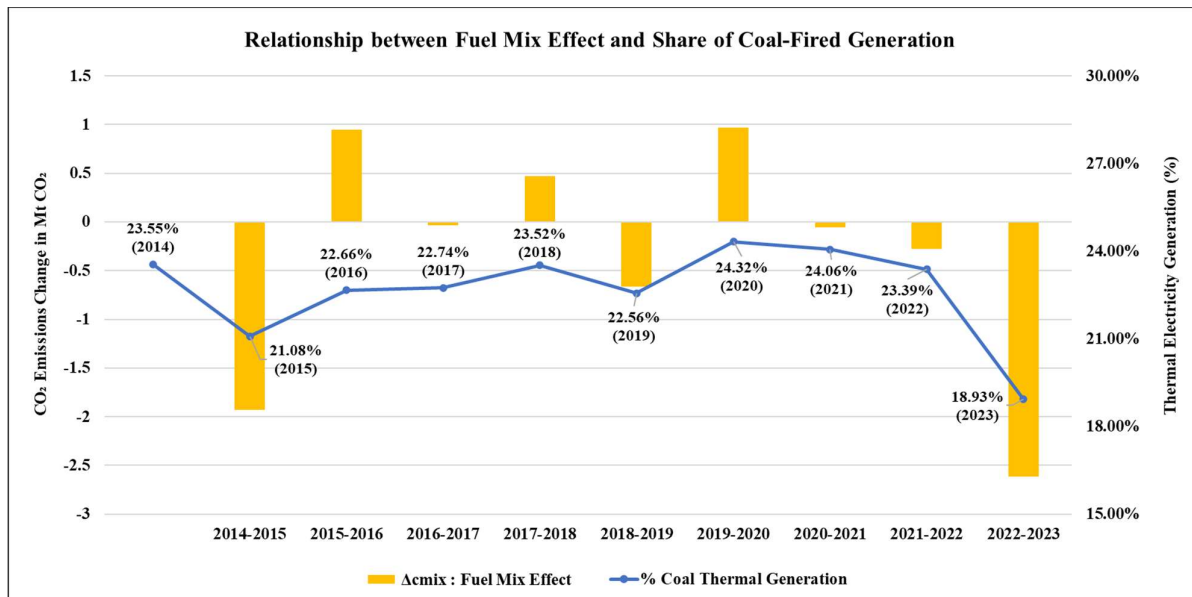


Fig. 8: Relationship between Fuel Mix Effect and Share of Coal-Fired Generation (2014–2023).

Overall, these results indicate that fuel substitution—particularly the shift from coal to natural gas—has played a meaningful, though secondary, role in reducing CO<sub>2</sub> emissions from Thailand's electricity sector.

#### 4) Thermal Efficiency Effect ( $\Delta C_{eff}$ )

The thermal efficiency effect ( $\Delta C_{eff}$ ) reflects changes in fuel-to-electricity conversion efficiency and constitutes the largest emission mitigation driver in Thailand's electricity sector during 2014–2023, contributing a cumulative reduction of -12.96 Mt CO<sub>2</sub>.

As shown in Fig. 9, the temporal pattern of  $\Delta C_{eff}$  closely aligns with changes in fossil fuel generation efficiency. Periods in which the fuel-to-electricity ratio declines—indicating improvements in conversion efficiency—coincide with more negative  $\Delta C_{eff}$  values, reflecting stronger efficiency-driven emission reductions. Conversely, years characterized by higher fuel-to-electricity ratios are associated with weaker or positive  $\Delta C_{eff}$  values. This consistency indicates that variations in fossil fuel generation efficiency are a key determinant of the thermal efficiency effect observed over the study period.

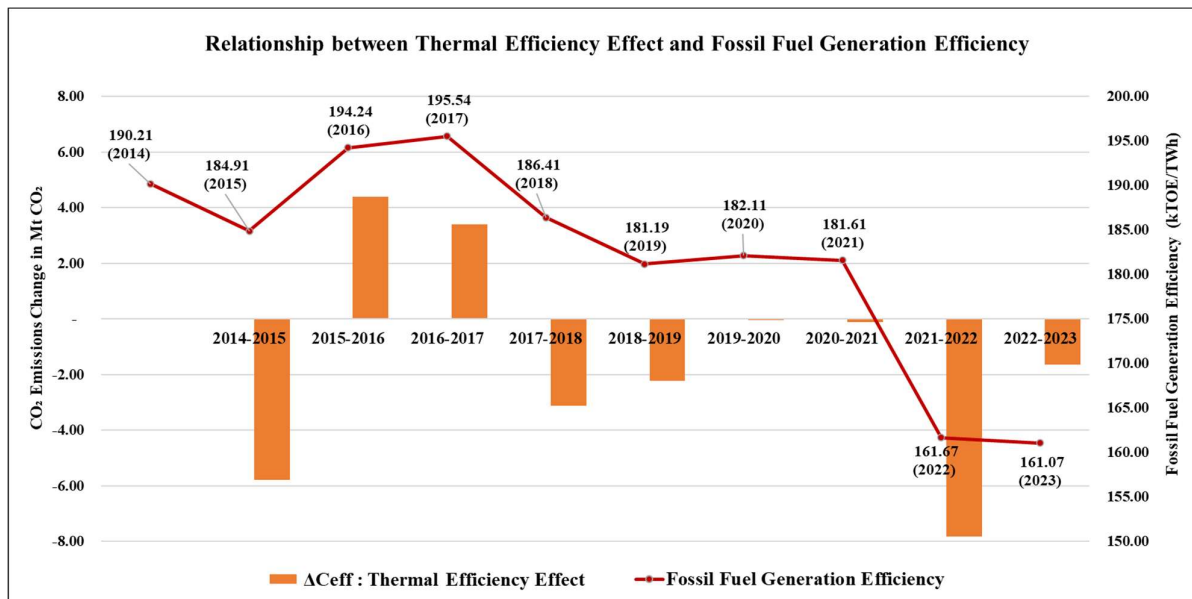


Fig. 9: Relationship between Thermal Efficiency Effect and Fossil Fuel Generation Efficiency (2014–2023).

These results highlight that improvements in fossil fuel generation efficiency play a central role in mitigating CO<sub>2</sub> emissions, while the effectiveness of efficiency gains remains sensitive to fluctuations in electricity demand and system-level dispatch conditions.

Overall, the decomposition results indicate that while electricity demand growth remains the primary upward pressure on emissions, structural decarbonization, fuel substitution, and sustained improvements in power plant efficiency—particularly through the retirement of aging, low-efficiency units and the increased deployment of combined-cycle gas turbine (CCGT) technology—have played critical roles in mitigating CO<sub>2</sub> emissions in Thailand's electricity sector.

#### 4.2.3 Scenario-Based Decomposition Results for the 2030 NDC, 2050 Carbon Neutrality, and 2065 Net-Zero GHG Emission Pathways

This section presents scenario-based decomposition results for possible CO<sub>2</sub> emission pathways in Thailand's electricity generation sector under four mitigation scenarios (Scenarios 1, 1A, 2, and 2A), as defined in Section 3.3.2. The analysis is conducted relative to an electricity-sector Business-as-Usual (BAU) pathway, which serves as the reference baseline for evaluating emission reductions.

The BAU pathway is treated as a policy-consistent reference case and does not represent a mitigation scenario. Instead, it provides a counterfactual emission trajectory against which the effectiveness of NDC-aligned mitigation scenarios is assessed. Accordingly, emission reductions of 30% and 40% are interpreted as percentage reductions relative to the electricity-sector BAU level in the corresponding target years.

The analysis evaluates whether the four mitigation scenarios are consistent with Thailand's 2030 Nationally Determined Contribution (NDC) targets, as well as with the longer-term policy objectives of carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. In addition, the results examine how alternative assumptions regarding electricity demand growth and supply-side transitions may lead to different possible long-term emission pathways.

Using a comparative scenario approach in combination with the Logarithmic Mean Divisia Index (LMDI) decomposition framework, this section identifies the relative contributions of activity, structural, fuel-mix, and thermal efficiency effects in shaping emission outcomes across scenarios.

#### 1) Comparison of CO<sub>2</sub> Emissions Across Scenarios

Table 5 and Fig. 10 compare scenario-based estimated CO<sub>2</sub> emissions for Thailand's

electricity generation sector under the four mitigation scenarios over the period 2020–2065, with 2020 adopted as the base year. Although historical electricity-sector emission data are available through 2023, the year 2020 is selected to ensure consistency with Thailand’s national energy planning framework, particularly the Draft Power Development Plan (PDP 2024–

2037), which reports policy benchmarks at five-year intervals (2020, 2025, 2030, and beyond).

Using 2020 as the base year facilitates direct comparability between historical LMDI decomposition results for the period 2014–2023 and scenario-based analytical pathways aligned with national planning milestones.

**Table 5:** Scenario-Based Estimated CO<sub>2</sub> Emissions under Four Mitigation Scenarios (Mt CO<sub>2</sub>).

| Year   | Scenario 1 | Scenario 1A | Scenario 2 | Scenario 2A | BAU Target | NDC 30 Target | NDC 40 (Unconditional)* Target |
|--------|------------|-------------|------------|-------------|------------|---------------|--------------------------------|
| 2020** | 88.55      | 88.55       | 88.55      | 88.55       | 180.1      | 126.07        | 101.61                         |
| 2025   | 96.47      | 94.76       | 86.65      | 86.54       | 178.8      | 125.16        | 100.93                         |
| 2030   | 79.69      | 67.68       | 68.38      | 67.65       | 120.0      | 84.00         | 67.70                          |
| 2035   | 69.23      | 63.17       | 55.51      | 55.28       | 112.0      | 78.40         | 63.19                          |
| 2040   | 55.06      | 52.66       | 43.37      | 43.37       | 93.9       | 65.80         | 52.98                          |
| 2045   | 40.29      | 38.96       | 32.24      | 32.24       | 84.0       | 58.80         | 47.39                          |
| 2050   | 23.99      | 23.99       | 19.50      | 19.50       | 73.6       | 51.52         | 41.52                          |
| 2065   | -          | -           | -          | -           | -          | -             | -                              |

Note: (1) \*The NDC 40 (Unconditional) represents the 33.3% domestic reduction from the electricity-sector BAU and excludes the 6.7% conditional component dependent on international support.

(2) \*\*The 2020 values reported for Scenarios 1, 1A, 2, and 2A represent historical electricity-sector CO<sub>2</sub> emissions estimated from the author’s LMDI decomposition analysis for the period 2014–2023.

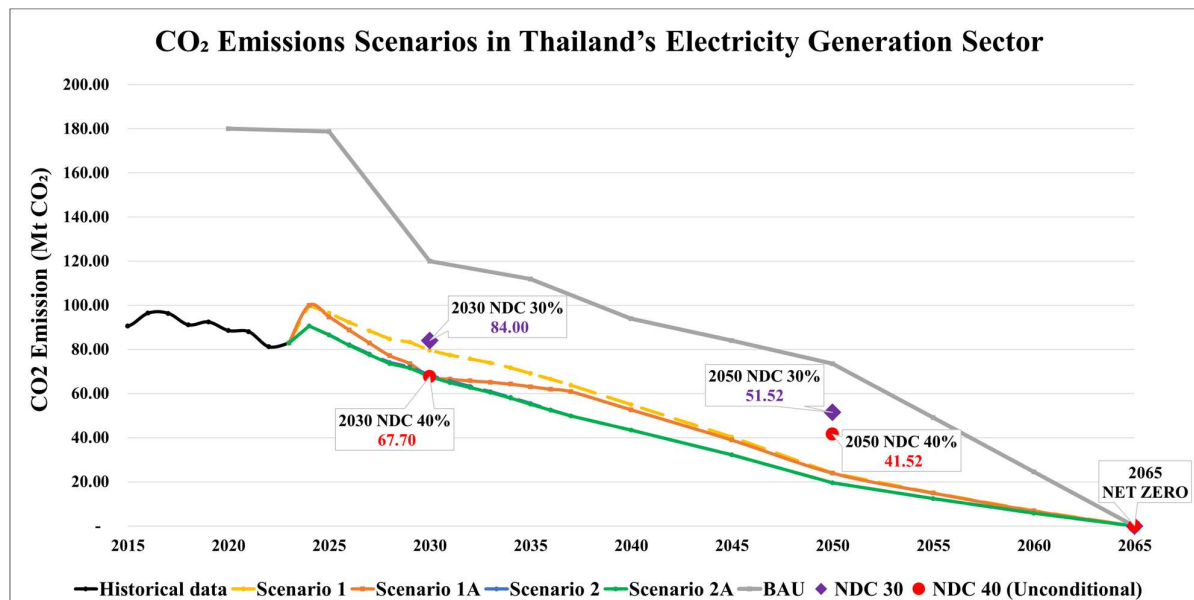


**Fig. 10:** Scenario-Based CO<sub>2</sub> Emission Pathways under Four Mitigation Scenarios in Thailand’s Electricity Generation Sector.

Note: The NDC 40 (Unconditional) represents the 33.3% domestic reduction from the electricity-sector BAU and excludes the 6.7% conditional component dependent on international support.

It should be noted that the 2020 values reported for Scenarios 1, 1A, 2, and 2A represent historical electricity-sector CO<sub>2</sub> emissions estimated from the author's LMDI decomposition analysis. In contrast, the BAU, NDC 30, and NDC 40 (Unconditional) values shown for 2020 are analytical reference levels derived from the constructed electricity-sector BAU pathway and corresponding percentage reduction targets. These values do not represent observed emissions but serve as benchmark levels for scenario comparison.

## 2) LMDI Decomposition Results by Scenario

**Table 6** presents the additive LMDI decomposition of changes in total CO<sub>2</sub> emissions ( $\Delta C$ ) into five contributing effects: activity ( $\Delta C_{act}$ ), structural ( $\Delta C_{str}$ ), fuel-mix ( $\Delta C_{mix}$ ), thermal efficiency ( $\Delta C_{eff}$ ), and emission-factor ( $\Delta C_{ef}$ ) effects across the four mitigation scenarios. All emission changes are interpreted relative to the electricity-sector BAU pathway in order to isolate the net mitigation effects arising from alternative demand and supply-side assumptions.

### ▪ Scenario 1 (PDP-aligned pathway)

Under Scenario 1, CO<sub>2</sub> emissions are estimated under the scenario assumptions to decline from 88.55 Mt CO<sub>2</sub> in 2020 to 23.99 Mt CO<sub>2</sub> by 2050. The activity effect remains positive throughout the projection period, reflecting continued

electricity demand growth under PDP-aligned assumptions. However, increasingly negative structural and fuel-mix effects more than offset this upward pressure. Improvements in thermal efficiency contribute additional reductions, although their marginal impact diminishes toward mid-century.

As illustrated in **Fig. 11**, structural transformation and fuel substitution appear to be the dominant drivers of long-term decarbonization in this policy-consistent pathway.

### ▪ Scenario 1A (Accelerated renewable and coal phase-down)

Under the scenario assumptions, Scenario 1A shows deeper emission reductions through stronger negative structural and fuel-mix effects driven by faster renewable energy expansion and earlier coal retirement. The estimated emission level reaches 67.68 Mt CO<sub>2</sub> by 2030, broadly consistent with the NDC 40 (Unconditional) benchmark defined relative to the electricity-sector BAU.

Although the activity effect remains positive under high-demand conditions, it is fully offset by more aggressive supply-side transformation. As shown in **Fig. 12**, fuel substitution and structural change appear to dominate the emission pathway in this accelerated decarbonization scenario.

**Table 6:** LMDI Decomposition of CO<sub>2</sub> Emissions in Thailand's Electricity Sector Across 4 Mitigation Scenarios (Mt CO<sub>2</sub>).

| Scenarios   | Year      | $\Delta C_{act}$ | $\Delta C_{str}$ | $\Delta C_{mix}$ | $\Delta C_{eff}$ | $\Delta C_{ef}$ | $\Delta C_{tot}$ |
|-------------|-----------|------------------|------------------|------------------|------------------|-----------------|------------------|
| Scenario 1  | 2020–2030 | 31.90            | -24.81           | -2.30            | -13.65           | -               | -8.87            |
|             | 2020–2050 | 31.46            | -62.92           | -17.85           | -15.26           | -               | -64.57           |
|             | 2020–2065 | 2.90             | -58.56           | -31.40           | -1.49            | -               | -88.55           |
| Scenario 1A | 2020–2030 | 29.35            | -29.82           | -6.62            | -13.79           | -               | -20.88           |
|             | 2020–2050 | 31.46            | -62.92           | -17.85           | -15.26           | -               | -64.57           |
|             | 2020–2065 | 2.90             | -58.56           | -31.40           | -1.49            | -               | -88.55           |
| Scenario 2  | 2020–2030 | 17.68            | -23.04           | -2.14            | -12.69           | -               | -20.18           |
|             | 2020–2050 | 21.38            | -57.82           | -18.55           | -14.06           | -               | -69.05           |
|             | 2020–2065 | 2.44             | -58.56           | -30.95           | -1.49            | -               | -88.55           |
| Scenario 2A | 2020–2030 | 17.59            | -23.40           | -2.41            | -12.69           | -               | -20.91           |
|             | 2020–2050 | 21.38            | -57.82           | -18.55           | -14.06           | -               | -69.05           |
|             | 2020–2065 | 2.44             | -58.56           | -30.95           | -1.49            | -               | -88.55           |

Note: Positive values denote emission increases; negative values denote reductions.  $\Delta C_{tot}$  is decomposed into  $\Delta C_{act}$ ,  $\Delta C_{str}$ ,  $\Delta C_{mix}$ ,  $\Delta C_{eff}$ , and  $\Delta C_{ef}$  (Mt CO<sub>2</sub>).

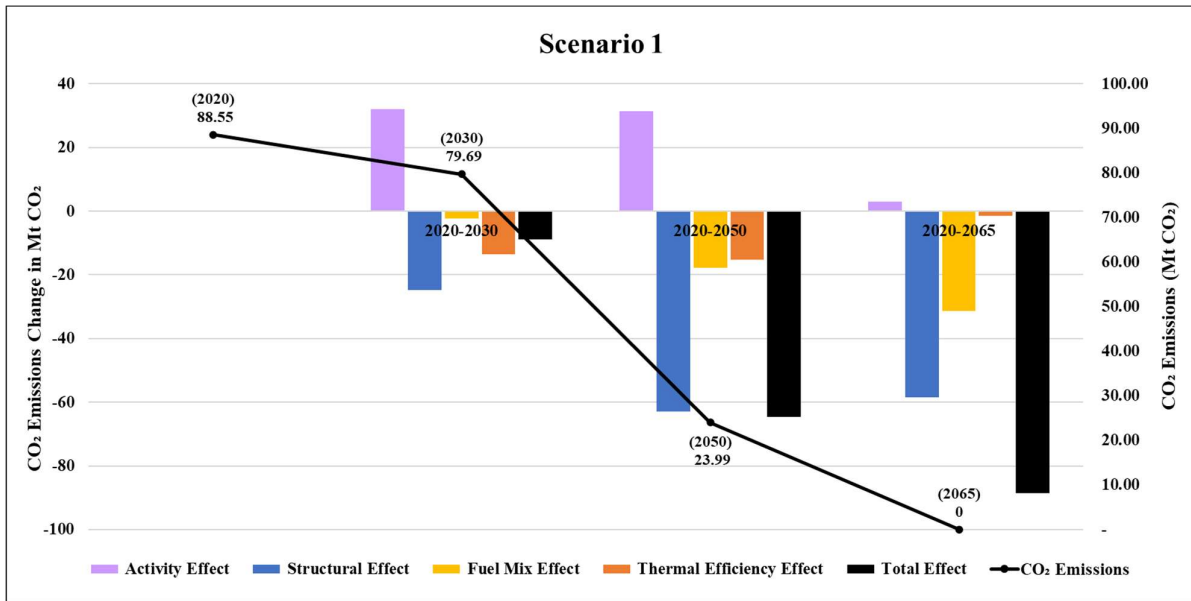


**Fig. 11:** LMDI Decomposition of CO<sub>2</sub> Emissions in Thailand's Electricity Sector under Scenario 1 (PDP-Aligned Pathway), 2020–2065.

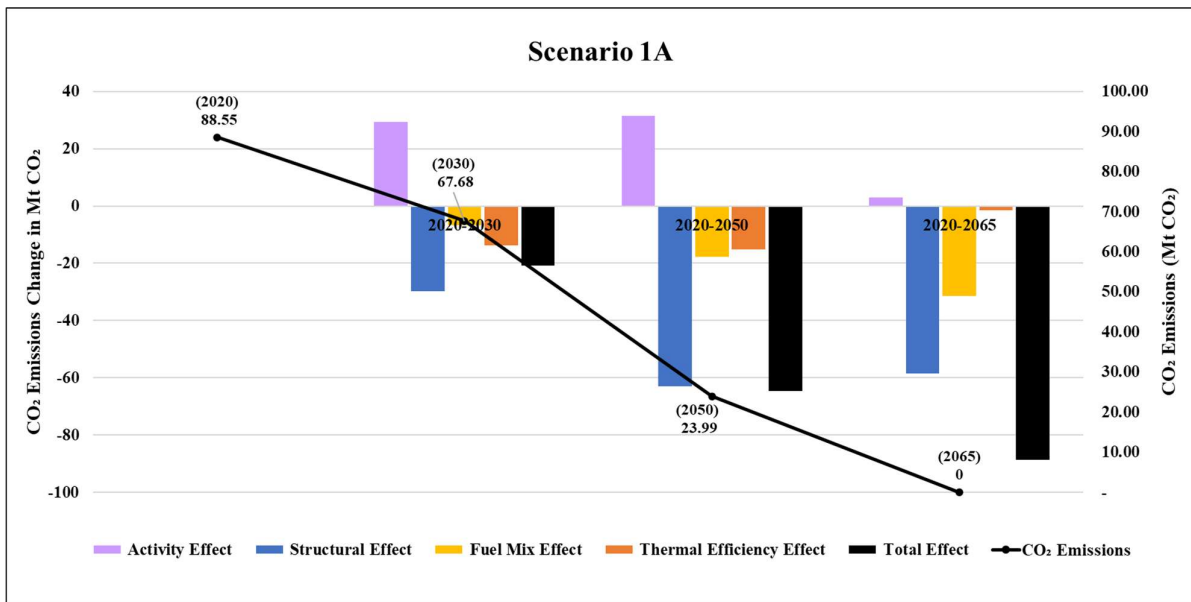


**Fig. 12:** LMDI Decomposition of CO<sub>2</sub> Emissions under Scenario 1A (Accelerated Renewable and Coal Phase-Down Pathway), 2020–2065.

▪ *Scenario 2 (Lower-demand pathway)*

Scenario 2 assumes moderated electricity demand growth, resulting in a smaller positive activity effect compared with Scenario 1. Emissions are estimated under the scenario assumptions to decline to 68.38 Mt CO<sub>2</sub> in 2030 and further to 19.50 Mt CO<sub>2</sub> by 2050.

While structural and efficiency effects remain important drivers of emission reductions, the reduced activity effect lowers upward emission pressure, enabling cumulative mitigation gains to accumulate more rapidly. **Fig. 13** demonstrates that demand moderation may significantly enhance the effectiveness of structural and efficiency improvements.

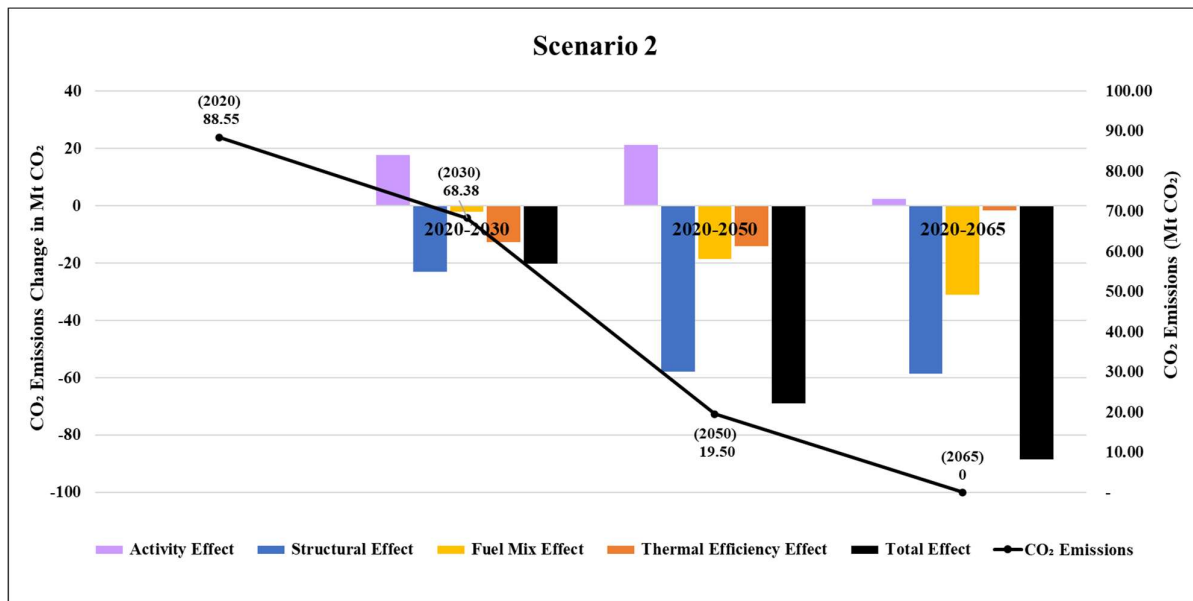


**Fig. 13:** LMDI Decomposition of CO<sub>2</sub> Emissions under Scenario 2 (Lower-Demand Pathway Based on Historical Trend), 2020–2065.

▪ *Scenario 2A (Lower demand with enhanced renewables)*

Scenario 2A combines moderated electricity demand growth with accelerated renewable deployment and faster coal phase-out. Under this integrated pathway, emissions are estimated to decline to 67.65 Mt CO<sub>2</sub> by 2030—which is broadly consistent with the NDC 40 (Unconditional)

benchmark—and continue falling toward near-zero levels by 2065.

Although the activity effect remains positive and comparable to Scenario 2, it is more than offset by strongly negative structural, fuel-mix, and efficiency effects. As illustrated in **Fig. 14**, Scenario 2A shows the deepest and most sustained decarbonization pathway among all scenarios.

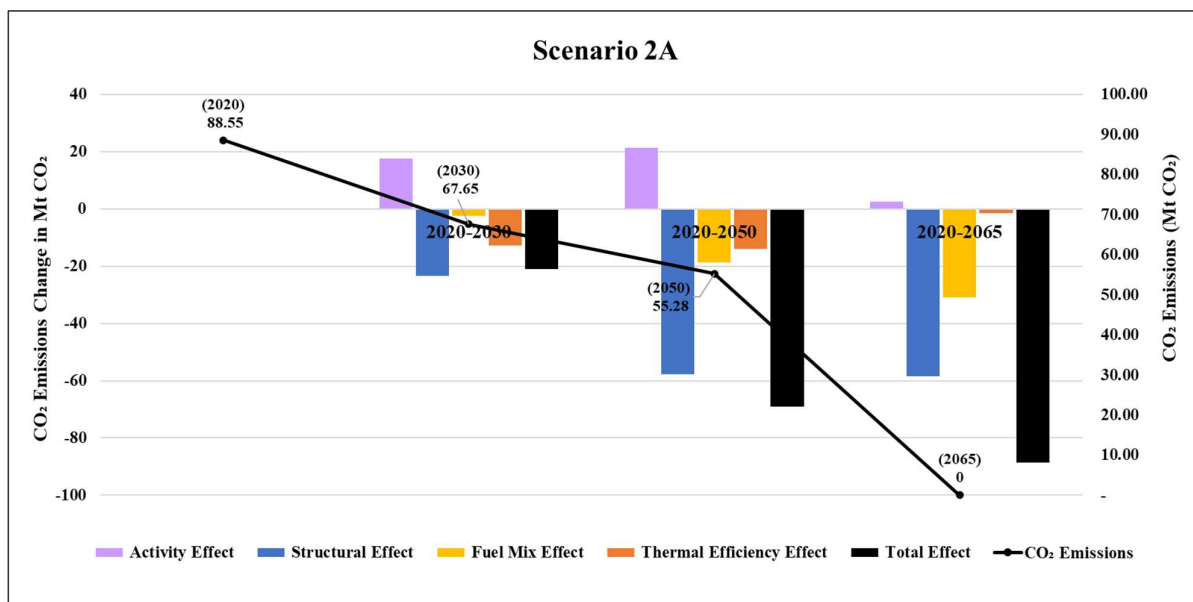


**Fig. 14:** LMDI Decomposition of CO<sub>2</sub> Emissions under Scenario 2A (Lower-Demand Pathway with Enhanced Renewables), 2020–2065.

### Overall Comparative Insights

Across all scenarios, structural transformation and fuel substitution consistently appear to be the primary drivers of long-term emission reductions, while activity growth remains a persistent upward pressure. Scenarios that combine moderated demand growth with accelerated supply-side transition (particularly Scenario 2A) are associated with the most robust and durable decarbonization outcomes.

The decomposition results therefore highlight the importance of aligning demand-side moderation with aggressive structural and fuel-mix transformation if Thailand seeks to align the electricity sector with medium- and long-term climate objectives.

### 4.3 Policy Implications

The combined results from the LMDI decomposition and scenario analysis provide clear guidance for Thailand's power-sector decarbonization strategy. Although structural change, fuel substitution, and efficiency improvements have contributed significantly to emission reductions, electricity demand growth remains the dominant upward driver across all scenarios. Only the enhanced mitigation pathways (Scenarios 1A and 2A), which combine accelerated renewable deployment with earlier coal phase-down, are fully consistent with Thailand's -40% NDC target and long-term net-zero objectives.

#### 1) Managing the activity effect ( $\Delta C_{act}$ )

Mitigating the activity effect requires strengthening nationwide energy-efficiency policies, demand-side management, and reductions in electricity intensity across the industrial, commercial, and residential sectors. Without moderating electricity demand growth, emission reductions achieved through structural transformation may be partially offset.

#### 2) Strengthening the structural effect ( $\Delta C_{str}$ )

Deeper emission reductions from the structural effect depend on accelerating the transition toward a renewable-dominated generation mix. This transition must be supported by grid modernization, energy storage deployment, and regulatory reforms that enhance system flexibility and integration of variable renewable energy.

#### 3) Enhancing the fuel-mix effect ( $\Delta C_{mix}$ )

Further improvements in the fuel-mix effect require decisive coal phase-down and rapid renewable energy expansion, as demonstrated in Scenarios 1A and 2A. These measures are essential for aligning Thailand's power sector with its NDC and Long-Term Low Emission Development Strategy (LT-LEDS) commitments.

#### 4) Sustaining the thermal efficiency effect ( $\Delta C_{eff}$ )

Continued progress in the thermal efficiency effect will depend on upgrading existing thermal power assets and adopting high-efficiency generation technologies. However, the long-term mitigation potential of this effect is expected to decline gradually as fossil-based generation is phased out.

#### 5) Utilizing the Emission Factor Effect ( $\Delta C_{ef}$ )

While the emission-factor effect remained constant in the historical analysis, future emission reductions beyond 2050 would require the deployment of carbon capture, utilization, and storage (CCUS) technologies, as well as the adoption of low-carbon fuels such as hydrogen and ammonia to address residual emissions.

Overall, achieving Thailand's climate targets for 2030, 2050, and 2065 would require coordinated and sustained action across all five decomposition drivers. The results indicate that accelerated renewable energy deployment, combined with effective electricity demand management, represents the most robust and resilient pathway for long-term decarbonization of the power sector.

## 5. Conclusion

### 5.1 Summary and Key Findings

This study applied the Logarithmic Mean Divisia Index (LMDI) method to examine the drivers of CO<sub>2</sub> emissions in Thailand's electricity generation sector during the period 2014–2023 and to evaluate future mitigation pathways aligned with national climate targets.

Three key findings emerge from the analysis.

First, although electricity-sector CO<sub>2</sub> emissions fluctuated over time, total emissions declined overall during 2014–2023. The observed trajectory

reflects periods of demand-driven growth, efficiency-led reduction, and pandemic-related contraction. Natural gas remained the dominant source of emissions, while coal's contribution declined steadily and oil played only a marginal role.

Second, the LMDI decomposition reveals that emission changes resulted from the interaction of opposing forces. Electricity demand growth (the activity effect) was the primary upward driver of emissions, whereas structural transformation, fuel substitution, and—most notably—improvements in thermal efficiency contributed to emission reductions. Overall mitigation during the historical period was therefore achieved through technological upgrading and gradual shifts toward cleaner electricity generation.

Third, the long-term scenario analysis suggests that Thailand's ability to align the electricity sector with national climate targets depends strongly on electricity demand growth and the pace of structural transformation in the power sector. Under the assumptions used in this study, moderate mitigation pathways appear sufficient to align with the -30% NDC benchmark, but they may be insufficient for deeper emission reductions. Accelerated mitigation pathways—characterized by faster renewable energy deployment and earlier coal phase-down—are more consistent with the -40% NDC benchmark and long-term carbon neutrality and net-zero emission objectives. Across all scenarios, structural and fuel-mix effects appear to become increasingly important over time, while the activity effect remains persistently positive.

Taken together, these findings suggest that Thailand's power-sector decarbonization strategy must simultaneously manage electricity demand growth and accelerate structural change toward low-carbon electricity generation.

## 5.2 Limitations

Several limitations of this study should be acknowledged.

First, the analysis relies on aggregated national-level data and fixed IPCC default emission factors, which do not capture plant-level heterogeneity or changes in fuel characteristics over time.

Second, the LMDI approach is deterministic and does not explicitly incorporate uncertainty or sensitivity analysis. As a result, scenario outcomes depend on assumptions derived from the PDP 2024 and the LT-LEDS.

Third, the study focuses exclusively on CO<sub>2</sub> emissions from electricity generation and does not consider other greenhouse gases, co-pollutants, economic costs, or distributional impacts.

Fourth, the scenario analysis does not incorporate detailed power-system dispatch, grid constraints, investment costs, electricity price effects, industrial competitiveness, or market dynamics. Therefore, the scenario results should be interpreted as indicative possible pathways rather than definitive predictions.

Finally, the scenario framework reflects policy assumptions developed prior to the adoption of Thailand's NDC 3.0; subsequent policy updates may alter future emission pathways and mitigation benchmarks.

## 5.3 Further Research

Future research should

- (i) incorporate plant-level and technology-specific data,
- (ii) extend decomposition analysis to other sectors and cross-sectoral interactions,
- (iii) integrate LMDI with energy-system or economy-wide models,
- (iv) update scenario design to reflect evolving NDC commitments and regional energy integration, and
- (v) include electricity price, industrial competitiveness, and economic cost considerations in future scenario assessment.

Such extensions would strengthen the analytical basis for Thailand's long-term energy and climate policy.

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## References

- Ang, B. W. (2004). Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy*, 32(7), 1131–1139.
- Ang, B. W. (2005). The LMDI approach to decomposition analysis: A practical guide. *Energy Policy*, 33(7), 867–871.
- Ang, B. W., Zhang, F. Q., & Choi, K.-H. (1998). Factorizing changes in energy and environmental indicators through decomposition. *Energy*, 23(6), 489–495.
- Chen, C., Inamdar, M. N., & Al-Odaini, A. (2025). Decomposition analysis of carbon emission drivers in Thailand's power sector. *International Journal of Engineering Advances*, 2(3), 1–10.
- Chontanawat, J., Wiboonchutikula, P., & Buddhivanich, A. (2020). An LMDI decomposition analysis of carbon emissions in the Thai manufacturing sector. *Energy Reports*, 6, 705–710.
- Chontanawat, J., Wiboonchutikula, P., & Buddhivanich, A. (2020). Decomposition analysis of the carbon emissions of the manufacturing and industrial sector in Thailand. *Energies*, 13(4), 798.
- Department of Alternative Energy Development and Efficiency. (2024). *Thailand energy balance 2023*. Ministry of Energy, Bangkok.
- Economic Research Institute for ASEAN and East Asia (ERIA). (2021). *Thailand energy outlook*. ERIA, Jakarta.
- Electricity Generating Authority of Thailand (EGAT). (2024). *Annual report 2023*. EGAT, Nonthaburi.
- Ember. (2024). *ASEAN power review 2024*. Ember, London.
- Energy Policy and Planning Office (EPPO). (2024). *Report on carbon dioxide (CO<sub>2</sub>) emissions from energy consumption 2023*. Ministry of Energy, Bangkok.
- Energy Regulatory Commission (ERC). (2023). *Annual report 2022*. ERC, Bangkok.
- Energy Regulatory Commission (ERC). (2024). *Annual report 2023*. ERC, Bangkok.
- Intergovernmental Panel on Climate Change (IPCC). (2006). Chapter 1: Introduction. In *2006 IPCC guidelines for national greenhouse gas inventories (Vol. 2: Energy)*. IGES. Retrieved from [https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2\\_Volume2/V2\\_1\\_Ch1\\_Introduction.pdf](https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf)
- Intergovernmental Panel on Climate Change (IPCC). (2006). Chapter 2: Stationary combustion. In *2006 IPCC guidelines for national greenhouse gas inventories (Vol. 2: Energy)*. IGES. Retrieved from [https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2\\_Volume2/V2\\_2\\_Ch2\\_Stationary\\_Combustion.pdf](https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf)
- International Energy Agency (IEA). (2023). *Thailand's clean electricity transition*. IEA, Paris.
- International Energy Agency (IEA). (2024). *Southeast Asia energy outlook 2024*. IEA, Paris.
- Liu, B., Guan, Y., Shan, Y., Cui, C., & Hubacek, K. (2023). Emission growth and drivers in mainland Southeast Asian countries. *Journal of Environmental Management*, 329, 117034.
- Mai, L., Ran, Q., & Wu, H. (2020). A LMDI decomposition analysis of carbon dioxide emissions from the electric power sector in northwest China. *Natural Resource Modeling*, 33(4), e12284.
- Ministry of Energy, Thailand. (2018). *Alternative energy development plan (AEDP) 2018–2037*. Ministry of Energy, Bangkok.
- Ministry of Energy, Thailand. (2024). *Draft power development plan (PDP) 2024–2037*. Ministry of Energy, Bangkok.
- Ministry of Natural Resources and Environment, Thailand. (2022). *Thailand's second updated nationally determined contribution*. Ministry of Natural Resources and Environment, Bangkok.
- Muangthai, I., Lewis, C., & Lin, S. J. (2014). Decoupling effects and decomposition analysis of CO<sub>2</sub> emissions from Thailand's thermal

- power sector. *Aerosol and Air Quality Research*, 14(7), 1929–1938.
- Office of Natural Resources and Environmental Policy and Planning (ONEP). (2022). *Thailand's fourth biennial update report under the UNFCCC*. ONEP, Bangkok.
- Our World in Data. (2025). *Annual CO<sub>2</sub> emissions by world region. Global Carbon Project*. Retrieved from <https://ourworldindata.org/grapher/annual-co-emissions-by-region>
- Pita, P., Winyuchakrit, P., & Limmeechokchai, B. (2020). Analysis of factors affecting energy consumption and CO<sub>2</sub> emissions in Thailand's road passenger transport. *Heliyon*, 6(10).
- Ritchie, H., Rosado, P., & Roser, M. (2025). *Annual CO<sub>2</sub> emissions by world region. Global Carbon Budget*. Retrieved from <https://ourworldindata.org/grapher/annual-co-emissions-by-region>
- Shrestha, R. M., Anandarajah, G., & Liyanage, M. H. (2009). Factors affecting CO<sub>2</sub> emission from the power sector of selected countries in Asia and the Pacific. *Energy Policy*, 37(6), 2375–2384.
- Thailand. (2022). Thailand's Long-Term Low Greenhouse Gas Emission Development Strategy (Revised version). *United Nations Framework Convention on Climate Change (UNFCCC)*. Retrieved from [https://unfccc.int/sites/default/files/resource/Thailand%20LT-LEDS%20%28Revised%20Version%29\\_08Nov2022.pdf](https://unfccc.int/sites/default/files/resource/Thailand%20LT-LEDS%20%28Revised%20Version%29_08Nov2022.pdf)
- Thailand Greenhouse Gas Management Organization (TGO). (2024). *Investment requirements for power sector decarbonization*. TGO, Bangkok.
- U.S. Environmental Protection Agency (US EPA). (2009). *Stationary combustion technical support document* (Revised February 2, 2009).
- Zhang, C., Zhang, M., & Zhang, N. (2017). CO<sub>2</sub> emissions from the power industry in China's Beijing–Tianjin–Hebei region: Decomposition and policy analysis. *Polish Journal of Environmental Studies*, 26(3).