

Article

Decomposition Analysis of Carbon Emission Drivers in Thailand's Power Sector

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Abstract: This study investigates the driving factors of carbon emissions in Thailand's power sector from 2002 to 2022 using the Logarithmic Mean Divisia Index (LMDI) decomposition method. The objective is to provide a systematic and quantitative assessment of how socioeconomic and technological developments have influenced emission dynamics. The results indicate that total emissions rose from approximately 62 Mt in 2002 to a peak of 90 Mt in 2013, before stabilizing and slightly declining in recent years, reflecting improvements in efficiency and structural transformation. Economic growth was the largest contributor, adding a cumulative 43.83 Mt, followed by population growth (9.52 Mt). In contrast, structural transformation—primarily the gradual substitution of fuel oil with natural gas—reduced emissions by about 21.81 Mt, while enhanced efficiency in coal consumption contributed an additional 20.86 Mt reduction. Electricity intensity exerted a modest positive effect (4.39 Mt), and the influence of the carbon emission factor was minimal (0.61 Mt). The findings suggest that Thailand's power sector has achieved relative decoupling between economic growth and emissions, though absolute decoupling has yet to occur. The analysis underscores the critical importance of accelerating renewable energy deployment and strengthening energy efficiency initiatives to meet Thailand's carbon neutrality target by 2050 and its net-zero emissions goal by 2065. This study fills a gap in the existing literature by providing the first multi-factor decomposition analysis of Thailand's power sector emissions, offering valuable empirical insights and policy implications for sustainable energy transitions in developing economies.

Keywords: carbon emissions; power sector; LMDI; Thailand

1. Introduction

Amid the escalating challenge of global climate change, the power sector—one of the largest sources of carbon emissions, plays a pivotal role in achieving carbon neutrality through green and low-carbon transformation [1]. As a major emerging economy in Southeast Asia, Thailand faces the dual challenge of sustaining economic growth while curbing carbon emissions. The country's rapid economic development has led to a surge in energy consumption and, consequently, electricity demand. Thailand's modern power system remains heavily dependent on fossil fuels: natural gas accounts for approximately 66% of total power generation, coal contributes about 17%, and renewables comprise only around 12%, significantly below the global average [2]. This fossil-fuel-based structure not only heightens dependence on conventional energy investments—primarily in thermal power plants that are major sources of carbon emissions, but also poses a major obstacle to meeting Thailand's national targets of carbon neutrality by 2050 and net-zero emissions by 2065 [3]. Therefore, it is essential to conduct a detailed and systematic examination of the driving factors behind carbon emissions in the power sector to formulate an evidence-based and effective mitigation pathway.

Existing research on Thailand's energy strategy and carbon emissions has largely concentrated on descriptive analyses at the national or macro level, or on the potential of

Received: 30 August 2025

Revised: 07 September 2025

Accepted: 26 September 2025

Published: 10 October 2025



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individual technological pathways [4-6]. While some studies have explored influencing factors, their analyses often remain qualitative or fragmented, lacking quantitative decomposition to disentangle the specific effects of various drivers over time. As a result, the relative contributions of socioeconomic and technological factors to historical emission changes remain unclear. In particular, there is a notable absence of long-term, multi-factor decomposition analyses-using well-established methods such as the Logarithmic Mean Divisia Index (LMDI) to systematically identify and quantify the underlying determinants of carbon emissions in Thailand's power sector. This research gap limits the precision of identifying priority areas for emission mitigation and weakens the foundation for developing scientifically grounded and targeted policy measures.

Accordingly, this study aims to quantitatively assess the driving forces behind carbon emission changes in Thailand's power sector over the past two decades. By incorporating multiple dimensions-demographic, economic, structural, and technological-it examines how GDP growth, population dynamics, electricity intensity, energy structure, and generation efficiency have shaped the evolution of CO₂ emissions. The objectives are threefold: (1) to reveal the historical effects of key socioeconomic and technological factors on emission dynamics; (2) to identify dominant drivers and potential leverage points for emission reduction; and (3) to evaluate the degree of decoupling between power-sector emissions and economic growth. Through a systematic and quantitative analysis based on twenty years of sectoral data, this study provides robust empirical evidence and policy-relevant insights into the mechanisms governing emission dynamics in Thailand's power sector.

2. Literature Review

Within the framework of global climate governance, the power sector-one of the largest sources of carbon emissions-plays a crucial role in achieving national carbon neutrality targets through green and low-carbon transformation [7]. According to studies by the IPCC and the IEA, carbon emissions in the power industry are influenced by multiple factors, including economic development, population growth, energy structure, and technological progress [8,9]. Among these, the expansion of energy consumption driven by economic growth is recognized as the most significant positive contributor to emissions [10]. Conversely, the increasing penetration of renewable energy and improvements in fossil fuel efficiency serve as key mitigating factors [11]. These dynamic interactions have become central to global research on energy and climate policy, forming both the theoretical foundation and analytical framework for country-level investigations into emission drivers.

In analyzing the determinants of carbon emissions, Index Decomposition Analysis (IDA) has emerged as a mainstream methodological approach. Among its techniques, the Logarithmic Mean Divisia Index (LMDI) method-proposed by Ang et al.-has gained widespread adoption due to its technical strengths: perfect decomposition (no residuals), full additivity, and straightforward interpretability of results [12]. The LMDI method enables the quantification of individual influences on carbon emissions from factors beyond economic growth, such as industrial structure, energy intensity, and fuel mix. This methodological precision provides robust data support for evaluating energy and climate policies, making it an indispensable analytical tool in the fields of energy economics and environmental policy [13].

Previous studies on Thailand and other Southeast Asian countries have primarily focused on national or regional energy strategies, industrial development trends, and the technological potential of specific renewable energy sources. Some research has conducted decomposition analyses of carbon emissions in Thailand's manufacturing and industrial sectors [14], and in Indonesia's industrial sector [15]. Although these studies contribute valuable insights into regional energy policies, long-term and systematic quantitative analyses of the driving forces behind carbon emissions in the power sector remain

scarce. Existing research has not sufficiently clarified the relative roles of economic expansion, efficiency improvement, and structural transformation in shaping emission trajectories. Consequently, their findings provide limited guidance for developing targeted low-carbon strategies or deep decarbonization pathways.

To address this research gap, the present study applies the LMDI decomposition method to systematically analyze Thailand's power sector from 2002 to 2022, quantifying the historical contributions of socioeconomic and technological factors to carbon emissions. The novelty of this research lies in constructing the first multi-factor decomposition framework specifically tailored to Thailand's power sector. By identifying the principal driving and mitigating forces, this study not only enriches empirical understanding of emission dynamics but also provides evidence-based recommendations for prioritizing policy measures toward carbon neutrality. Furthermore, its findings offer valuable references for guiding low-carbon transitions in the power sectors of other emerging economies across Southeast Asia.

3. Methodology

3.1. Carbon Emissions in the Electricity Sector

The primary sources of carbon emissions in the electricity sector are thermal power plants, which rely on fossil fuels such as coal, oil, and natural gas, whereas hydropower and other renewable sources are inherently low-carbon or carbon-free [16]. In Thailand, thermal power plants account for approximately 80% of total electricity generation [2]; therefore, this study focuses specifically on emissions originating from these facilities. Carbon emissions are estimated following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, using the standard methodology recommended by the IPCC. The corresponding calculation formula is presented in Equation (1).

$$C = \sum_i C_i = \sum_i (E_i \times SC_i \times EF_i \times O_i \times k) \quad (1)$$

In this equation, C_i denotes the carbon emissions from fuel type i (Mt); E_i represents the consumption of fuel type i (Mt); SC_i is the average lower heating value of fuel type i (kJ/kg); EF_i refers to the carbon content per unit of energy for fuel type i (tC/TJ); and O_i indicates the carbon oxidation rate, representing the proportion of carbon oxidized to CO_2 during combustion. The constant k is defined as the ratio of the molecular weight of CO_2 to that of carbon. Table 1 summarizes the parameters used in the calculation, including the potential carbon content, oxidation rate, and CO_2 emission factor for each fuel type.

Table 1. Fuel parameters and emission factors.

Type	Coal	Diesel Oil	Fuel Oil	Gas
Average lower heating value (kJ/kg or kJ/m ³)	20908	42652	41816	38931
Unit value of carbon content (tC/TJ)	26.4	20.2	21.1	15.3
Carbon oxidation rate(%)	93	98	98	99
Emission factor (kgCO ₂ /kg or kgCO ₂ /m ³)	1.8801	3.0959	3.1705	2.1622

3.2. LMDI Factor Decomposition Method

The Logarithmic Mean Divisia Index (LMDI) model, proposed by Ang, has been widely used for the decomposition of energy consumption and carbon emissions [17]. This approach offers significant advantages, including additive consistency and the elimination of residual terms, thereby enabling a more accurate estimation of the contributions of various driving factors to changes in carbon emissions [18,19]. It has thus become one of the most widely adopted decomposition methods in energy and environmental studies. Based on the Kaya identity and the emission mechanism of Thailand's power sector, carbon emissions can be expressed as shown in Equation (2) below:

$$C = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{EF}{E} \times \frac{F}{EF} \times \frac{C}{F} \quad (2)$$

In this equation, C represents CO₂ emissions from the power sector (Mt); P denotes the population of Thailand (million persons); GDP refers to Thailand's gross domestic product (million USD); E and EF indicate total electricity generation and thermal power generation, respectively (GWh); and F represents the amount of fuel consumed in the power generation process (ktoe). Using the ratios of these variables, carbon emissions can be further decomposed as presented in Equation (3):

$$C = P \times A \times EI \times S \times CE \times EF \quad (3)$$

In this equation, P denotes the population of Thailand (million persons); A represents GDP per capita, reflecting the level of affluence (USD/person); EI refers to electricity generation per unit of GDP, representing electricity intensity (kWh/USD); S indicates the share of thermal power generation in total electricity generation, reflecting the energy structure; CE denotes coal consumption per unit of thermal power generation, representing coal power efficiency (ktoe/GWh); and EF refers to CO₂ emissions per unit of coal consumed in the thermal power sector, also known as the thermal power carbon emission factor (CO₂/kg). This model attributes changes in carbon emissions to six factors: population effect, per capita GDP effect, electricity intensity effect, energy structure effect, coal power efficiency effect, and carbon emission factor effect. By setting the initial year of the study period as 0 and the final year as t, the change in carbon emissions is defined as $\Delta C = C_t - C_0$, as shown in Equation (4).

$$\Delta C_P + \Delta C_A + \Delta C_{EI} + \Delta C_S + \Delta C_{CE} + \Delta C_{EF} \quad (4)$$

Each decomposition term is calculated using the logarithmic mean weight, as shown in Equation (5):

$$\Delta C_x = L(C_t, C_0) \times \ln\left(\frac{X_t}{X_0}\right) = \frac{C_t - C_0}{\ln C_t - \ln C_0} \times \ln\left(\frac{X_t}{X_0}\right) \quad (5)$$

When $C_t = C_0$, Let $L = C_t$. The change of each factor is calculated using the logarithmic function to obtain its growth rate, which is then weighted and averaged into the total change in emissions. Through these formulas, the relative effects of the influencing factors on carbon emissions in the power sector can be derived.

3.3. Data Sources

The data used in this study were primarily obtained from official statistical yearbooks published by the National Statistical Office of Thailand, including the Thailand Statistical Yearbook, Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook, and Thailand Environmental Statistics Yearbook. These sources provide nationwide annual data on electricity production, energy consumption, economic development, and demographic structure. The time series spans 2002 to 2022, a period during which significant transformations occurred in Thailand's energy structure and power sector. This comprehensive dataset enables a systematic analysis of the impacts of various socioeconomic and technological factors on carbon emissions in the power sector. The specific data sources are summarized in Table 2.

Table 2. Main variables and data sources.

Variable Type	Variable Name	Data Description	Data Source
Economic	GDP	Gross Domestic Product	Thailand Statistical Yearbook
Social	Population	Total population	Thailand Statistical Yearbook
Energy Consumption	Coal consumption in power generation	Amount of coal consumed in power generation	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook
	Fuel oil consumption in power generation	Amount of fuel oil consumed in power generation	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook

	Natural gas consumption in power generation	Amount of natural gas consumed in power generation	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook
	Electricity intensity	Electricity generated per unit of GDP	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook
Energy Efficiency	Coal consumption rate	Coal consumed per unit of electricity generation	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook
	Share of thermal power	Share of thermal power generation in total output	Thailand Energy Statistics Yearbook, Thailand Electricity Yearbook

4. Result and Discussion

4.1. Carbon Emissions in the Electricity Sector

Based on the carbon emission accounting formula for the power sector, and using the compiled data on electricity sector energy consumption along with key parameters for various fuel types (see Table 1), this study calculates CO₂ emissions of Thailand's power sector from 2002 to 2022. The energy parameters employed are primarily drawn from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and other authoritative sources. The calculation results are presented in the figures: Figure 1 illustrates the trend of carbon emissions in Thailand's power sector, while Figure 2 shows the relative shares of different energy sources in electricity generation.

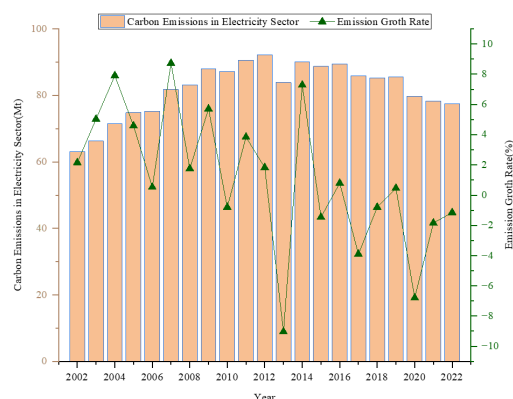


Figure 1. Carbon emission trends of Thailand's power sector, 2002-2022.

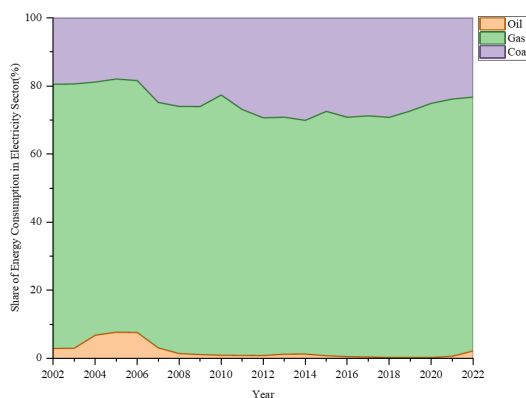


Figure 2. Shares of energy consumption in Thailand's power sector, 2002-2022.

Figure 2 illustrates the changes in the energy consumption pattern of Thailand's power sector between 2002 and 2022. Throughout the period, natural gas consistently dominated the energy mix, contributing approximately 70%-80% of the total supply and serving as the primary fuel for electricity generation [20]. This dominance aligns with the distribution of domestic natural gas reserves and the national power policy's emphasis on supply security. Coal has always played a secondary role, typically accounting for 20%-30% of the mix. While less prevalent than natural gas, coal-fired power has remained a stable and long-term supplementary resource due to its economic and reliable characteristics. However, as a high-carbon energy source, coal is a major target in the transition toward a low-carbon power system [21].

The share of fuel oil was low even in the early 2000s, peaking in 2005, and has since gradually declined, approaching 0% in recent years, in line with the global trend of phasing out oil-fired generation. Despite the decreasing share of fuel oil, the overall power structure remains heavily reliant on fossil fuels-particularly natural gas and coal-resulting in a relatively low share of renewable energy in the electricity mix.

4.2. LMDI Factor Decomposition Results

Using the LMDI model, data on population, GDP, total electricity generation capacity, thermal power generation capacity, coal consumption, and carbon emissions of Thailand's power sector from 1995 to 2022 were employed to decompose the changes in carbon emissions attributable to electricity generation. The results indicate that, over this period, thermal power carbon emissions in Thailand accumulated to 15.68 Mt. The contribution values and rates of the key driving factors to changes in carbon emissions are presented in Tables 3 and 4. In Table 3, the absolute contributions of each driver to thermal power carbon emissions are denoted as ΔCP and ΔCA , while Table 4 reports their corresponding average annual contribution rates, denoted as RP and RA , respectively.

Table 3. Decomposition of contribution to changes in power sector carbon emissions (2002-2022).

Period	ΔCP	ΔCA	ΔCEI	ΔCS	ΔCCE	ΔCEF	ΔC
2001-2002	0.5466	1.4101	1.2198	0.2036	2.2141	-1.5168	4.0775
2002-2003	0.5663	3.1296	0.5924	-0.3534	-1.6682	-0.9373	1.3295
2003-2004	0.5515	3.8808	-0.3997	0.4345	-1.2743	-0.0150	3.1779
2004-2005	0.5611	3.5898	0.9475	0.4487	-0.9420	0.6355	5.2406
2005-2006	0.5690	2.3634	1.1332	-0.1356	-0.4746	-0.1757	3.2797
2006-2007	0.5676	3.0259	0.2671	-1.5601	-2.0813	0.1797	0.3988
2007-2008	0.6009	3.5211	-1.3488	0.4505	1.5353	1.8063	6.5652
2008-2009	0.6148	0.7759	-0.7230	1.9095	-1.2626	0.1165	1.4311
2009-2010	0.6077	-1.2371	0.7085	0.1337	4.5933	-0.0600	4.7462
2010-2011	0.5922	5.7603	2.8688	-1.7641	-6.3748	-1.7857	-0.7034
2011-2012	0.5711	0.1931	-1.1637	-4.1956	5.7543	2.1931	3.3523
2012-2013	0.5967	5.8321	1.7682	0.4490	-8.2656	1.2722	1.6526
2013-2014	0.5329	1.8213	-1.5139	-0.4604	-8.7178	0.0030	-8.3348
2014-2015	0.4735	0.3773	1.4305	-0.3313	3.6912	0.4750	6.1163
2015-2016	0.4205	2.3556	0.1642	-0.4687	-2.2971	-1.4875	-1.3129
2016-2017	0.4045	2.6072	0.3555	-3.5201	0.0419	0.8120	0.7009
2017-2018	0.3593	3.2173	-2.9154	-4.2905	0.3847	-0.2397	-3.4844
2018-2019	0.2772	3.2743	-2.1746	-4.0708	1.8316	0.1752	-0.6871
2019-2020	0.2159	1.6218	1.2897	0.4726	-2.2917	-0.9149	0.3934
2020-2021	0.1969	-5.3068	2.7257	-1.5548	-0.8063	-1.0723	-5.8175
2021-2022	0.1326	1.1319	0.1407	-2.1979	-0.1860	-0.4907	-1.4695
Total	9.5210	43.8328	4.3873	-21.8148	-20.8570	0.6069	15.6762

Table 4. Decomposition of contribution rates to changes in power sector carbon emissions (2002-2022).

Period	RP	RA	REI	RS	RCE	REF
2001-2002	0.1341	0.3458	0.2992	0.0499	0.5430	-0.3720
2002-2003	0.4260	2.3540	0.4456	-0.2658	-1.2548	-0.7050
2003-2004	0.1735	1.2212	-0.1258	0.1367	-0.4010	-0.0047
2004-2005	0.1071	0.6850	0.1808	0.0856	-0.1798	0.1213
2005-2006	0.1735	0.7206	0.3455	-0.0413	-0.1447	-0.0536
2006-2007	1.4233	7.5883	0.6697	-3.9124	-5.2195	0.4506
2007-2008	0.0915	0.5363	-0.2054	0.0686	0.2338	0.2751
2008-2009	0.4296	0.5422	-0.5052	1.3343	-0.8822	0.0814
2009-2010	0.1280	-0.2606	0.1493	0.0282	0.9678	-0.0126
2010-2011	-0.8419	-8.1895	-4.0786	2.5081	9.0632	2.5388
2011-2012	0.1704	0.0576	-0.3471	-1.2516	1.7165	0.6542
2012-2013	0.3611	3.5291	1.0700	0.2717	-5.0016	0.7698
2013-2014	-0.0639	-0.2185	0.1816	0.0552	1.0459	-0.0004
2014-2015	0.0774	0.0617	0.2339	-0.0542	0.6035	0.0777
2015-2016	-0.3203	-1.7942	-0.1251	0.3570	1.7496	1.1330
2016-2017	0.5772	3.7197	0.5072	-5.0222	0.0597	1.1584
2017-2018	-0.1031	-0.9234	0.8367	1.2314	-0.1104	0.0688
2018-2019	-0.4034	-4.7653	3.1649	5.9245	-2.6656	-0.2550
2019-2020	0.5489	4.1228	3.2785	1.2013	-5.8257	-2.3258
2020-2021	-0.0338	0.9122	-0.4685	0.2673	0.1386	0.1843
2021-2022	-0.0903	-0.7702	-0.0957	1.4957	0.1266	0.3340
Average	0.1290	0.3341	0.2310	0.2745	-0.1763	0.2076

From 2002 to 2022, the population effect (Δ CP and RP) contributed directly to the growth of carbon emissions in Thailand's power sector, although its impact was relatively small compared to that of economic growth. Over the entire study period, population growth added approximately 9.52 Mt to emissions, with an average annual contribution rate of 0.13, indicating that it represents a cumulative and long-term factor. In most years, population growth was positive, peaking at 1.42 in 2006-2007 and 0.43 in 2008-2009, exerting a significant influence on electricity demand and associated emissions. Conversely, in years such as 2010-2011, the population effect was negative (-0.84), reflecting slow population growth and the dominance of economic expansion in driving energy demand.

During this period, Thailand's population increased from approximately 62 million to 71 million, accompanied by rising electricity demand from residential, commercial, and public sectors. Although declining birth rates and an aging population suggest that demographic impacts on emissions may gradually diminish, factors such as urbanization, increased household electrification, and the widespread adoption of air conditioning may partially offset this decline. Overall, population dynamics constitute an important, though not sole, determinant of long-term carbon emissions in the power sector.

Between 2002 and 2022, the per capita GDP effect (Δ CA and RA) was a major driver of carbon emission growth in Thailand's power sector, contributing approximately 43.83 Mt, with an average annual contribution rate of 0.33, substantially higher than other factors. This underscores the critical role of economic development-particularly rising living standards and consumer purchasing power-in stimulating electricity demand and, consequently, carbon emissions. During this period, Thailand's per capita GDP increased from roughly USD 2,000 to nearly USD 7,000, driving a surge in electricity consumption through widespread household appliance use, expansion of commercial services, and growing industrialization. The influence of per capita GDP was particularly pronounced in 2006-2007 and 2010-2011, contributing 7.59 Mt and 5.76 Mt respectively, during periods

of rapid economic growth. Conversely, in 2009-2010, emissions were slightly reduced (-1.24 Mt) due to the economic recession triggered by the global financial crisis.

The power intensity effect (ΔCEI and REI) contributed 4.39 Mt to carbon emissions over the study period, with an average annual rate of 0.23. Power intensity measures electricity consumption per unit of GDP, and the positive sign indicates that economic growth continued to drive higher electricity demand without significant decoupling. Although Thailand undertook some industrial optimization, rapid industrialization, urbanization, infrastructure development, and widespread household electrification-particularly the increased use of air conditioning-sustained rising electricity demand per unit of economic output. This suggests that while energy efficiency measures were implemented, they were insufficient to offset overall consumption growth. Future mitigation of the power intensity effect will require extensive energy-saving measures, industrial efficiency improvements, demand-side management, and low-carbon restructuring of the power generation mix.

The energy structure effect (ΔCS and RS) had a net negative impact on carbon emissions, reducing them by approximately -21.81 Mt from 2002 to 2022. However, the mean annual contribution rate of 0.27 indicates that in some years, structural changes still positively contributed to emissions. Thailand's power generation has long been dominated by natural gas (60%-70%) and coal (~20%). The shift toward natural gas helped reduce emission intensity due to its lower carbon content, whereas continued coal use offset much of this benefit. The progressive phase-out of fuel oil also contributed positively to emissions reduction. Despite some growth in renewable energy, its share remained below 15% by 2022, well under the global average. Overall, changes in the energy structure had a moderate effect on emissions reduction, but the fossil-fuel-dominated pattern persists, highlighting the need for faster adoption of green energy to achieve larger cuts.

The coal consumption rate effect (ΔCCE and RCE) significantly constrained carbon emissions, contributing approximately -20.86 Mt, with an average annual rate of -0.18. Efficiency improvements in coal-fired units, operational optimization, and the phase-out of inefficient plants helped prevent further increases in emissions. Nevertheless, coal's share in the generation mix remained around 20%, and growing electricity demand slowed the decline in emissions rather than reversing the trend. Moving forward, deploying high-efficiency clean coal technologies and increasing the share of renewables will be essential to further reduce emissions.

Finally, the carbon emission factor effect (ΔCEF and REF) had a minor positive impact, contributing 0.61 Mt over the study period, with an average annual rate of 0.21. This indicates that fuel emission factors remained relatively consistent, contributing little to variations in carbon emissions. Minor fluctuations observed in certain years may be attributed to changes in fuel quality or imported coal shares. Given Thailand's continued reliance on natural gas and coal, the carbon emission factor effect plays a relatively small role among the determinants of power sector emissions.

5. Conclusion

This study employs the LMDI decomposition method to conduct an in-depth analysis of the driving factors of carbon emissions in Thailand's power sector from 2002 to 2022. By quantifying six major effects-population scale, economic development, power intensity, energy structure, coal consumption efficiency, and emission factors-the following conclusions are drawn:

Thailand's power sector has not yet achieved absolute decoupling between carbon emissions and economic growth; however, signs of relative decoupling are evident. Total carbon emissions increased from approximately 62 Mt in 2002 to a peak of 90 Mt in 2013, after which they entered a fluctuating plateau, never surpassing the earlier peak by 2022. This indicates that although economic development (per capita GDP cumulative contribution: 43.83 Mt) and population growth (9.52 Mt) strongly drove emissions, improvements in energy efficiency and structural transformation moderated the absolute growth.

Economic growth remains the dominant factor in rising carbon emissions, with the per capita GDP effect contributing most significantly to the cumulative increase over the study period. Rapid industrialization, rising living standards, and expanding electricity demand were the primary drivers behind the growth in emissions.

At the same time, advancements in energy efficiency and structural transformation played an important role in restraining emissions growth, although these measures have not fully offset the pressures from economic expansion. In particular, improvements in coal consumption efficiency (-20.86 Mt) reflect technological upgrades and operational optimization, while structural changes-phasing out fuel oil and increasing the share of natural gas (-21.81 Mt)-actively contributed to emissions reduction. Nevertheless, the overall energy mix remains heavily fossil-fuel-based, with renewables contributing only ~12% in 2022, highlighting the limited progress in structural decarbonization.

The carbon emission factor effect had a minimal impact (0.61 Mt), indicating that the carbon content of fossil fuels used for power generation remained largely stable and did not drive significant changes in emissions. Therefore, future mitigation efforts should prioritize the substitution of fossil fuels with zero-carbon energy resources rather than improvements in the quality of currently used fuels.

6. Policy Implications

The decomposition results of this study indicate that carbon emissions in Thailand's power sector are shaped by the interplay of economic growth, efficiency-driven suppression, and a slow structural transition. To achieve its 2050 carbon neutrality target, Thailand must adopt a more ambitious and systematic policy framework. Based on the empirical analysis, the following recommendations are proposed:

Accelerate renewable energy deployment and transform the energy mix. Power market reforms should be implemented, including competitive bidding mechanisms and long-term power purchase agreements. Significant expansion of distributed solar PV should be supported through net metering policies, accompanied by rapid investment in smart grids and energy storage systems to enhance grid flexibility and facilitate a systematic transition toward low-carbon electricity.

Strengthen energy efficiency management to curb power-sector emissions. Mandatory efficiency standards and labeling systems should be enforced for industrial and residential equipment, while demand-side management programs should be expanded to optimize load profiles and reduce peak-time electricity reliance. Additionally, fiscal incentives and tax benefits can support industrial energy retrofits, effectively lowering carbon intensity from the consumption side.

Introduce carbon pricing mechanisms to internalize the external costs of energy use. Establishing a national Emissions Trading Scheme (ETS) or implementing a carbon tax would embed the cost of carbon emissions into market operations. Such price signals can guide power producers toward low-carbon technologies, encourage energy-saving behavior among consumers, and sustain momentum for renewable energy development.

Enhance regional grid interconnection to optimize clean energy utilization. Strengthening cross-border grid infrastructure with neighboring countries, such as Laos and Malaysia, would allow Thailand to import abundant low-carbon hydropower, providing a cost-effective and environmentally friendly solution to meeting domestic electricity demand.

Acknowledgments: Thank you to all parties who contributed to the preparation of this research.

Author Contributions: Chen Chen conducted the research, performed the data analysis, and drafted the manuscript. Mohammad Nizamuddin Inamdar provided supervision, contributed to the conceptual framework, and revised the manuscript. Aiman Al-Odaini assisted with methodology design, literature review, and editing. All authors reviewed and approved the final version of the manuscript.

Funding: This research received no external funding.

Reference

1. B. Doda, and S. Fankhauser, "Climate policy and power producers: The distribution of pain and gain," *Energy Policy*, vol. 138, p. 111205, 2020. doi: 10.1016/j.enpol.2019.111205
2. P. Saosee, B. Sajjakulnukit, and S. H. Gheewala, "Environmental externalities of wood pellets from fast-growing and para-rubber trees for sustainable energy production: A case in Thailand," *Energy Conversion and Management: X*, vol. 14, p. 100183, 2022. doi: 10.1016/j.ecmx.2022.100183
3. G. Sahin, G. Isik, and W. G. J. H. M. van Sark, "Predictive modeling of PV solar power plant efficiency considering weather conditions: A comparative analysis of artificial neural networks and multiple linear regression," *Energy Reports*, vol. 10, pp. 2837–2849, 2023.
4. P. Sonaard, N. Ketjoy, and Y. Mensin, "Market strategy options to implement Thailand demand response program policy," *Energy policy*, vol. 173, p. 113388, 2023. doi: 10.1016/j.enpol.2022.113388
5. V. N. Xuan, N. T. P. Thu, and P. X. Hoa, "Carbon dioxide emissions, population, foreign direct investment, and renewable energy nexus: new insights from Thailand," *Energy Reports*, vol. 11, pp. 4812–4823, 2024. doi: 10.1016/j.egyr.2024.04.045
6. Y. Hu, B. Li, and M. Ahmad, "Green trading and ecological sustainability under macroeconomic policy framework," *Geoscience Frontiers*, vol. 15, no. 3, p. 101776, 2024. doi: 10.1016/j.gsf.2023.101776
7. S. Lin, J. Lin, R. Jing, X. Ye, H. Han, Y. Bian, and Q. You, "Energy, environmental, economic, and social assessment of photovoltaic potential on expressway slopes: A case in Fujian Province, China," *Energy Reports*, vol. 12, pp. 4374–4389, 2024. doi: 10.1016/j.egyr.2024.09.066
8. X. Wu, C. Xu, T. Ma, J. Xu, and C. Zhang, "Carbon emission of China's power industry: driving factors and emission reduction path," *Environmental Science and Pollution Research*, vol. 29, no. 52, pp. 78345–78360, 2022. doi: 10.1007/s11356-022-21297-5
9. H. Liu, A. Anwar, A. Razzaq, and L. Yang, "The key role of renewable energy consumption, technological innovation and institutional quality in formulating the SDG policies for emerging economies: evidence from quantile regression," *Energy Reports*, vol. 8, pp. 11810–11824, 2022. doi: 10.1016/j.egyr.2022.08.231
10. C. Ye, Y. H. Zheng, X. L. Han, and S. J. Chen, "Can increased economic complexity and reduced carbon emissions of the logistics industry go hand in hand? Evidence from countries along the Belt and Road," *Advances in Climate Change Research*, vol. 14, no. 5, pp. 789–797, 2023.
11. T. Sultana, M. S. Hossain, L. C. Voumik, and A. Raihan, "Does globalization escalate the carbon emissions? Empirical evidence from selected next-11 countries," *Energy Reports*, vol. 10, pp. 86–98, 2023. doi: 10.1016/j.egyr.2023.06.020
12. M. Peyvandi, A. Hajinezhad, and S. F. Moosavian, "Investigating the intensity of GHG emissions from electricity production in Iran using renewable sources," *Results in Engineering*, vol. 17, p. 100819, 2023. doi: 10.1016/j.rineng.2022.100819
13. J. D. Rivera-Niquepa, D. Rojas-Lozano, P. M. De Oliveira-De Jesus, and J. M. Yusta, "Methodology for selecting assessment periods of Logarithmic Mean Divisia Index decomposition techniques," *Energy Strategy Reviews*, vol. 50, p. 101241, 2023. doi: 10.1016/j.esr.2023.101241
14. J. Chontanawat, P. Wiboonchutikula, and A. Buddhivanich, "An LMDI decomposition analysis of carbon emissions in the Thai manufacturing sector," *Energy Reports*, vol. 6, pp. 705–710, 2020. doi: 10.1016/j.egyr.2019.09.053
15. A. Hidayatno, A. R. Destyanto, and S. T. Noor, "Conceptualizing carbon emissions from energy utilization in Indonesia's industrial sector," *Energy Procedia*, vol. 156, pp. 139–143, 2019. doi: 10.1016/j.egypro.2018.11.118
16. H. P. Jagtap, A. K. Bewoor, R. Kumar, M. H. Ahmadi, M. E. H. Assad, and M. Sharifpur, "RAM analysis and availability optimization of thermal power plant water circulation system using PSO," *Energy reports*, vol. 7, pp. 1133–1153, 2021.
17. B. W. Ang, "LMDI decomposition approach: A guide for implementation," *Energy Policy*, vol. 86, pp. 233–238, 2015.
18. Y. Liu, Y. Jiang, H. Liu, B. Li, and J. Yuan, "Driving factors of carbon emissions in China's municipalities: a LMDI approach," *Environmental Science and Pollution Research*, vol. 29, no. 15, pp. 21789–21802, 2022. doi: 10.1007/s11356-021-17277-w
19. S. Li, Q. Xu, J. Liu, L. Shen, and J. Chen, "Experience learning from low-carbon pilot provinces in China: Pathways towards carbon neutrality," *Energy Strategy Reviews*, vol. 42, p. 100888, 2022. doi: 10.1016/j.esr.2022.100888
20. P. Wolfram, P. Kyle, J. Fuhrman, P. O'Rourke, and H. McJeon, "The hydrogen economy can reduce costs of climate change mitigation by up to 22%," *One Earth*, vol. 7, no. 5, pp. 885–895, 2024.
21. W. Shen, J. Qiu, and Z. Dong, "Electricity network planning targeting Low-Carbon energy transition," *Global Energy Interconnection*, vol. 1, no. 4, pp. 487–499, 2018.

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