Evolution of Carbon Emissions and GDP Decoupling in Vietnam's Electricity Sector

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Abstract. This study examines the key drivers of carbon emissions in Vietnam's electricity sector from 2002 to 2022 and investigates the evolving decoupling dynamics between economic growth and emissions. Employing the IPCC (2006) emission factor methodology for emissions estimation and the Tapio decoupling model to evaluate GDP-emissions elasticity, the analysis reveals a dramatic rise in emissions over the period, accelerating post-2010 amid 8-10% annual electricity demand growth. Coal's share in power generation escalated from 18% in 2005 to about 50% in 2020, fueling multiple-fold emission increases. The decoupling trajectory unfolds in three phases: expansive negative decoupling dominated 2001-2010, signaling carbon-intensive development; intermittent strong decoupling appeared in 2011-2015 despite coal's persistence; and sustained strong decoupling emerged in 2019-2022, driven by renewable energy surges and efficiency gains. These insights emphasize Vietnam's coal dependency while underscoring renewables' role in decoupling sustainability. Policy recommendations advocate expedited clean energy adoption, power mix restructuring, and reduced coal reliance to meet climate goals.

Keywords: *Carbon Emissions; Power Sector; Decoupling Analysis; Vietnam*

1. Introduction

In the context of global climate change and the ongoing energy transition, the power sector, one of the largest sources of carbon emissions [1], occupies a central position in the pursuit of carbon neutrality. Identifying the driving forces behind emissions in this sector is therefore vital for the design of effective mitigation strategies. This challenge is particularly pronounced in rapidly growing Southeast Asian economies, where surging electricity demand coupled with carbon-intensive energy structures has made the region a hotspot of global emission growth. Vietnam offers a representative example: its electricity demand has expanded at an average annual rate of 8–10%, while the share of coal-fired power has surged from 18% in 2005 to nearly 50% in 2020, leading to a several-fold increase in carbon emissions over the past two decades. A comprehensive investigation into the emission-driving mechanisms of power sectors in such economies is thus of pressing and practical importance.

Most existing research has concentrated on major emitters such as China and the United States or on mature European economies [2,3], while giving limited attention to emerging Southeast Asian countries that are experiencing profound energy system transformations. Studies focusing on Vietnam and similar economies are generally restricted to either factor decomposition or decoupling analyses in isolation, without establishing a comprehensive framework that links emission drivers to the dynamic interplay between economic growth and carbon emissions. This leaves a critical gap in the literature, underscoring the need for research that not only provides country-specific case studies of Southeast Asia but also integrates methodological approaches to yield a more holistic understanding.

This study aims to systematically identify the key drivers of carbon emissions in Vietnam's power sector during the period 2002–2022 and to clarify the dynamic decoupling relationship between economic growth and carbon emissions. Vietnam is chosen as a representative case given its status as one of the fastest-growing economies in Southeast Asia, characterized by rapidly rising energy demand and a pronounced dependence on coal-fired generation. Against this backdrop, the research addresses two central questions: (1) What factors have predominantly contributed to the increase in power-sector emissions, and which factors have served to constrain them? (2) How has the decoupling relationship between economic growth and power-sector emissions evolved over time, and what underlying policy and technological drivers have influenced this process?

This study establishes an integrated analytical framework that combines carbon emission decomposition with decoupling theory. Carbon emissions are calculated using the emission factor method recommended by the IPCC (2006) [4,5], ensuring methodological rigor and international comparability. To complement this, the Tapio decoupling model is applied to examine the elasticity relationship between economic growth and carbon emissions [6]. The combined use of these approaches not only enables precise quantification of the contributions of key driving factors but also provides a dynamic assessment of the consistency between emission reduction policies and growth trajectories. In doing so, the framework offers targeted policy insights for Vietnam and other emerging economies undergoing rapid energy transitions.

2. Literature Review

Accurate estimation of carbon emissions and the analysis of their decoupling from economic growth represent core themes in energy economics and climate change research [7]. For emission accounting, the emission factor method developed by the IPCC has become the internationally recognized standard. This methodology establishes a calculation framework based on key parameters such as fuel consumption, calorific value, carbon content, and oxidation rate, thereby providing a scientific foundation for the compilation of national emission inventories [8]. In recent years, measurement accuracy has been further enhanced through the incorporation of localized parameters and the use of higher-frequency data.

Within decoupling analysis, the elasticity model proposed by Tapio (2005) has gained wide application for its capacity to distinguish among eight distinct decoupling states [9]. Moving beyond a simple binary classification, this model provides a more refined characterization of the dynamic interplay between economic growth and carbon emissions. A substantial body of research based on this framework has shown that developed economies generally achieve strong decoupling through energy structure optimization and technological innovation, whereas developing economies are more frequently associated with phases of expansive negative decoupling [10-12]. These insights have become an important reference for understanding the diverse decoupling patterns that emerge across different stages of economic development.

However, notable research gaps remain. On the one hand, studies focusing on emerging Southeast Asian economies, particularly Vietnam, are relatively scarce. These countries are undergoing rapid economic growth and surging energy demand, with coal-dominated energy structures that render carbon emission challenges especially acute [13]. On the other hand, existing research often treats carbon emission accounting and decoupling analysis as separate strands, failing to fully utilize precise emission data to uncover the driving mechanisms behind decoupling states. This separation limits the policy relevance and practical value of research findings.

This study focuses on Vietnam as a typical emerging economy in Southeast Asia by adopting internationally recognized IPCC calculation methods and the Tapio decoupling model. It not only fills a gap in regional research but also, through methodological integration and innovation, provides new evidence for understanding the complex relationship between economic growth and carbon emissions in rapidly industrializing countries. The research findings will offer a scientific basis for formulating precise carbon emission reduction policies in Southeast Asia and hold significant practical guidance for promoting regional green transition.

3. Methodology

3.1 Carbon Emissions in the Power Sector

In Vietnam, the power sector's primary sources of carbon emissions are thermal power plants that rely on coal, oil, and natural gas [14]. Over the past two decades, Vietnam has witnessed a rapid expansion of coal-fired power generation, making thermal power plants the dominant contributor to national electricity supply and a key driver of energy-related carbon emissions. Given that thermal generation accounts for the majority of Vietnam's electricity output, this study places particular emphasis on the estimation of emissions from thermal power plants. The assessment of carbon emissions is conducted in line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, ensuring methodological consistency and comparability with international studies [15]. Specifically, the calculation of carbon emissions follows the IPCC recommended formula.

$$C=\sum_{i} M_i \times EF_i=\sum_{i} M_i \times SC_i \times O_i \times k$$

In this equation, C refers to the total CO_2 emissions caused by electricity generation in year t; $i = 1, 2, 3$ represent coal, natural gas, and oil, and M_i represents the standardized quantity of the i-th fossil fuel utilized. EF_i represents the emission factor of the i-th fuel. SC_i represents the carbon content per unit of calorific value of the i-th fossil fuel, while O_i denotes its oxidation rate. The constant k is defined as the ratio of the molecular weight of CO_2 to carbon. Table 1 presents the potential carbon content, oxidation rates, and CO_2 emission factors.

Table 1. Fuel parameters and emission factors.

Type	Coal	Diesel Oil	Fuel Oil	Gas
Average lower heating value (kJ/kg or kJ/m3)	20908	42652	41816	38931
Unit value of carbon content (SC_i)	26.4	20.2	21.1	15.3
Carbon oxidation rate (%)	93	98	98	99
Emission factor ($kgCO_2$/kg or $kgCO_2$/m3)	1.8801	3.0959	3.1705	2.1622

3.2 Tapio Decoupling Elasticity Index

The concept of decoupling is widely used in energy economics because it measures the dynamic correlations between energy consumption and economic development. In order to analyze the connection between power sector development and pollution in Vietnam, we find an elastic relation between power sector carbon emissions and power sector output based on Tapio's decoupling model [16,17]. The formula is as follows. Here, represents the decoupling effect of CO_2 emissions from the Gross Domestic Product (GDP) in Vietnam.

$$\alpha=\frac{\%\Delta C}{\%\Delta G}=(\frac{\Delta C}{\Delta C_0})/(\frac{\Delta G}{\Delta G_0})=\frac{C^t/C^0-1}{G^t/G^0-1}$$

Here, α represents the decoupling effect of CO_2 emissions from the Gross Domestic Product (GDP) in Vietnam. %ΔC and %ΔG represent the percentage change in CO_2 emissions and the percentage change of GDP. ΔC and %ΔG represent the CO_2 emissions and GDP in the year t. According to the previous research, Tapio's decoupling model divides the calculation results into 8 categories (Table 2). Among them, strong decoupling is the best state, which indicates that the carbon emission of the power sector decreases when the GDP increases, while strong negative decoupling is the most unfavorable state, which shows that there is an increase in the carbon emission when the GDP decreases, and it is a kind of crude and ineffective way of economic development.

Table 2 Decoupling Classification Standards between Carbon Emissions and Electricity Generation

Decoupling Classification Standards		ΔG	ΔC	α
Decoupling	Weak decoupling	> 0	> 0	0<α < 0.8
	Strong decoupling	> 0	< 0	α < 0
	Recessive decoupling	< 0	< 0	α > 1.2
Negative decoupling	Expansive negative decoupling	> 0	> 0	α > 1.2
	Strong negative decoupling	< 0	> 0	α < 0
	Weak negative decoupling	< 0	< 0	0 < α < 0.8
Coupling	Expansive coupling	> 0	> 0	0.8 < α < 1.2
	Recessive coupling	< 0	< 0	0.8 < α < 1.2

3.3 Data Sources

The data used in this paper were derived from several official statistics and authoritative sources related to the Vietnamese power sector. Electricity production and consumption data were derived from the Vietnam Energy Statistics Handbook of the Energy Commission. Energy balance tables and records covering the period 2002-2022 were obtained from Vietnam's energy balance tables and records from 2002 to 2022. Carbon emissions coefficients were computed according to guidelines published by the Intergovernmental Panel on Climate Change (IPCC). For computational accuracy, fossil fuel consumption data were compared with the Compendium of Environment Statistics published by Statistics Vietnam, and socioeconomic indicators such as GDP were obtained from the World Bank and Statistics Vietnam. The combination of these multidimensional data provided a consistent basis for decomposition analysis.

4. Discussion

4.1 Carbon Emissions in the Power Sector

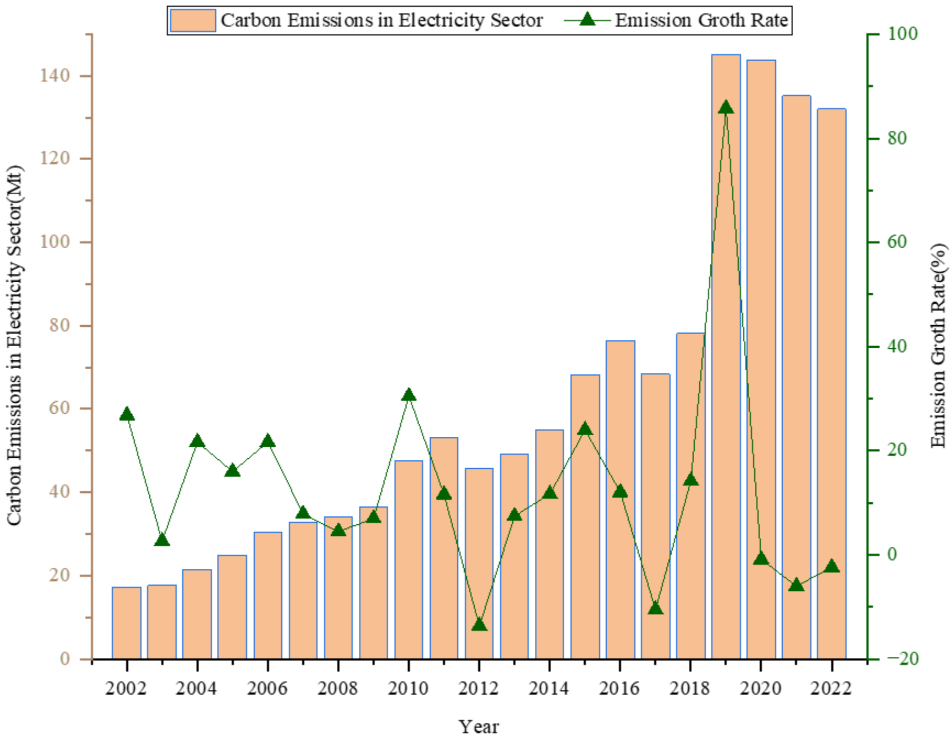

Figure 1. Carbon emission trends of Vietnam’s power sector, 2002–2022

Figure 1 presents the evolution of carbon emissions and their growth rate in Vietnam’s electricity sector during 2002–2022. Over the past two decades, carbon emissions followed a persistent upward trajectory, with a noticeable acceleration after 2010 and a pronounced peak between 2016 and 2019. This pattern is closely linked to Vietnam’s rapid economic expansion and rising electricity demand, which, according to the International Energy Agency (IEA) and the World Bank, increased at an average annual rate of 8–10% over the same period. The rapid deployment of coal-fired power plants was the primary driver of this surge. For example, the share of coal-based generation rose from approximately 18% in 2005 to nearly 50% in 2020, which aligns well with the sharp escalation in emissions observed in the figure. The growth rate of emissions reveals more dynamic variations. Prior to 2010, emission growth was relatively high yet unstable, reflecting structural adjustments in Vietnam's generation mix as well as fluctuations in demand. After 2010, several sharp spikes in growth occurred, corresponding to the commissioning of large coal-fired units, which triggered sudden jumps in carbon output. By contrast, in the period 2020–2022, the growth rate of emissions declined markedly, even approaching zero. This reversal can be explained by two major factors: first, the COVID-19 pandemic temporarily dampened electricity demand and slowed industrial activity; second, Vietnam intensified efforts to diversify its energy mix by accelerating renewable energy development. Data from the Ministry of Industry and Trade indicate that solar and wind capacity expanded rapidly between 2020 and 2021, with their combined share rising from less than 1% in 2019 to around 13% in 2021. This expansion significantly moderated the growth of carbon emissions despite the continued presence of coal in the power system.

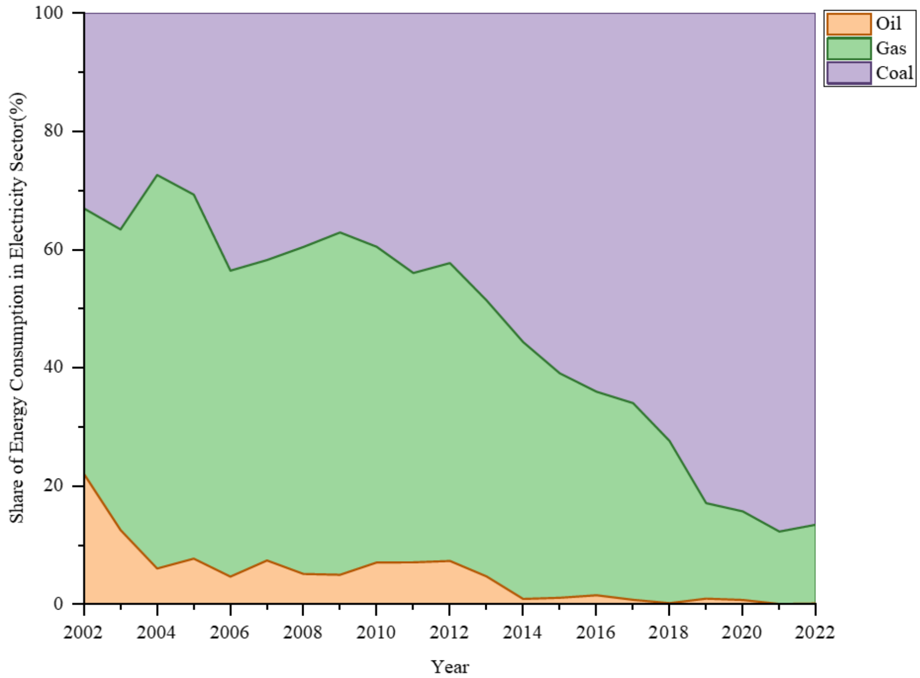

Figure 2. Shares of energy consumption in Vietnam's power sector, 2002–2022

Figure 2 illustrates the changes in the share of different energy sources in the electricity sector's primary energy consumption in Vietnam from 2002 to 2022. Overall, coal has consistently held a dominant position, while natural gas accounted for a significant proportion in the early years but has declined rapidly in recent years, and oil has contributed only marginally. Specifically, in 2002 natural gas represented nearly 50% of energy consumption in the power sector, making it one of the most important energy sources at the time. However, with the large-scale expansion of coal-fired power plants, the share of natural gas began to decline steadily from 2010 onward, falling to less than 10% by 2020. This trend reflects Vietnam's heavy reliance on coal in its energy strategy. According to data from the International Energy Agency (IEA), Vietnam's coal consumption grew at an average annual rate of more than 11% between 2010 and 2020, with coal-fired power capacity increasing from about 4 GW in 2005 to nearly 20 GW by 2020. As a result, the share of coal in the figure surged after 2010, exceeding 80% by 2019 and becoming the absolute backbone of the electricity sector. In contrast, oil maintained a consistently low share (below 5%) throughout the period and almost completely disappeared from the electricity mix after 2015. This indicates that Vietnam has gradually phased out oil-fired generation, which is costly, highly polluting, and less efficient.

Synthesizing the insights from Figures 1 and 2, it becomes evident that carbon emission growth in Vietnam's power sector is closely intertwined with its evolving energy structure. The rapid expansion of coal-fired power plants has satisfied the country's surging electricity demand but simultaneously triggered a substantial increase in emissions. Meanwhile, the declining contribution of natural gas and the near elimination of oil-based generation have further entrenched coal's dominance in the energy mix. Although renewable energy deployment has accelerated in recent years, its share remains insufficient to fundamentally shift the overall trajectory. These findings highlight that, in order to achieve its emission reduction and energy transition objectives, Vietnam must significantly accelerate the adoption of clean energy technologies, restructure its power mix, and reduce its heavy reliance on coal.

4.2 Tapio decoupling results

Figures 3 and Table 3 reveal the dynamic relationship between economic growth and CO_2 emissions in Vietnam's power sector from 2001 to 2022. By examining the rate of change in carbon emissions (%ΔC), GDP growth rate (%ΔG), the elasticity coefficient (α), and the corresponding decoupling states, this period can be divided into three distinct stages.

The first stage (2001 to 2010) was characterized predominantly by expansive negative decoupling. During this period, economic growth was frequently accompanied by disproportionately high increases in CO_2 emissions. For instance, between 2001 and 2002, GDP grew by 6.3%, while carbon emissions surged by 26.8%, yielding an elasticity coefficient of 4.25. A similar trend occurred in 2009-2010, when the elasticity coefficient climbed to 4.75. These results highlight the rapid expansion of coal-fired power generation, where emissions increased much faster than economic output, underscoring Vietnam's heavy reliance on carbon-intensive energy. Exceptions did exist: in 2002–2003 and 2007–2008, the sector experienced weak decoupling, as CO_2 emissions grew more slowly than GDP; while in 2006–2007, the outcome was expansive coupling, with emissions and GDP growing almost in tandem.

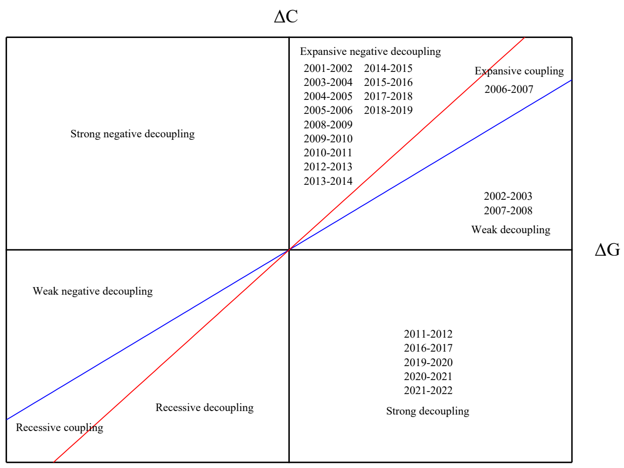

Figure 3. Results of the GDP elasticity of CO_2 emission

Table 3. The decoupling between CO_2 emissions and GDP

Period	%ΔC	%ΔG	α	Decoupling state
2001-2002	0.2683	0.0632	4.2458	Expansive negative decoupling
2002-2003	0.0262	0.0690	0.3795	Weak decoupling
2003-2004	0.2166	0.0754	2.8736	Expansive negative decoupling
2004-2005	0.1600	0.0755	2.1205	Expansive negative decoupling
2005-2006	0.2165	0.0698	3.1021	Expansive negative decoupling
2006-2007	0.0787	0.0713	1.1034	Expansive coupling
2007-2008	0.0445	0.0566	0.7852	Weak decoupling
2008-2009	0.0698	0.0540	1.2940	Expansive negative decoupling
2009-2010	0.3050	0.0642	4.7483	Expansive negative decoupling
2010-2011	0.1160	0.0641	1.8088	Expansive negative decoupling
2011-2012	-0.1366	0.0550	-2.4811	Strong decoupling
2012-2013	0.0744	0.0555	1.3392	Expansive negative decoupling
2013-2014	0.1168	0.0642	1.8192	Expansive negative decoupling
2014-2015	0.2398	0.0699	3.4322	Expansive negative decoupling
2015-2016	0.1204	0.0669	1.7992	Expansive negative decoupling
2016-2017	-0.1053	0.0694	-1.5173	Strong decoupling
2017-2018	0.1420	0.0746	1.9020	Expansive negative decoupling
2018-2019	0.8575	0.0736	11.6524	Expansive negative decoupling
2019-2020	-0.0085	0.0287	-0.2966	Strong decoupling
2020-2021	-0.0601	0.0255	-2.3552	Strong decoupling
2021-2022	-0.0234	0.0812	-0.2885	Strong decoupling

The second stage (2011 to 2015) remained dominated by expansive negative decoupling, though some fluctuations emerged. Notably, in 2011–2012, GDP grew by 5.5% while CO_2 emissions declined by 13.7%, resulting in an elasticity coefficient of –2.48 and indicating strong decoupling. This suggests that structural adjustments in the power sector or shifts in electricity demand may have temporarily reduced emissions. However, this improvement was short-lived, as subsequent years reverted to expansive negative decoupling, reflecting the continued dominance of coal in the sector.

The third stage (2016 to present) marked a turning point. In 2016-2017, strong decoupling reappeared, with GDP growth accompanied by a decline in emissions, likely driven by the accelerated deployment of renewable energy. Yet in 2018–2019, the sector experienced an extreme case of expansive negative decoupling: CO_2 emissions skyrocketed by 85.8%, while GDP increased by only 7.4%, yielding an elasticity coefficient as high as 11.65. This outcome reflected the large-scale commissioning of new coal-fired power plants. After 2019, however, the decoupling trend improved markedly. From 2019 to 2020, GDP expanded by 2.9% while emissions fell by 0.9%; in 2020-2021, GDP grew modestly while emissions dropped by 6.0%; and in 2021-2022, GDP surged by 8.1% while emissions still declined by 2.3%. All of these instances represent strong decoupling, largely attributable to two factors: first, reduced electricity demand during the COVID-19 pandemic, and second, the rapid expansion of renewable energy, particularly solar and wind power.

Overall, Vietnam's decoupling trajectory can be divided into three phases: from 2001 to 2010, economic growth was highly dependent on carbon-intensive development; between 2011 and 2015, occasional strong decoupling occurred but coal remained dominant; and since 2016, instances of strong decoupling have become increasingly frequent, particularly during 2019-2022. This indicates that despite the continued rise in electricity demand, improvements in energy efficiency, the expansion of renewables, and structural transformations in the power system are gradually reducing carbon intensity.

These findings carry important policy implications. Vietnam's experience demonstrates that sustained strong decoupling is achievable, but it requires consistent policy support and large-scale investment in low-carbon technologies. The extreme negative decoupling of 2018-2019 also serves as a warning against overreliance on coal-fired power. To achieve long-term emission reductions while maintaining economic growth, Vietnam must accelerate its clean energy transition, optimize the energy mix, and ensure that future power development aligns with its climate commitments under the Paris Agreement.

5. Conclusion

This study conducts an in-depth analysis of the driving factors behind carbon emissions in Vietnam's power sector from 2002 to 2022, and employs the Tapio decoupling model to examine the dynamic relationship between carbon emissions and economic growth. The main conclusions are as follows:

Primarily, carbon emissions in Vietnam’s power sector have shown a significant upward trend over the past two decades, primarily driven by the surge in electricity demand resulting from rapid economic growth and the swift expansion of coal-fired power infrastructure to meet that demand. Energy structure analysis indicates that coal has shifted from a supplementary fuel to the absolute dominant source, accounting for more than 80%, which directly explains the sharp increase in emissions.

Furthermore, the Tapio decoupling analysis reveals the evolving relationship between economic growth and power sector emissions. In the early period (2001–2010), the sector was dominated by “expansive negative decoupling,” indicating that economic growth relied heavily on carbon-intensive energy. Although a brief episode of “strong decoupling” emerged in the middle period (2011–2015), the dominance of coal remained unshaken. It was not until the recent period (2019–2022) that “strong decoupling” became sustained and stable, suggesting that the rapid deployment of renewables (particularly solar and wind), improvements in energy efficiency, and external shocks such as the COVID-19 pandemic collectively helped to weaken the traditional link between carbon emissions and economic growth.

Overall, Vietnam’s power sector is now at a critical turning point in its low-carbon transition. While coal is likely to remain a cornerstone of the energy system in the short term, the recent emergence of sustained strong decoupling demonstrates that it is feasible to curb emission growth while maintaining economic expansion. However, consolidating and accelerating this positive momentum will require robust policy support. The future trajectory will ultimately depend on Vietnam’s ability to continuously optimize its energy mix, reduce dependence on fossil fuels, and pursue a steadfast transition toward clean energy.

6. Policy Implications

The findings of this study yield important policy implications for Vietnam’s low-carbon transition in the power sector. To simultaneously achieve its climate commitments and ensure energy security, policymakers should prioritize the following measures:

The energy structure must be decisively optimized by accelerating the transition away from coal. Strict implementation of the Power Development Plan is essential, particularly the provisions restricting new coal capacity and gradually shifting coal-fired plants from baseload to peaking roles. In parallel, mechanisms for the early retirement of coal facilities should be established, coupled with the large-scale deployment of renewable energy to safeguard system reliability.

Market mechanisms and policy incentives need to be reinforced. The adoption of carbon pricing instruments, such as a carbon tax or emissions trading scheme, would internalize the environmental costs of coal and enhance the economic competitiveness of renewables. Complementary reforms to the renewable energy auction system and distributed generation policies should be advanced to attract private investment, while grid modernization must be accelerated to overcome integration bottlenecks.

Energy efficiency and demand-side management should be elevated as strategic priorities. Mandatory efficiency standards for industrial, commercial, and residential sectors, combined with the adoption of advanced energy-saving technologies, can significantly reduce demand pressures. Demand response initiatives, leveraging dynamic pricing signals, should be implemented to promote peak shaving and load shifting, thereby curbing emissions growth at the source.

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