Journal of Environmental Protection, 2025, 16(6), 541-552
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Decomposition and Decoupling Analysis of Carbon Dioxide Emissions in Vietnam's Agricultural Sector in the Period 2005-2021

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How to cite this paper: Linh, B.K., Song, N.V. and Huyen, V.N. (2025) Decomposition and Decoupling Analysis of Carbon Dioxide Emissions in Vietnam's Agricultural Sector in the Period 2005-2021. *Journal of Environmental Protection*, **16**, 541-552.
https://doi.org/10.4236/jep.2025.166028

Received: April 25, 2025
Accepted: June 10, 2025
Published: June 13, 2025

Abstract

The study examined the CO_2 emission fluctuations of Vietnam's agricultural sector from 2005 to 2021. By decoupling between carbon emissions and economic growth, the study shows that Vietnam's agricultural sector experiences four decoupling states: strong decoupling, weak decoupling, expansive negative decoupling, and expansive coupling. Typically, strong decoupling occurred in the period 2009-2014, and 2019-2020, which are considered the best decoupling states where continued growth in the economy is accompanied by a further contraction in CO_2 emissions. The negative decoupling expanded in the period 2014-2017 where the growth rate of CO_2 emissions was many times higher than economic growth. The LMDI technique has been used to analyze the factors behind the changes in CO_2 emissions of the agricultural sector. The results indicated that depending on the period, the labor effect, income effect, carbon intensity effect, and energy intensity effect are the main causes of the increase or decrease in CO_2 emissions of the agricultural sector. Overall, income effect and energy intensity effect was the main cause of the increase in CO_2 emissions of the agricultural sector in this period.

Keywords

CO_2 Emissions, Decoupling, LMDI Technique, Agriculture

1. Introduction

Vietnam is experiencing continuous economic growth and advancements in agriculture, resulting in higher energy consumption and increased CO_2 emissions. The agricultural sector contributed approximately one-quarter of Vietnam's greenhouse gas emissions in 2014 [1]. The total greenhouse gas emissions in agriculture are projected to rise from 20 $MtCO_2eq$ in 2000 to 65 $MtCO_2eq$ in 2005 and 85 $MtCO_2eq$ by 2030 [2]. In the greenhouse gas emission reduction plan, Vietnam has pledged to ensure that by 2030, total emissions reductions will reach a minimum of 121,9 million tons CO_2 eq; methane emissions will not exceed 45,9 million tons CO_2 eq; and carbon absorption in forestry and land use will be increased, contributing to the national commitment to achieve net-zero emissions by 2050. This will lay the foundation for sustainable development, enhancing the added value and competitiveness of the Agriculture and Rural Development sector (Ministry of Agriculture & Rural Development of Vietnam [3].

In addition to technical studies measuring CO_2 emissions, recent research has focused on analyzing the socio-economic factors affecting CO_2 emissions in Vietnam. Generally, factors such as economic growth, personal income, population growth, urbanization, economic structure, human capital, and energy consumption are considered and evaluated for their positive or negative impacts on CO_2 emissions [4]-[10]. Studies of factors affecting CO_2 emissions have existed since the 1980s, utilizing various methods, with the LMDI (Logarithmic mean Divisia index) method being favored due to its advantage of not leaving a residual term and handling zero values in data sets [11] [12]. Using this method, the article analyzes the decomposition of factors behind the fluctuations of CO_2 emissions in Vietnam's agriculture sector to identify key determinants in the increase or decrease of emissions. Combining with the Decoupling Index (DI), the article further investigates the decoupling between CO_2 emissions and agricultural GDP to elucidate the relationship between CO_2 emissions and economic growth.

2. Research Method

2.1. Data Collection Method

The study utilizes data collected from 2006 to 2021. The statistics on CO_2 emissions and energy consumption by sector in Vietnam are sourced from the International Energy Agency (IEA), while the data on employment and GDP in Vietnam's agricultural sector are obtained from the General Statistics Office of Vietnam (**Table 1**).

Table 1. Data and data sources.

Data	Data sources	Link to access
CO_2 emissions in the agricultural sector	IEA	https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=VIETNAM&fuel=CO2%20emissions&indicator=CO2BySector [13]
Total final consumption (TFC) in the agricultural sector	IEA	https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=VIETNAM&fuel=Energy%20consumption&indicator=TFCShareBySector [14]

Continued

Employment in agriculture	General Statistics Office of Vietnam	https://www.gso.gov.vn/px-web-2/?pxid=V0242&theme=D%C3%A2n%20s%E1%BB%91%20v%C3%A0%20lao%20%C4%91%E1%BB%99ng [15]
Agriculture GDP (constant 2010 prices)	General Statistics Office of Vietnam	https://www.gso.gov.vn/px-web-2/?pxid=V0303&theme=T%C3%A0i%20kho%E1%BA%A3n%20qu%E1%BB%91c%20gia [16]

2.2. Analysis Method

2.2.1. Decoupling Index (DI)

Initially, the study examines the decoupling between CO_2 emissions (C) and economic growth in Vietnam's agricultural sector. The Decoupling Index (DI), as proposed by Tapio [17], is used to differentiate economic output from environmental harm. Decoupling CO_2 emissions from economic development is crucial for environmental management [18]. The Decoupling Index (DI) is calculated for the ratio of CO_2 emissions to the GDP of the agricultural sector:

$$DI_{GDP} = \frac{\left(C_t - C_{t-1}\right) / C_{t-1}}{\left(GDP_t - GDP_{t-1}\right) / GDP_{t-1}} = \frac{\%\Delta C}{\%\Delta GDP}$$

where C_{t-1} and GDP_{t-1} represent the lagged CO_2 emissions and economic growth. These values are calculated based on the continuous chain method, such as t, $(t-1)$. %ΔC and %ΔGDP denote the growth rates of CO_2 emissions and GDP over two consecutive years.

The Decoupling Index (DI) can be classified into three categories: decoupling, negative decoupling, and coupling. Furthermore, it can be subdivided into several subcategories depending on the values of ΔC and ΔGDP.

Table 2. Classification of the Decoupling Index (DI).

Decoupling status	Value		
	%ΔC	%ΔGDP	DI
Negative decoupling	Weak negative decoupling	< 0	< 0
	Strong negative coupling	> 0	< 0
	Expansive negative decouping extended negative coupling	> 0	> 0
Decoupling	Recessive decoupling latent decoupling	< 0	< 0
	Strong decoupling	< 0	> 0
	Weak decoupling	> 0	> 0
Coupling	Recessive coupling latent coupling	< 0	< 0
	Expansive coupling growth coupling	> 0	> 0

Source: [19] Tapio (2025).

2.2.2. Decomposition Model

Decoupling status		Value		
		%ΔC	%ΔGDP	DI
Negative decoupling	Weak negative decoupling	< 0	< 0	0 < DI < 0.8
	Strong negative decoupling	> 0	< 0	DI < 0
	Expansive negative decoupling	> 0	> 0	DI > 1.2
Decoupling	Recessive decoupling	< 0	< 0	DI > 1.2
	Strong decoupling	< 0	> 0	DI < 0
	Weak decoupling	> 0	> 0	0 < DI < 0.8
Coupling	Recessive coupling	< 0	< 0	0.8 < DI < 1.2
	Expansive coupling	> 0	> 0	0.8 < DI < 1.2

A widely used model for quantitatively analyzing CO_2 emissions was introduced by Japanese professor Yoichi Kaya during a workshop organized by the IPCC in 1989 [20] [21]. The model establishes a simple mathematical equation that relates economic, demographic, and environmental factors to estimate global CO_2 emissions from human activities as follows:

$$CO_2 = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CO_2}{E} \quad (1)$$

$$\text{or } CO_2 = P \times Inc \times EI \times CI \quad (2)$$

in which:

CO_2: Total CO_2 emissions ($MtCO_2$)

P: Population (people)

GDP: Gross Domestic Product (VND)

E: Total Energy consumption (GJ)

This relationship is explained by the fact that population growth (P) is one of the primary factors leading to CO_2 emissions in all countries, especially in developing nations. Income or GDP per capita is a measure of living standards and serves as a gauge for fossil fuel consumption within a society. Energy intensity (EI) (E/GDP) reflects the amount of energy required to produce one unit of economic output, serving as a measure of energy efficiency for an economy or country. Carbon intensity (CI) (CO_2/E) indicates the relative carbon emissions per unit of energy or fuel consumed. This measures how effectively countries utilize polluting energy sources such as coal, oil, and gas. Increasing the use of renewable energy will help reduce carbon intensity, whereas countries that still rely on fossil fuels to drive economic growth will have fewer opportunities to lower carbon intensity.

To align with the study, formula (1) is adjusted for application in the agricultural sector, where P is the labor force employed in agriculture, GDP is the agricultural gross product (calculated at 2010 constant prices), and E is energy consumption in agriculture. In the additive LMDI technique as guided by Ang [22], the arithmetic change of a composite index is decomposed. This allows the study to identify and rank the causal impacts leading to trends in CO_2 emissions based on comparison. In the additive LMDI technique, the difference in CO_2 emissions between two years (year 0 and year t) can be expressed in Mt CO_2 as follows:

$$\Delta C_{tot} = \Delta C_P + \Delta C_{Inc} + \Delta C_{EI} + \Delta C_{CI}$$

where ΔC_{tot} represents the change in total CO_2 emissions, which is decomposed into the effects of labor (ΔC_P), income effect (ΔC_{Inc}), energy intensity effect (ΔC_{EI}), and carbon intensity effect (ΔC_{CI}). The relevant formulas for these decomposing factors are as follows:

$$\Delta C_P = \frac{CO_2^t - CO_2^0}{\ln CO_2^t - \ln CO_2^0} \times \ln \frac{P^t}{P^0}$$

$$\Delta C_{Inc} = \frac{CO_2^t - CO_2^0}{\ln CO_2^t - \ln CO_2^0} \times \ln \frac{Inc^t}{Inc^0}$$

$$\Delta C_{EI} = \frac{CO_2^t - CO_2^0}{\ln CO_2^t - \ln CO_2^0} \times \ln \frac{EI^t}{EI^0}$$

$$\Delta C_{CI} = \frac{CO_2^t - CO_2^0}{\ln CO_2^t - \ln CO_2^0} \times \ln \frac{CI^t}{CI^0}$$

3. Results and Findings

3.1. Decoupling Status of Vietnam's Agricultural Sector

The research findings derived from the analysis of the Decoupling Index (DI) values in the agricultural sector indicate that the sector has experienced all three states: decoupling, negative decoupling, and coupling.

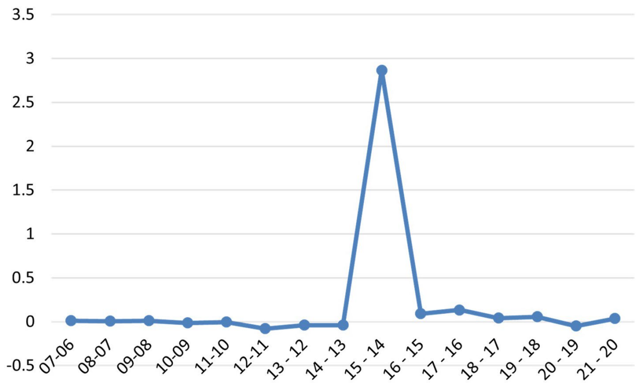
Based on the theoretical framework provided in Table 2 and the calculated results presented in Table 3, some observations regarding the decoupling status during the period from 2005 to 2021 can be discussed as follows.

In 2005-2006, the agricultural sector experienced a weak decoupling status during the period from 2006 to 2009. This weak decoupling occurs when economic growth is relatively higher than the growth of CO_2 emissions. In the period from 2009 to 2014, the agricultural sector transitioned to a strong decoupling. This can be regarded as the best decoupling state, as the agricultural sector maintained economic growth while the rate of CO_2 emissions decreased (Figure 1). However, in the subsequent period (2014-2017), an extended negative decoupling state emerged, reflecting growth in both GDP and CO_2 emissions in the agricultural sector, but the rate of CO_2 emissions growth significantly outpaced economic growth (Figure 1 and Figure 2). The primary reason for this extended negative decoupling is the burning of fossil fuels with high carbon usage. This status was at its worst in 2014-2015, as evidenced by the significant demand for fossil fuels such as gasoline, oil, and natural gas in the agricultural sector in 2015, resulting in a marked increase in CO_2 emissions for that year (Figure 1). The growth coupling status observed in the years 2017-2019 and 2020-2021 (Figure 3) further indicates that both CO_2 emissions and economic growth in the agricultural sector increased together, however, adjustments have been made to ensure that economic growth outpaced the growth of emissions.

Table 3. Decoupling Status of Vietnam's Agricultural Sector 2005-2021.

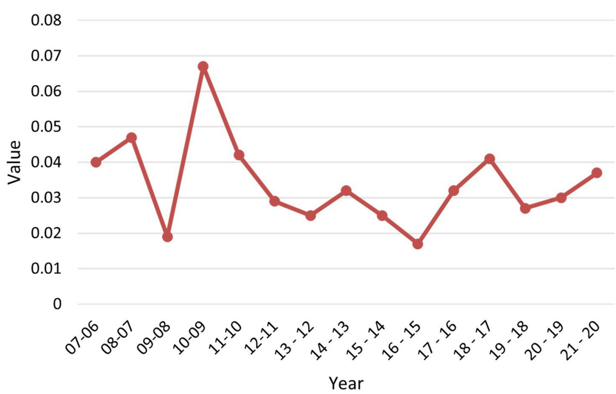
Year	%ΔC	%ΔGDP	DI	Status
07-06	0.011	0.040	0.266	Weak Decoupling
08-07	0.007	0.047	0.143	Weak Decoupling
09-08	0.012	0.019	0.636	Weak Decoupling
10-09	−0.014	0.067	−0.214	Strong Decoupling
11-10	−0.003	0.042	−0.072	Strong Decoupling
12-11	−0.079	0.029	−2.766	Strong Decoupling
13-12	−0.038	0.025	−1.520	Strong Decoupling
14-13	−0.038	0.032	−1.185	Strong Decoupling
15-14	2.866	0.025	114.313	Expansive Negative Decoupling
16-15	0.093	0.017	5.644	Expansive Negative Decoupling
17-16	0.135	0.032	4.264	Expansive Negative Decoupling
18-17	0.041	0.041	0.985	Expansive coupling
19-18	0.058	0.027	2.166	Expansive coupling
20-19	−0.048	0.030	−1.582	Strong Decoupling
21-20	0.037	0.037	0.996	Expansive coupling

Note: The data in Table 3 is calculated by author on the 29th of September 2024.



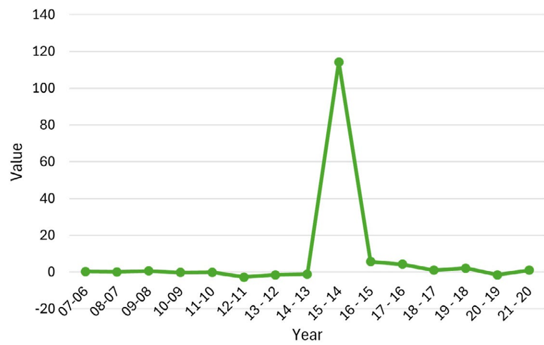
Note: Figure 1 is derived from the data presented in Table 3.

Figure 1. Trend of CO_2 Emissions Change (2006-2021).



Note: Figure 2 is derived from the data presented in Table 3.

Figure 2. Trend of GDP Growth Rate (2006-2021).



Note: Figure 3 is derived from the data presented in Table 3.

Figure 3. Trend of the Decoupling Index (2006-2021).

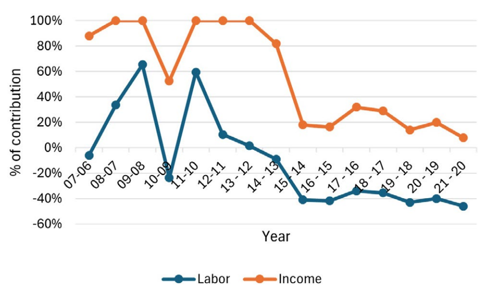
3.2. Results of the Decomposition Model

Using the LMDI technique. the factors affecting CO_2 emission fluctuations can be quantified. Table 4 presents the results of the LMDI analysis for CO_2 emissions in the agricultural sector from 2006 to 2021.

Table 4. Results of CO_2 emission decomposition analysis in the agricultural sector.

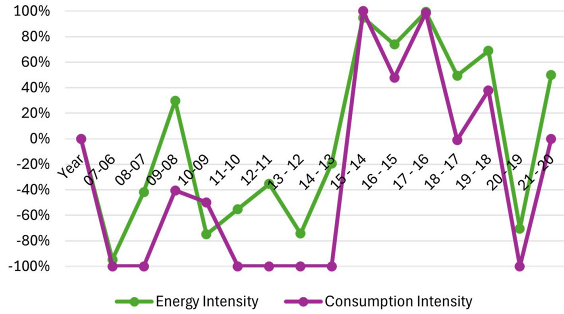
Year	ΔP	ΔInc	ΔEI	ΔCI	ΔC
07 - 06	−4.30	67.39	−43.65	−2.44	17
08 - 07	25.30	49.93	−26.87	−37.36	11
09 - 08	20.49	10.84	8.34	−19.67	20
10 - 09	−48.82	156.69	−198.24	66.38	−24
11- 10	40.55	27.57	−40.28	−32.83	−5
12 - 11	4.61	39.87	−61.74	−112.74	−130
13 - 12	0.57	36.37	−70.61	−24.33	−58
14 - 13	−4.96	49.78	−19.40	−80.42	−55
15 - 14	−167.39	240.54	3720.96	200.89	3995
16 - 15	−236.70	329.16	634.70	−224.16	503
17 - 16	−208.89	404.83	604.00	−3.94	796
18 - 17	−338.57	613.73	202.58	−206.74	271
19 - 18	−579.66	768.07	388.91	−175.33	402
20 - 19	−435.06	650.12	−400.66	−168.39	−354
21 - 20	−1550.83	1810.83	264.22	−265.21	259
Total	−3,484	5,256	4,962	−1,086	5,648

Note: The data in Table 4 is calculated by author on the 29th of September 2024.



Note: Figure 4 is derived from the data presented in Table 4.

Figure 4. Labor and Income contributions to CO_2 emission changes (2006-2021).



Note: Figure 5 is derived from the data presented in Table 4.

Figure 5. Energy and Consuption Intensity contributions to CO_2 emission changes (2006-2021).

Based on the results of the decomposition analysis, we can examine the fluctuations in CO_2 emissions in the agricultural sector across different periods:

2006-2009 period: This period experienced a growing trend in CO_2 emissions, although it was at a low growth rate. During this time, the effects of income and labor contributed to increased emissions, while the effects of energy intensity and carbon intensity helped reduce them (Figure 4). The agricultural sector was still largely traditional, relying on human and animal power with minimal machinery use. Intensive agricultural practices improved productivity, supporting economic growth. Land consolidation started in 2008, but fragmented land parcels significantly hindered agricultural modernization. Most farming households remained tied to agriculture due to limited non-agricultural livelihood opportunities [23]. Overall, from 2005 to 2009, the agricultural sector exhibited stable growth in terms of income and labor, with low mechanization leading to moderate energy consumption and carbon emissions.

2010-2014 period: This period saw a reduction in emissions due to improved labor efficiency (Figure 4). As shown in Table 4, in 2010, CO_2 emissions decreased by 24 Mt CO_2, primarily due to a significant reduction in the energy intensity effect (−198.24 Mt CO_2), despite an increase in income per labor. This indicates the agricultural sector's efforts toward more efficient energy use. In the following years, the effects of carbon intensity and energy intensity played vital roles in reducing CO_2 emissions. The substantial reduction in these two effects arose from several factors. First, this period saw an increased application of scientific and technological advancements in agriculture while still maintaining reasonable scales and avoiding excessive reliance on fossil energy. Second, the impact of the agricultural restructuring policy towards increasing added value and sustainable development according to Decision 899/QD-TTg of the Vietnam Government; in addition, many localities have begun to implement organic agriculture and high-tech agriculture models such as Lam Dong, Dong Nai, Hanoi, etc. These policies encouraged farmers to reduce dependence on high-emission input materials like chemical fertilizers and pesticides, thereby decreasing carbon intensity per unit of energy consumed. Third, the fluctuation of energy prices and input costs, notably in 2011-2012, when rising fuel prices forced farmers to reduce energy consumption and operate more efficiently, contributed to lower carbon intensity. This period also saw the increased popularity of energy-saving technologies and the reuse of agricultural by-products, such as biogas.

2015-2019 period: This period was marked by unusual fluctuations, including a dramatic spike in emissions (**Figure 5**), particularly in 2015 compared to 2014, where the CO_2 emissions gap reached 3995 Mt CO_2 largely attributed to the energy intensity effect (ΔEI = 3720.96%, as mentioned in **Table 4**). This surge likely resulted from efforts to promote mechanization in agriculture. Decision No. 68/2013/QD-TTg dated November 14, 2013 of the Vietnam Prime Minister on support policies to reduce losses in agriculture and Circular No. 08/2014/TT-BNNPTNT dated March 20, 2014 of the Ministry of Agriculture and Rural Development of Vietnam guiding the implementation of a number of articles of Decision No. 68/2013/QD-TTg have strongly promoted the process of agricultural mechanization. These initiatives enabled businesses, cooperatives, and households to receive support for purchasing agricultural machinery and equipment. As a result, the proportion of households owning various types of machinery primarily used for agricultural, forestry, and fishery production increased by 74.0% in 2016 compared to 2011 [24]. Machinery and equipment were used diversely across all stages of the production process, with significant increases in quantity. On average, for every 100 households engaged in agricultural, forestry, and fishery activities, there were 0.74 vehicles used for production purposes; 100 rice-farming households used an average of 28.87 motorized sprayers, 0.44 combined harvesters, 2.84 other types of harvesters, and 4.02 motorized rice threshers [25]. Consequently, the demand for fossil fuels to power agricultural machinery and equipment surged during this period, leading to a substantial increase in CO_2 emissions.

CO_2 emissions in the agricultural sector dropped in 2019 and 2020 (**Figure 5**), coinciding with the global COVID-19 pandemic, which profoundly impacted the global energy system. In 2020, various lockdown measures were implemented to control the spread of COVID-19, restricting transportation, agriculture, industry, and production activities. While these measures negatively affected socio-economic activities, they had a positive impact on the environment [26] [27]. However, in the report of IEA [28], the increase in global CO_2 emissions in 2021 compared to 2020 was the highest annual increase on record in absolute terms, as economies recovered from the pandemic through financial measures and rapid vaccine rollout. The rise in CO_2 emissions in 2021 corresponded with the global economic growth. This was also a growth coupling status between CO_2 emissions and GDP growth. The research findings align with the IEA's conclusions regarding the increase in CO_2 emissions in Vietnam's agricultural sector in 2021 compared to 2020, primarily driven by the income effect.

Overall, the total CO_2 emissions fluctuation from 2006 to 2021 amounted to 5,648 Mt CO_2 (**Table 4**), driven by the income effect and energy intensity effect (with the income effect being larger). It is evident that, for Vietnam's agricultural sector, the income effect is the primary driver of CO_2 emissions growth. This is because increased income in agriculture is often accompanied by expanded production scales, enhanced mechanization, and investment in machinery and equipment. High-energy-consuming activities such as post-harvest processing, transportation, and agricultural product processing have also been promoted to enhance the value added in the agricultural sector. These factors significantly contribute to energy consumption and the use of high CO_2 emitting energy sources, leading to an increase in total emissions. This presents a critical concern for policymakers, as rising incomes or production values, without improvements in energy efficiency, risk making agricultural development unsustainable.

The labor effect and carbon intensity effect contribute to reducing CO_2 emissions. The labor effect reflects changes in the structure and efficiency of labor use in the agricultural sector, positively influencing CO_2 emission reductions. This is largely due to the adoption of modern farming techniques and automation, which help increase labor productivity and reduce dependence on inefficient traditional practices. Although the contribution of the carbon intensity effect is still relatively low, it indicates the potential for reducing carbon emissions in agriculture through a transition from high CO_2 emitting energy sources, such as gasoline, oil, and coal, to cleaner energy alternatives like solar power, biomass, and biogas derived from agricultural waste.

4. Conclusions

The use of the decoupling index (DI) demonstrates that Vietnam's agricultural sector underwent four distinct decoupling states from 2006 to 2021: strong decoupling, weak decoupling, extended negative decoupling, and growth coupling. Throughout this period, the agricultural sector consistently maintained GDP growth rates; however, there were phases during which the growth rate of GDP did not keep pace with the rise in CO_2 emissions. Notably, during the period from 2014 to 2017, the state of extended negative decoupling reflected a situation where CO_2 emissions growth significantly exceeded economic growth in the agricultural sector.

The findings from the LMDI technique illustrate that fluctuations in CO_2 emissions in the agricultural sector are driven by the labor effect, income effect, carbon intensity effect, and energy intensity effect. Among these, the labor effect and carbon intensity effect contribute to CO_2 emission reductions, while the income and energy intensity effects play a predominant role in increasing emissions. Since 2014, CO_2 emissions have shown a strong upward trend compared to previous periods, indicating that the mechanization of agriculture has led to increased fossil fuel use. To address rising CO_2 emissions in agriculture, it is important to promote the use of renewable energy sources through incentives and subsidies, encouraging farmers to switch from fossil fuels. Furthermore, adopting energy-efficient technologies and sustainable practices can help reduce emissions associated with mechanization, fostering a more environmentally sustainable agricultural sector. The finding emphasizes the need for the agricultural sector to transition from fossil fuel energy sources to renewable energy to ensure sustainable agricultural development.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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