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ARTICLE

Factors Affecting CO_2 Emissions from Direct Energy Household Consumption in Vietnam

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ABSTRACT

The energy sector is pivotal in Vietnam's commitment to achieving net-zero emissions by 2050. This study employs a combination of Structural Decomposition Analysis (SDA) and decoupling approaches based on data from Vietnam's energy statistics and the Vietnam Living Standards Survey (VHLSS) for 2016, 2018, and 2020. The primary aim is to elucidate the effects of direct energy consumption by household groups on CO_2 emissions, examine factors affecting emissions, and clarify the relationship between CO_2 emissions from household energy consumption and economic growth in Vietnam. Research results underscore that household groups make considerable use of electricity and Liquefied Petroleum Gas (LPG), simultaneously reducing the proportion of firewood, rice husk, sawdust, agricultural by-products and other fuels. The decrease in energy intensity emerges as the primary factor in lowering household emissions, while population growth and economic efficiency exert the opposite effect. Additionally, the research reveals disparities in emissions between urban and rural areas, similarly among household groups within the given location. Despite maintaining a robust decoupling status between emissions from household consumption and economic growth, unsustainable risks persist, particularly with the increase in electricity demand. The study also highlights the uneven impact of the COVID-19 epidemic on CO_2 emissions across household groups. Drawing upon these findings, several recommendations are proposed to control CO_2 emissions from direct energy household consumption to facilitate the most effective household decarbonisation process

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while ensuring sustainable economic growth in Vietnam.
Keywords: CO_2 Emissions; Energy; Household Consumption; SDA; Decoupling Analysis; COVID Epidemic; Economic Growth; Vietnam

1. Introduction

Energy plays a pivotal role in all activities, with energy consumption as a leading cause of CO_2 emissions [1]. Predictions indicate a 28% increase in global energy consumption from 2015 to 2040. Notably, in Asia, annual energy consumption is projected to rise by an average of 1.7% during this period [2]. The assurance of energy security and environmental sustainability is integral to reducing poverty and achieving sustainable economic growth [3]. Reducing CO_2 emissions can also lead to the generation of new technologies, increase cost efficiency, and facilitate the transition to a low-carbon economy [4]. Hence, there is a global interest in researching the environmental repercussions of energy consumption.

While existing studies predominantly focus on industrial, construction, and transportation activities regarding greenhouse gas emissions (GHG) from energy consumption [5–9], the emissions from the residential sector receive comparatively little attention. According to data from the European Parliament [10], residential area emissions account for 17.5% of global CO_2 emissions.

Household energy usage constitutes a substantial portion of total energy consumption and CO_2 emissions. Household energy demand has a relatively stable growth rate, with an average annual increase of 1.4% since 2014 [11]. In the U.S., direct energy consumption by households accounts for 38% of the country's CO_2 emissions [12]. In the Middle East, the primary cause of CO_2 emissions in the long run is the consumption of energy [13].

Many studies [14, 15] have used the factor decomposition method to focus on determining the contribution of household consumption to changes in emissions. Some researchers [16–23] applied SDA to in-depth analysis of changes related to energy consumption and clarified the factors that contribute to environmental pollution. This has proven that SDA is an effective method for designing energy-saving and emission-reduction policies.

Besides understanding the influence of factors on changes in household carbon emissions, identifying the relationship between economic growth and household emissions is also urgent when the importance of emissions is increasingly emphasized in the context of strong economic growth in countries. The decoupling indicator is widely used to evaluate the degree to which economic development depends on carbon emissions [24]. This approach is beneficial for clarifying the asynchronous relationship between economic growth and changes in emissions at the local level [8, 25] and national levels [26–29]. Other studies have performed detailed analyses to address total emissions effectively without hindering economic growth at the sectoral level. However, studies related to residential areas are relatively limited. Ma et al. [30] indicated that household CO_2 emissions in China from 1994 to 2012 generally exhibit weak but strong decoupling during 1995–1998 and a coupled state in 2002–2004 and 2008–2009. L. Zhao, T. Zhao and Yuan [31] employed the decoupling method to explore decarbonization trends based on changes in per capita consumption between urban and rural areas at the national and provincial levels.

In Vietnam, economic expansion has resulted in a corresponding increase in energy demand. According to the Vietnam Energy Statistics Report 2022, total Final Energy Consumption (TFEC) experienced substantial growth of 7.9% annually from 2015 to 2019, culminating in 64.542 KTOE 2019. Notably, Vietnam exhibits high energy intensity relative to other global counterparts, with a primary energy intensity of 20 GJ/USD in 2015, in contrast to the world average of 8 GJ/USD [32]. According to Vietnam's BAU Emissions Scenario, by 2050, 81% of emissions will originate from the energy sector.

Energy research is an emerging field in Vietnam. However, investigations related to household energy consumption are notably scarce. A limited number of studies analyze the effects of household characteristics (such as income, household size, housing parameters, and other social impacts), climate, and government policies on household energy consumption [33–37]. Furthermore, only a limited number of studies explore the relationship between energy consumption and carbon emissions in Vietnam, as exemplified by the work of Minh, Ngoc and Van [38].

The risk of substantial growth in CO_2 emissions from household energy consumption persists amid Vietnam's ongoing industrialization and modernization. Concurrently, the country grapples with the looming threat of energy shortages, prompting serious concerns about the need for energy conservation and effective energy utilization strategies. Resolution No. 55-NQ/TW issued by the Vietnamese Politburo in 2020 has emphasized the importance of economic development and efficient consumption of energy, as well as environmental protection. This is considered an essential national policy. Therefore, one of the most important policy goals that Vietnam needs to aim for is the limitation of energy consumption in the residential sector to reduce CO_2 emissions.

The novelty of the research is first evident in the combined application of the SDA method with the Kaya index and decoupling index. This approach aids in elucidating the influence of key factors contributing to changes in emissions and understanding the relationship between economic growth and CO_2 emissions. Second, while most existing research focuses mainly on CO_2 emissions originating from the fossil energy consumption of households, this study aims to analyze emissions from mixed household consumption activities, encompassing both fossil energy and biomass energy. Consequently, the findings of this study are anticipated to offer a more general and realistic perspective on the current situation of CO_2 emissions from household groups in Vietnam. The third is that this analysis provides a more detailed examination of the level of household groups compared to existing studies. This contribution is significant for gaining insights into the behaviour of households regarding emissions from direct energy consumption and, subsequently, for refining policies aimed at decarbonizing the consumption activities of household groups in Vietnam. The fourth, clarifying the factors influencing CO_2 emissions from household consumption activities and understanding the relationship between economic growth and CO_2 emissions from household consumption activities, is a relatively new and challenging endeavour in Vietnam. Addressing this problem is essential for supporting the development of policies related to sustainable energy development in the country.

The remaining sections are structured as follows: Section 2 presents an overview of the data sources and outlines the research methods applied. The primary findings of the research are presented and discussed in Section 3. Section 4 summarises the key research results and puts forth policy recommendations based on the findings presented in the preceding sections.

2. Methodology and Data

2.1. Methodology

2.1.1. Structural Decomposition Analysis (SDA)

According to the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, emissions from direct household consumption activities are determined according to the following formula:

$$E_H = Y_{mn} * C_{mn} \tag{1}$$

Where E_H represents the total CO_2 emissions arising from direct consumption activities of household groups, and m is the type of household group, in which m = 1, 2, 3, and 4 corresponds to groups of urban farming households, groups of urban non-farming households, groups of rural farming households, and groups of non-farming households in rural areas.

Moreover, when n = 1, 2,... 6, it signifies six distinct forms of energy; C_mn represents the emission intensity linked to energy form n, and Y_mn represents the energy consumption of household group m.

The study employed a combination of SDA and the Kaya index to investigate the key factors influencing household consumption emissions over time. According to Ang [39], formula (1) is restructured based on the Kaya index as follows:

$$E_H = P\frac{G}{P}\frac{Y_{mn}}{G}C_{mn} = Pgy_{mn}C_{mn} \tag{2}$$

In this context, P and G denote Vietnam's overall population and Gross Domestic Product (GDP), respectively. The variable 'g' represents economic efficiency, calculated as $g = \frac{G}{P}$. Moreover, y_{mn} denotes energy intensity 'n' by the household group 'm', calculated as $y_{mn} = \frac{y_{mn}}{G}$. Therefore, CO_2 emissions from households are influenced by factors including population, economic efficiency, and energy consumption intensity at the household level.

As the emission intensity of energy forms remains constant, SDA is applied to decompose changes in CO_2 emissions dE_H to changes attributable to population dP, economic efficiency dg, and energy intensity dy_{mn}. Consequently, formula 2 is reformulated as follows:

$$\begin{aligned} dE_H &= dE_{H_p} + dE_{H_g} + dE_{H_{ymn}} \\ &= d\left(P\right) g y_{mn} C_{mn} + dP\left(g\right) y_{mn} C_{mn} \\ &\quad + dPg\left(y_{mn}\right) C_{mn} \end{aligned} \tag{3}$$

Equation (4) was utilized to measure the emission impacts resulting from changes in these factors by applying the discrete decomposition of Equation (3):

$$\Delta E_H = \mathrm{f}(\Delta E_{H\,P}) + \mathrm{f}(\Delta E_{H\,g}) + \mathrm{f}(\Delta E_{H\,y_{mn}}) \tag{4}$$

The change from the base period to the target period is represented by $\Delta E_{H\,p}$, ΔE_{H_g}, and $\Delta E_{H\,y_{mn}}$, respectively. To achieve greater accuracy in the results, the "polar decomposition method"[40] was used to obtain the decomposition equation of ΔE_H:

$$\mathrm{f}(\Delta E_{H\,p}) = \frac{1}{2}\Delta P(g_1 y_{mn1} + g_2 y_{mn2}) \tag{5}$$

$$\mathrm{f}(\Delta E_{H\,g}) = \frac{1}{2}(P_0 \Delta g y_{mn1} + P_1 \Delta g y_{mn0}) \tag{6}$$

$$\mathrm{f}(\Delta E_{H\,y_{mn}}) = \frac{1}{2}(P_0 g_0 \Delta y_{mn} + P_1 g_1 \Delta y_{mn}) \tag{7}$$

Where, $\Delta P = P_1 - P_0$, $\Delta g = g_1 - g_0$, $\Delta y_{mn} = y_{mn1} - y_{mn0}$.

2.1.2. Decoupling Analysis

The decoupling indicator is employed to measure the quantitative relationship between various indicators. In this context, decoupling refers to a scenario where the growth rate of CO_2 emissions is less than the rate of GDP growth. Tapio[41] characterized eight states of decoupling, as illustrated in **Table 1**.

Table 1. Eight states of decoupling, according to Tapio[41].

$\Delta GDP < 0$		$\Delta GDP > 0$	
$\Delta CO_2 > 0$ $\%\Delta CO_2/\%\Delta GDP < 0$	Strong negative decoupling	$\Delta CO_2 < 0$ $\%\Delta CO_2/\%\Delta GDP < 0$	Strong decoupling
$\Delta CO_2 < 0$ $0 < \%\Delta CO_2/\%\Delta GDP < 0.8$	Weak negative decoupling	$\Delta CO_2 > 0$ $0 < \%\Delta CO_2/\%\Delta GDP < 0.8$	Weak decoupling
$\Delta CO_2 < 0$ $0.8 < \%\Delta CO_2/\%\Delta GDP < 1.2$	Recessive coupling	$\Delta CO_2 > 0$ $0.8 < \%\Delta CO_2/\%\Delta GDP < 1.2$	Expansive coupling
$\Delta CO_2 < 0$ $\%\Delta CO_2/\%\Delta GDP > 1.2$	Recessive decoupling	$\Delta CO_2 > 0$ $\%\Delta CO_2/\%\Delta GDP > 1.2$	Expansive negative decoupling

Source: Tapio[41].

This paper systematically examines the state of decoupling concerning the population, economic activity, and energy intensity within distinct household groups, as outlined below:

$$\begin{aligned} D_{E_H} &= \frac{\%\Delta E_H}{\%\Delta GDP} \\ &= \frac{\%\Delta E_{H\,P} + \%\Delta E_{H\,g} + \%\Delta E_{H\,y_{mn}}}{\%\Delta GDP} \\ &= D_{E_{H\,P}} + D_{E_{H\,g}} + D_{E_{H\,y_{mn}}} \end{aligned} \tag{8}$$

Consequently, D_{E_H} serves as the total decoupling index. $D_{E_{H\,P}}$, $D_{E_{H\,g}}$, and $D_{E_{H\,y_{mn}}}$ denote the decoupling index corresponding to the specific three factors: population, economic activities, and energy intensity of households. Given the sustained rapid growth of Vietnam's GDP in the recent period, this study focuses exclusively on discussing the states where ΔGDP > 0.

Combining SDA and decoupling analysis provides a more comprehensive understanding of the drivers of CO_2 emissions in economic growth. So, the study can reveal how changes in population, energy intensity, and economic effectiveness influence emissions and economic growth over time, offering a more nuanced understanding of sustainability trends.

2.2. Data

In light of the limited availability of national and environmental account information in Vietnam, this article employs a diverse array of data sources to analyze the fluctuations in CO_2 emissions arising from direct energy consumption of households during the period from 2016 to 2020. Data about energy consumption, categorized by energy type, is sourced from Vietnam's energy statistics. Data from the Vietnam Household Living Standards Surveys (VHLSS) of 2016, 2018, and 2020 is used to investigate the detailed trends in energy consumption within various household groups. The identified household groups consist of four distinct categories: H1 and H2 represent urban households, with H1 comprising farming households and H2 comprising non-farming households. Similarly, H3 and H4 denote rural household groups, where H3 signifies farming households, and H4 comprises non-farming households. Macro-level indicators of Vietnam's economy, including total population and GDP, are extracted from the data provided by the Vietnam General Statistics Office. Emission coefficients for different energy sources, provided by the Center for Research and Development on Energy Saving in Vietnam, are referenced in this analysis.

3. Results and Discussion

3.1. CO_2 Emissions Resulting from Household Energy Consumption in Vietnam for the Period 2016–2020

During 2016–2020, overall final energy consumption experienced a rapid increase, reflected in an average annual growth rate of 7.7%. The energy consumption of industrial sectors showed the most substantial growth, averaging an increase of 17.3%, surpassing the growth rates observed in the agriculture, trade, and service sectors in 2016–2020. Meanwhile, a slight downward trend in direct energy consumption within household groups has been observed, with an average decrease of 1.1%. Nevertheless, this sector continues to constitute a substantial portion, exceeding 15% of the total energy consumption in Vietnam (**Figure 1**). Hence, the aggregate CO_2 emissions from energy consumption in the period 2016–2020 slightly decreased from 44.7 million tons of CO_2 to 42.8 million tons of CO_2.

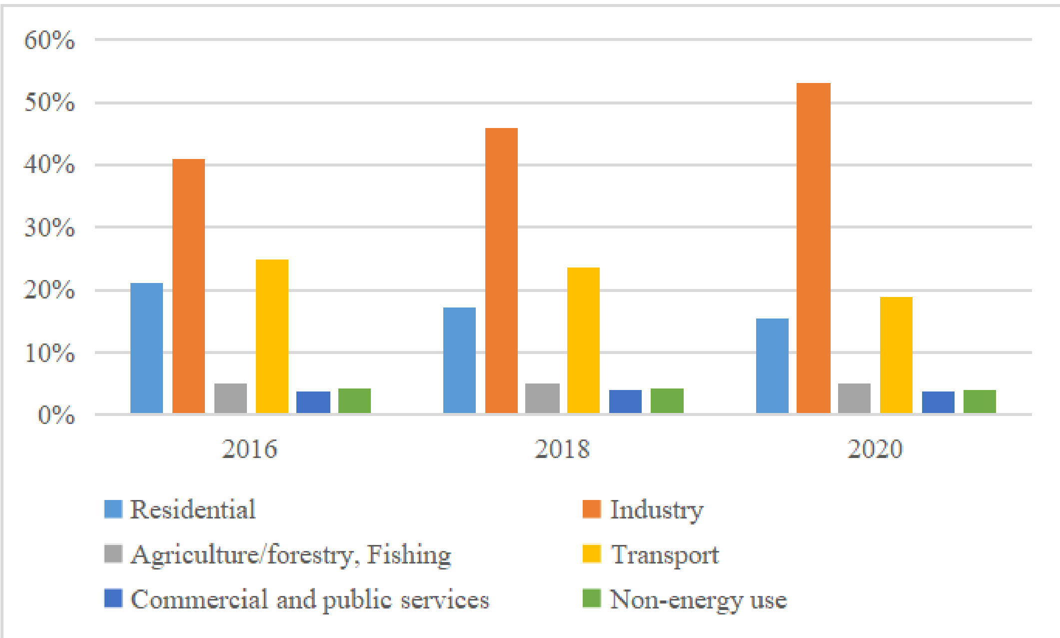

Figure 1. The proportion of direct energy consumption in Vietnam for the period 2016–2020.

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020.

According to a research report by the United Nations Development Programme (UNDP), forecasted GHG emissions from energy consumption in household groups for 2020 and 2030, based on Vietnam's "Usual Scenario" (BAU), are 16.5 and 20.5 $MTCO_2e$ (million tons of CO_2 equivalent), respectively. This data suggests that if CO_2 emissions from household consumption remain at the current high level, achieving the current net zero emissions target by 2050 will still face many difficulties and challenges.

CO_2 emissions from direct energy consumption vary based on the energy source and household group type (**Figures 2** and **3**). The highest proportion of CO_2 emissions in household groups comes from electricity consumption, with higher rates observed in urban households. This index highlights the significant role of electricity in the energy consumption structure of these household groups. However, emissions from electricity consumption are higher in rural areas than in urban ones because the larger population leads to greater electricity consumption. Moreover, non-farming household groups show a higher proportion of CO_2 emissions than farming household groups in both regions. CO_2 emissions from electricity consumption tend to increase from 2016 to 2020, particularly in urban farming households. Conversely, non-farming household groups in this area with the highest average income tend to transition to consuming solar thermal energy, contributing to a reduction in CO_2 emissions.

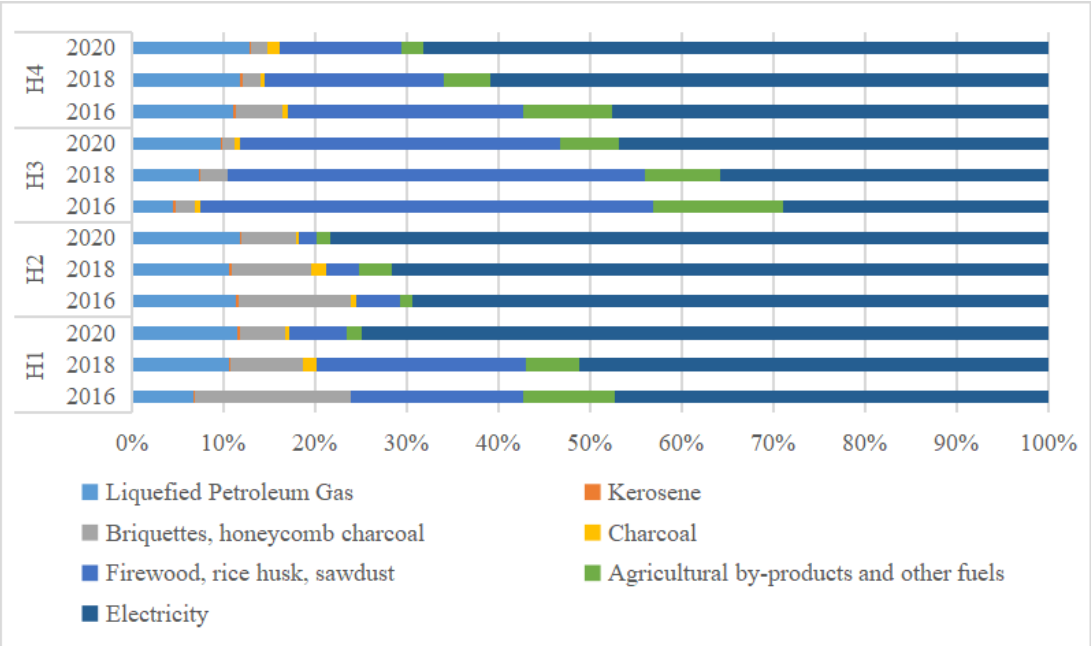

Figure 2. The proportion of CO_2 emissions by energy source and by household groups (%).
Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving.

Firewood, rice husks, and sawdust are the fuels consumed with the second-largest emission proportion. Unlike electricity, the emission proportion of this form of energy is higher in rural household groups than in urban household groups and higher in farming household groups than in non-farming household groups in the two areas. The emission proportion of agricultural by-products and other fuels, and briquettes, honeycomb charcoal in the consumption structure of household groups is relatively low. The quantity of emissions caused by the last fuel is higher in urban than rural.

The trend of reducing emissions from three fuel groups can be attributed to the decline in their consumption (**Figure 3**). The reason is the need to use more and more electrical appliances, as well as Liquefied Petroleum Gas (LPG), to replace these forms of energy increases to serve the daily needs of households. This includes lighting, cooking, grilling, operating household appliances, etc. Conversely, there is a growing trend toward using LPG in gas stoves for family cooking due to its convenience and ease of operation. As income levels rise, the demand for LPG is higher in rural than urban, leading to a faster increase in the proportion of this form of energy consumption in rural. Compared to biomass, including firewood, rice husk, sawdust, agricultural by-products and other fuels, the emission intensity of LPG is lower. Consequently, the increased demand for LPG contributes to minimizing the risk of environmental pollution.

The proportion of emissions from charcoal and kerosene is negligible in the household emissions structure.

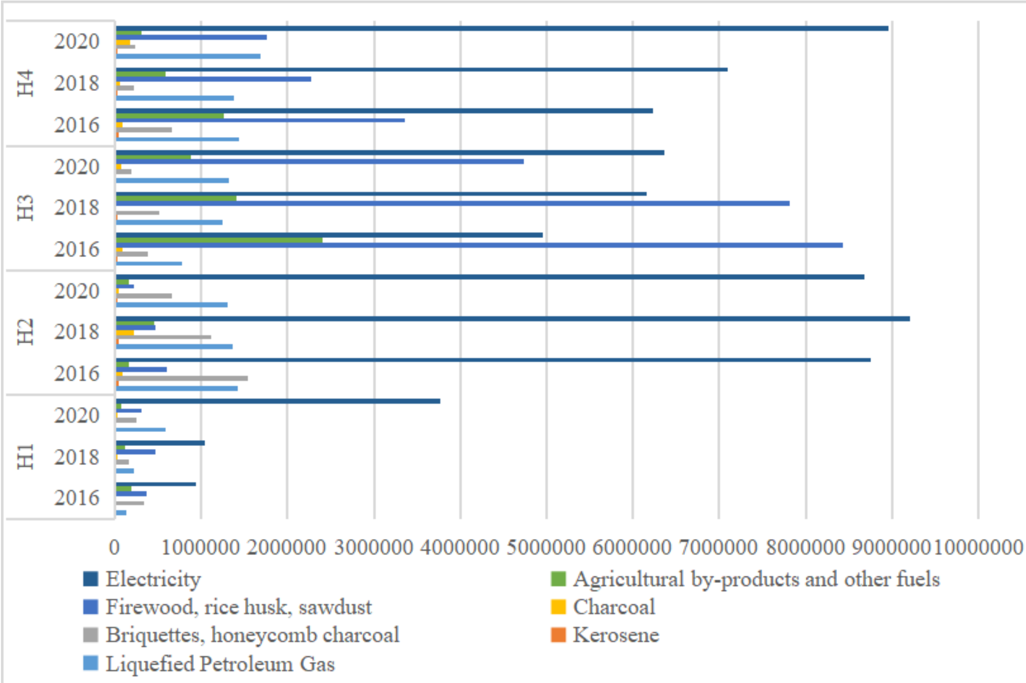

Figure 3. CO_2 emissions by energy source and by household groups (ton CO_2).

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving.

3.2. The Influence of Factors on Changes in CO_2 Emissions from Household Direct Energy Consumption

SDA analysis results show that the structure of the change in total CO_2 emissions and the change in CO_2 emissions due to the influence of factors in the two periods 2016–2018 and 2018–2020 are relatively similar (**Figure 4**). CO_2 emissions from direct household energy consumption decreased primarily due to a reduction in household energy intensity, accounting for 53% and 54% of the total CO_2 change in the respective research periods (2016–2018 and 2018–2020). Simultaneously, increased economic efficiency and population growth contributed to heightened CO_2 emissions. It is worth noting that economic growth was the predominant factor responsible for the most substantial increase in CO_2 emissions at 41% and 38% during 2016–2018 and 2018–2020, respectively. In the 2018–2020 period, despite a sharp decrease in CO_2 emissions resulting from reduced economic efficiency due to the impact of the COVID-19 epidemic 2020, there was a significant increase in household energy intensity. This increase led to a slight rise in total CO_2 emissions compared to 2016–2018. The influence of these three factors on the changes in emissions from energy consumption activities of household groups also varies significantly, depending on the source of energy consumed and the type of household group.

3.2.1. The Influence of Energy Intensity on Changes in CO_2 Emissions from Household Direct Energy Consumption

Energy intensity is a measure of the energy efficiency used by households in a country's economy. The energy intensity effect is the main factor slowing the growth of CO_2 emissions. Due to technological improvements, energy efficiency is increasing, leading to a decrease in household energy intensity.

Between 2016 and 2020, alterations in household energy intensity resulted in a decrease of 15.8 million tons of CO_2 (**Table 2**). Specifically, the reduction in energy intensity associated with firewood, rice husk, sawdust; agricultural by-products and other fuels; and briquettes and honeycomb charcoal markedly diminished CO_2 emissions, leading to a reduction of 9.2 million tons, 3.5 million tons, and 2.3 million tons of CO_2, respectively. The shift in the energy intensity of kerosene and charcoal results in a slight decrease in CO_2 emissions, suggesting potential for further reductions if such trends continue. Although the decline in energy intensity of firewood, rice husks, sawdust, agricultural by-products, and other fuels primarily decreases CO_2 emissions in rural households, the decrease in energy intensity of briquettes and honeycomb charcoal predominantly reduces CO_2 emissions in urban households.

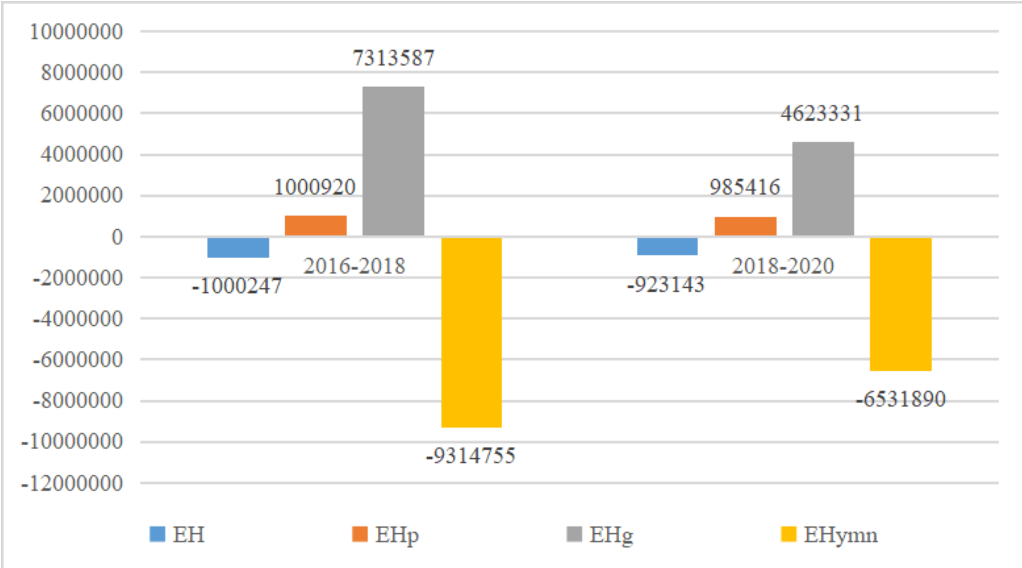

Figure 4. The influence of factors on changes in CO_2 emissions from household direct energy consumption (ton CO_2).
Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

Table 2. Changes in energy intensity and CO_2 emissions, influenced by energy intensity.

		LPG	Kerosene	Briquettes, Honeycomb Charcoal	Charcoal	Firewood, Rice Husk, Sawdust	Agricultural By-Products and Other Fuels	Electricity	Total
Change in energy intensity in 2016–2018	H1	0.0030	0.0001	–0.0082	0.0009	0.0007	–0.0038	–0.0022	**–0.0095**
	H2	–0.0188	–0.0005	–0.0247	0.0033	–0.0087	0.0085	–0.0396	**–0.0806**
	H3	0.0163	–0.0005	0.0022	–0.0028	–0.0774	–0.0491	0.0055	**–0.1059**
	H4	–0.0187	–0.0011	–0.0189	–0.0015	–0.0583	–0.0304	–0.0121	**–0.1412**
	Total	**–0.0183**	**–0.0021**	**–0.0497**	**–0.0001**	**–0.1438**	**–0.0748**	**–0.0484**	
Change in CO_2 emissions in 2016–2018	H1	52522	1332	–224444	28949	19522	–105967	–68720	**–296807**
	H2	–330899	–10438	–676269	102238	–243303	237421	–1230902	**–2152152**
	H3	285537	–10572	59794	–88371	–2155001	–1365742	171265	**–3103090**
	H4	–329132	–21654	–518201	–45836	–1623356	–846840	–377687	**–3762706**
	Total	**–321971**	**–41332**	**–1359120**	**–3020**	**–4002139**	**–2081128**	**–1506044**	
Change in energy intensity in 2018–2020	H1	0.0152	0.0002	0.0020	–0.0003	–0.0062	–0.0017	0.0666	**0.0758**
	H2	–0.0111	–0.0008	–0.0181	–0.0051	–0.0088	–0.0104	–0.0465	**–0.1009**
	H3	–0.0045	–0.0005	–0.0119	0.0014	–0.1198	–0.0209	–0.0168	**–0.1731**
	H4	0.0053	–0.0004	–0.0006	0.0028	–0.0238	–0.0104	0.0225	**–0.0047**
	Total	**0.0050**	**–0.0015**	**–0.0287**	**–0.0013**	**–0.1587**	**–0.0434**	**0.0258**	
Change in CO_2 emissions in 2018–2020	H1	312758	4456	62917	–9667	–202044	–54556	2419157	**2533020**
	H2	–228616	–18195	–579896	–187493	–286270	–337048	–1690111	**–3327628**
	H3	–91593	–11915	–381688	51216	–3895921	–681101	–611362	**–5622363**
	H4	109095	–9453	–19941	100218	–774879	–338664	818706	**–114919**
	Total	**101644**	**–35107**	**–918608**	**–45725**	**–5159115**	**–1411369**	**936390**	

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

The escalation in energy intensity of electricity and LPG results in an increase of 0.94 and 1.01 million tons of CO_2, respectively. Notably, during 2016–2018, emissions from these two types of fuel decreased; however, these indicators exhibited signs of a slight increase in 2018–2020. The decline in emissions of these two fuel sources during 2016–2018 is primarily concentrated in non-farming households in both urban and rural. These household groups, characterized by a higher average income than farming household groups, are more likely to possess energy-saving technologies. This ownership helps improve energy consumption efficiency and substantially reduces overall energy consumption and CO_2 emissions.

The increase in CO_2 emissions during 2018–2020, influenced by energy intensity, is primarily concentrated in groups of farming households in rural. These households represent the segment with the lowest average income among various groups, resulting in a limited ability to own electricity-saving technologies, particularly during periods of economic fluctuation such as the COVID-19 epidemic. The pandemic had multifaceted effects on energy intensity and CO_2 emissions, extending beyond the general economic slowdown. With lockdowns and restrictions on movement, energy consumption dropped in certain sectors, and residential energy use increased due to people spending more time at home, often relying more on electricity for heating, cooling, and entertainment. In parallel, the shift to remote work led to a decline in energy-intensive commuting but did not fully offset the increased residential energy demand. Additionally, the pandemic disrupted supply chains, slowing the transition to renewable energy projects and delaying the adoption of energy-efficient technologies. This circumstance leads to inefficient energy consumption, low energy consumption efficiency, and a substantial increase in CO_2 emissions.

For the remaining fuel types, the effect of energy intensity is negligible. In summary, the innovation in technologies that conserve energy, reduce emissions, and enhance household energy efficiency will be the most effective approach to reducing energy intensity, thereby contributing to the control of household CO_2 emissions.

3.2.2. The Influence of Population on Changes in CO_2 Emissions from Household Direct Energy Consumption

Population growth causes CO_2 emissions from household energy consumption to increase by nearly 2 million tons of CO_2 (**Table 3**). Among these, CO_2 emissions from electrical energy increased the most, accounting for over 50% of the total CO_2 emissions increase. Following this are emissions from firewood, rice husk, sawdust, LPG, agricultural by-products and other fuels, and briquettes, honeycomb charcoal. The influence of population on CO_2 emissions from the consumption of kerosene and charcoal fuels is insignificant.

Table 3. Changes in CO_2 emissions, influenced by population.

		LPG	**Kerosene**	**Briquettes, Honeycomb Charcoal**	**Charcoal**	**Firewood, Rice Husk, Sawdust**	**Agricultural By-Products and Other Fuels**	**Electricity**	**Total**
Change in CO_2 emissions in 2016–2018	H1	3929	79	5624	354	9423	3593	22355	**45356**
	H2	31503	907	30089	3325	12066	7056	203222	**288168**
	H3	22758	638	10095	1253	183932	43231	125597	**387504**
	H4	31931	798	10014	1695	63698	20982	150773	**279892**
	Total	**90122**	**2422**	**55822**	**6627**	**269119**	**74862**	**501947**	
Change in CO_2 emissions in 2018–2020	H1	9012	163	4629	654	8901	2279	54454	**80092**
	H2	30279	721	20188	2912	7792	7160	203775	**272826**
	H3	29160	479	8030	1009	143360	26016	142510	**350564**
	H4	34851	561	5214	2636	45823	10283	182565	**281934**
	Total	**103303**	**1923**	**38061**	**7211**	**205876**	**45738**	**583304**	

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

The impact of population growth causes an increase in CO_2 emissions from electricity and LPG consumption in non-farming household groups more than in farming households. Notably, the increase in emissions from urban farming households during 2018–2020, compared to 2016–2018, is significantly higher than in the other three household groups. This indicates that the pressure of high urbanization has led to a higher number of farming residents moving from rural to urban areas, causing the population of this household group in urban areas to increase faster than the remaining household groups. On the other hand, urban farming households tend to consume more electricity and LPG as income levels improve. Therefore, emissions caused by electricity and LPG consumption in this household group have increased. The trend of consuming more LPG and electricity to replace firewood, rice husk, sawdust, agricultural by-products and other fuels, and briquettes and honeycomb charcoal has resulted in a decrease in emissions from the consumption of these three forms of energy during 2018–2020 compared to the period 2016–2018 in household groups.

Population growth causes a rise in CO_2 emissions from the consumption of firewood, rice husks, sawdust, agricultural by-products and other fuels, predominantly in rural household groups. This increase is particularly pronounced in rural farming household groups, as they are the primary consumers of these two fuel sources in the economy. Consequently, with the rise in the population of this group of households, the consumption of firewood, rice husks, sawdust, agricultural by-products and other fuels experiences a rapid increase, leading to a significant upsurge in CO_2 emissions.

Meanwhile, CO_2 emissions from the consumption of briquettes, honeycomb charcoal increased more significantly in urban household groups than in rural ones, primarily escalating in urban non-farming household groups. Regarding the consumption of remaining fuels, population growth results in a negligible increase in CO_2 emissions.

3.2.3. The Influence of Economic Efficiency on Changes in CO_2 Emissions from Household Direct Energy Consumption

Economic efficiency plays a crucial role in the growth of CO_2 emissions from the direct energy consumption of household groups, with emissions increasing by 11.9 million tons of CO_2 during 2016–2020 (**Table 4**). Among these, CO_2 emissions from electrical energy experienced the most significant increase, accounting for over 50% of the total rise in CO_2 emissions. Subsequently, emissions from the consumption of firewood, rice husk, sawdust, LPG, agricultural by-products and other fuels, and briquettes, honeycomb charcoal. The impact of economic efficiency on CO_2 emissions from the consumption of kerosene and charcoal is relatively low compared to the remaining fuel groups.

The period 2018–2020 was affected by COVID-19, resulting in decreased GDP growth compared to the period 2016–2018. Consequently, economic efficiency declined, leading to lower emissions from energy consumption in all forms of energy in household groups compared to the previous period.

Table 4. Changes in CO_2 emissions, influenced by economic efficiency.

		LPG	Kerosene	Briquettes, Honeycomb Charcoal	Charcoal	Firewood, Rice Husk, Sawdust	Agricultural By-Products and Other Fuels	Electricity	Total
Change in CO_2 emissions in 2016–2018	H1	28031	562	42403	2341	68034	26806	162280	**330457**
	H2	230477	6639	222878	23279	89162	49250	1479884	**2101569**
	H3	162501	4696	72588	9740	1347344	323229	907503	**2827601**
	H4	233560	5940	76411	12617	473290	158279	1093863	**2053960**
	Total	**654569**	**17838**	**414281**	**47976**	**1977830**	**557564**	**3643530**	
Change in CO_2 emissions in 2018–2020	H1	41005	744	21398	3087	42253	10827	245949	**365263**
	H2	142156	3428	96247	14240	37362	34586	957227	**1285245**
	H3	136465	2275	38802	4534	682716	123806	667479	**1656077**
	H4	162347	2653	24412	11963	216607	49174	849590	**1316747**
	Total	**481973**	**9100**	**180858**	**33825**	**978938**	**218393**	**2720245**	

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

Higher economic efficiency results in higher CO_2 emissions from the consumption of most types of energy in rural household groups compared to urban household groups. Particularly for the consumption of briquettes and honeycomb charcoal, CO_2 emissions in urban household groups exceed those in rural household groups. Notably, emissions from the consumption of firewood, rice husks, sawdust, as well as agricultural by-products and other fuels in farming household groups in rural areas, and the consumption of electricity and briquettes, honeycomb charcoal in non-farming household groups in urban areas have increased sharply. Increased economic efficiency also significantly raises emissions from LPG and electricity consumption in urban farming household groups.

3.3. The Relationship between Economic Growth and CO_2 Emissions from Household Energy Consumption

During 2016–2020, the total decoupling indicator was negative, demonstrating a strong decoupling relationship between CO_2 emissions from household consumption and economic growth (**Figure 5**). This denotes a scenario wherein CO_2 emissions exhibit a decline while the economy's GDP experiences an increase. Upon examination of the decoupling indicator for each factor individually, it is observed that the relationship between CO_2 emissions and GDP varies. Under the influence of energy intensity, the relationship between CO_2 emissions and GDP is in a strong decoupling state. Under the influence of population, the relationship between CO_2 emissions and GDP is in a weak decoupling state. This signifies that CO_2 increases in parallel with economic growth, but the growth rate of emissions is lower than economic growth. Notably, under the influence of economic efficiency, the relationship between CO_2 emissions and GDP is in an expansive negative decoupling state. This indicates that the growth of CO_2 emissions exceeds that of economic growth. It is clear that, in the current context of Vietnam's rapid economic development, maintaining a sustainable state of strong decoupling requires concerted efforts to reduce energy intensity and limit population growth.

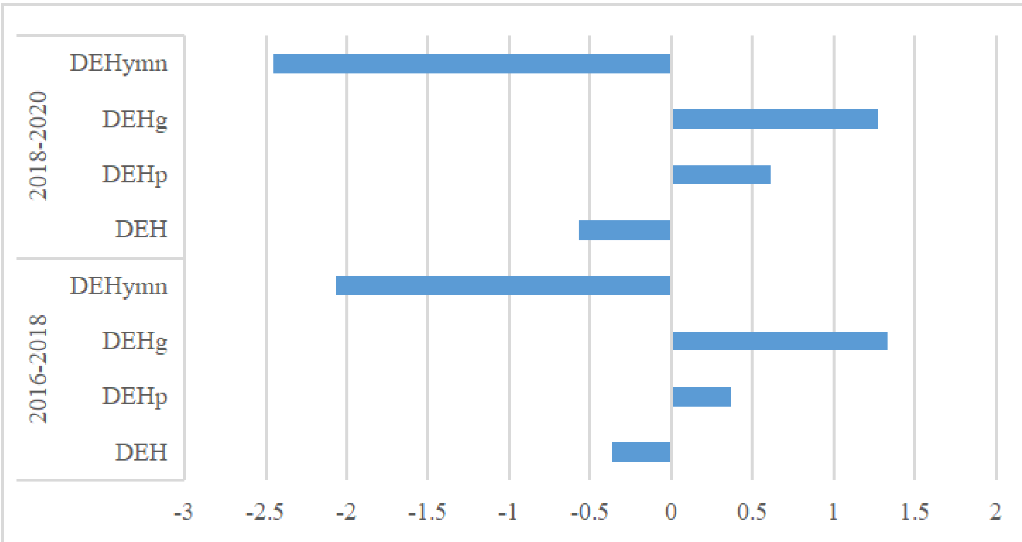

Figure 5. Total decoupling indicator for household CO_2 emissions and decoupling indicators for the population effect, economic activity effect, and energy intensity effect during 2016–2020.
Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

Based on the results of calculating the decoupling indicators for various forms of energy (**Figure 6**), it can be observed that the decoupling indicators for firewood, rice husk, sawdust, agricultural by-products and other fuels, and briquettes, honeycomb charcoal are negative. Consequently, the relationship between emissions from the consumption of these energy forms and GDP demonstrates a strong decoupling state. In contrast, the decoupling indicators for LPG and electricity are positive, indicating a weak decoupling, expansive coupling, and expansive negative decoupling state in the 2016–2020 period. Particularly noteworthy is a significant shift in the decoupling state for electricity from expansive coupling in the 2016–2018 period to expansive negative decoupling in the 2018–2020 period. This illustrates that the increasing electricity consumption poses a substantial risk of elevating emissions and altering the total decoupling state. However, owing to a significant decrease in the decoupling indicator for firewood, rice husks, sawdust, the total decoupling indicator in the second period is still maintained in a strong decoupling state. This underscores that the reduction of emissions from three forms of firewood, rice husks, sawdust, agricultural by-products and other fuels, and briquettes, honeycomb charcoal is a pivotal factor in ensuring the maintenance of a strong total decoupling state.

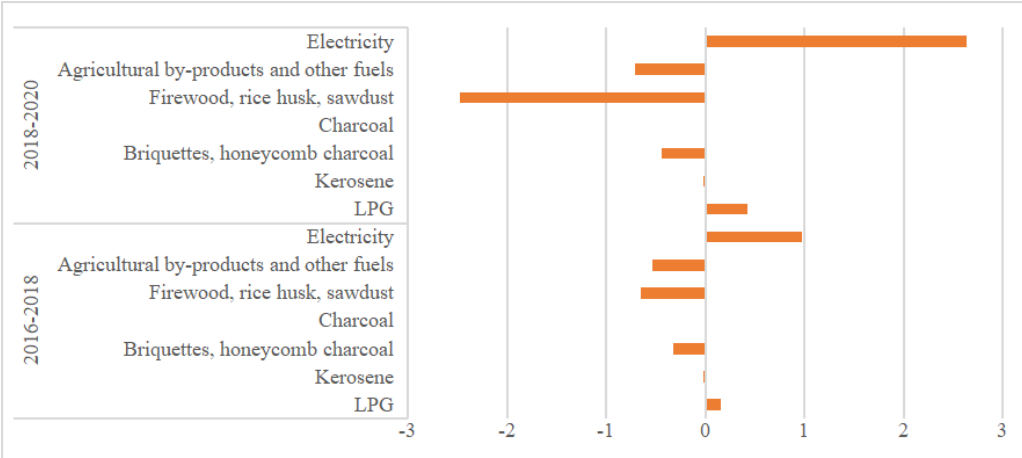

Figure 6. Decoupling indicators for energy types during 2016–2020.

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

The analysis of the decoupling indicator for each household group reveals noteworthy changes (**Figure 7**). Specifically, household groups H1 and H4 experienced rapid growth in their decoupling indicators, transitioning from weak decoupling and strong decoupling states in 2016–2018 to a state of expansive negative decoupling and expansive coupling in 2018–2020, respectively. In contrast, household groups H2 and H3 witnessed a decrease in their decoupling indicators, moving from a weak decoupling state in the 2016–2018 period to a strong decoupling state in the 2018–2020 period.

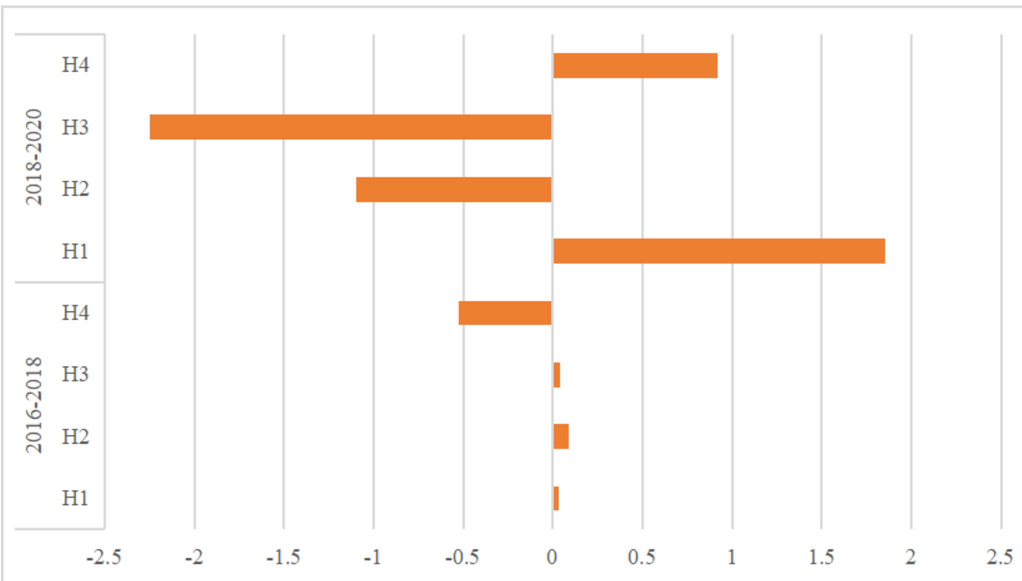

Figure 7. Decoupling indicators for household groups during 2016–2020.

Source: The author's calculations are based on data from Vietnam Energy Statistics 2020, VHLSS data from 2016, 2018, and 2020, data from the Center for Research and Development on Energy Saving, and data from the Vietnam General Statistics Office.

In conjunction with the findings presented in **Figures 2** and **3**, it is demonstrated that the primary driver behind the shift in decoupling states for groups H1 and H4 is the growing demand for electricity for various household activities. As urbanization accelerates, households H1, often involved in small-scale agriculture or urban farming, rely more heavily on electricity for irrigation, machinery, and cooling systems. This trend mirrors the broader urban development in Vietnam, where the rising standard of living and industrial growth leads to greater electricity consumption and increased CO_2 emissions. While households H4 were once less dependent on electricity, as local industries and small businesses (such as food processing or construction) expand, they face greater energy demands, particularly for industrial machinery and transportation. As a result, the emissions from these households increase, highlighting the challenge of decoupling state in rural non-agricultural areas where industrial growth is not yet paired with energy efficiency improvements or a transition to cleaner energy sources.

The reduction in the consumption of firewood, rice husks, sawdust emerges as the primary factor influencing the decoupling status of group H3. With the promotion of clean energy solutions, such as biogas and solar power, rural farming households have reduced their reliance on these traditional fuels. This shift is also driven by government policies focusing on promoting clean energy in rural areas and increasing awareness of the environmental and health impacts of biomass burning. The decline in biomass fuel consumption is a significant factor in the decoupling of emissions from economic growth in rural farming households, highlighting the role of clean energy solutions in promoting sustainable development in rural areas. For group H2, the transition in the decoupling state is notably attributed to the substitution of electricity with solar power. Urban non-farming households are increasingly adopting solar panels, particularly in urban areas where government incentives for renewable energy are more accessible and public awareness of environmental sustainability is higher. Additionally, reduced consumption of briquettes and honeycomb charcoal contributes significantly to the change in decoupling status for this group of households. This shift aligns with the growing focus on environmental sustainability and green technologies in urban areas, driven by government policies and consumer preferences for cleaner, renewable energy sources.

4. Conclusions and Recommendations

Based on the discussion, a comprehensive picture of the relationship between CO_2 emissions from direct energy household consumption and Vietnam has emerged. There are nine main conclusions drawn from the study:

1. The emission levels from direct energy consumption by households in 2016–2020 remained relatively high compared to the forecasted levels for 2020 by UNDP. This shows a challenge for Vietnam in reaching its goal of reducing net emissions to zero by 2050.
2. Research results indicated that income inequality caused the inequality in CO_2 emissions from energy consumption activities among different household groups. Therefore, income inequality can limit Vietnam's ability to engage in sustainable development. This result matches the findings in the study of Nguyen et al. [42].
3. SDA analysis results show that reduced household energy intensity is a significant limiting factor for CO_2 emissions, while population growth and increased economic efficiency contribute to the increase in CO_2 emissions. Compared to population growth, economic efficiency plays a more significant role in increasing CO_2 emissions from the direct energy consumption of household groups.
4. The increase in energy intensity for electricity and LPG leads to a rise in CO_2 emissions. In addition, the increase in emissions in 2018–2020 is mainly due to the impact of the COVID-19 epidemic, which limited the application of energy-saving technology by groups of rural farming households and led to higher emissions. The primary causes are financial, informational, and infrastructural barriers. Economic disruptions reduced household incomes further, making the upfront costs of technologies like solar panels or efficient farming equipment even more prohibitive. Moreover, supply chain issues limited the availability of these technologies in rural areas, while restrictions on movement disrupted awareness campaigns and technical support services. The reliance on traditional energy sources like firewood or kerosene intensified as infrastructure improvements stalled.
5. CO_2 emissions from electricity consumption increase the most compared to other forms of energy as the population grows. Depending on the source of energy consumed, the impact of population growth significantly increases CO_2 emissions in urban households and rural farming households.
6. Under the impact of economic efficiency, CO_2 emissions from the consumption of electric energy exhibit the most significant increase compared to other forms of energy. Increased economic efficiency leads to a sharp rise in CO_2 emissions from the consumption of firewood, rice

husk, sawdust, and other agricultural by-products and fuels in rural areas, as well as from the consumption of electricity, briquettes, and honeycomb charcoal in urban areas by non-farming household groups.

7. The relationship between CO_2 emissions from household consumption and economic growth in 2016–2020 is clarified as a strong decoupling. The findings indices indicate that the total strong decoupling still carries potential risks of change under the fluctuations of the component decoupling indicators.
8. The calculation results of decoupling indicators for various forms of energy reveal the relationship between emissions from electricity and LPG consumption and GDP growth exhibiting weak decoupling, expansive coupling, and expansive negative decoupling state during 2016–2020. The notable shift from expansive coupling in 2016–2018 to expansive negative decoupling in 2018–2020 for electricity indicates a significant risk of increased emissions with rising electricity consumption, contributing to a shift in the overall decoupling state.
9. The results of calculating the decoupling indicator for each household group indicate that increased electricity consumption has altered the decoupling state of groups H1 and H4 from weak decoupling and strong decoupling in 2016–2018 to expansive negative decoupling and expansive coupling in 2018–2020. This indicator shows that economic growth can lead to a sharp increase in CO_2 emissions from the electricity consumption of these two household groups.

Based on the above research results, we proposed the following recommendations to limit emissions from household energy consumption. First, there is a need to raise people's awareness about energy usage, focusing on electricity conservation and reducing the use of firewood, rice husks, and sawdust in cooking and living, particularly in rural households. Energy conservation is regarded as a national priority for both households and the government, particularly as energy prices rise and the implementation of carbon neutrality. Second, it is essential to encourage households to transition to clean energy sources with low carbon content, such as renewable energy, natural gas, solar energy, wind, and biogas, to minimize emissions. Third, there is a need to reduce energy intensity in household groups. To achieve this, there is a need to enhance social security policies, increase people's income levels, and narrow the income inequality gap between rural and urban areas. This will enable rural farming households to adopt many energy-saving technologies. Simultaneously, efforts should be made to attract investments in improving production technology and creating products at affordable costs. Fourth, comprehensive policies are required to control rapid population growth, particularly in rural areas. Fifth, the focus should be on developing policies to limit the adverse effects of the urbanization process, thereby curbing the growth of CO_2 emissions in urban areas. Sixth, there is a need for support policies for low-income household groups, such as urban farming households, in the event of economic shocks (e.g., pandemics and financial crises). Seventh, strengthening government incentives, such as subsidies for renewable energy installations and energy-efficient appliances, would accelerate the transition to cleaner energy sources, supporting Vietnam's goal to decouple economic growth from CO_2 emissions. In addition, expanding public awareness campaigns about the environmental and health benefits of renewable energy, especially in rural areas, would align with Resolution No. 55's objectives and foster a more sustainable energy future. Finally, urban areas, with their increasing electricity demand, could benefit from policies promoting grid-based renewable energy. On the other hand, rural regions should receive additional support for off-grid solutions like solar power and biogas. These targeted policies would complement Resolution No. 55's overarching goals and help address regional differences in energy use, ultimately facilitating a smoother and more inclusive transition to a sustainable energy system across Vietnam.

Author Contributions

Writing—original draft preparation, H.N.X.N.; writing—review and editing, H.N.X.N. and V.M.K.

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Institutional Review Board Statement

Ethical review and approval were waived for this study because it did not involve humans or animals.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data is unavailable due to privacy.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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