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Who emits more emission? the association between CO2 emissions and socio-economics characteristics of Indonesian household

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Abstract: Much research has been done on identifying socio-economic household links in developed countries. However, the study of household carbon emission (HCE) levels and related variables still needs to be examined, especially in developing countries. The study uses an ordinary least squares model to pinpoint the socio-economic elements that affect a household's carbon emission levels. SUSENAS (National Socio-economic Survey) data from March 2019 and 2021, covering 655,694 households, were used. This study used ordinary least squares (OLS) for the regression and dominance analyses (DA) to determine the most crucial factors affecting the HCE. The household characteristics, individuals, and residential conditions are used to measure socio-economic situations. The DA analysis shows that income and household size are the most crucial determinants of HCE. The OLS analysis reveals that the income variable exhibits a non-linear relationship with HCE as an inverted U-shape in the total HCE and most consumption categories. Wealthier households generate higher levels of household carbon emissions than poorer households. The variable of household size demonstrates a positive relationship with the HCE. The composition of household members also significantly affects household carbon emission levels, where the presence of working members and toddlers tends to increase household carbon emissions. The research also finds differences in consumption patterns between urban and rural households, resulting in varying levels of carbon emissions. The findings of this study can assist policymakers in formulating targeted policies to reduce household carbon emissions.
Keywords: Household Carbon Emission; Carbon Footprint; Household Level Data
JEL Classification: D13; I31; J22; K31

Introduction

Anthropogenic emissions represent one of the foremost drivers of climate change and environmental degradation (OWID, 2020). In response to this global challenge, the Paris Agreement of 2015, ratified by 191 countries (IRID, 2022), introduced the concept of net-zero emissions (NZE). NZE signifies a state in which emissions from human activities are balanced by nature's capacity to absorb them. Achieving NZE is essential to realize the objectives of the Paris Agreement, which include limiting the global average temperature increase between 1.5°C and 2°C compared to the pre-industrial era (IRID, 2022). Notably, CO2 emissions play a crucial role in attaining these Paris Agreement goals, as emphasized by a special report from the Intergovernmental Panel on Climate Change (IPCC, 2018). The swifter the reduction in CO2 emissions, the greater the likelihood of keeping the global temperature rise below 2°C. Numerous European, North American, South American, and Oceania countries have initiated efforts to curtail CO2 emissions, resulting in substantial reductions over the past two decades (OWID, 2020).

Nevertheless, despite these endeavors, global carbon emissions have yet to exhibit a significant decrease. In 2017, global CO2 emissions increased by 1.6% after deceleration from 2014 to 2016 (Figueres et al., 2017). Other reports indicate an uptick in CO2 emissions, particularly in Asian and African nations (OWID, 2020). Consequently, the drive to mitigate CO2 emissions must engage all countries, encompassing developed and developing nations and all stakeholders, including households.

Household participation is crucial because emissions from household consumption activities account for 72% of global greenhouse gas emissions and 70% of global CO2 emissions (Baiocchi et al., 2010; Hertwich & Peters, 2009; Niamir et al., 2020). For instance, household consumption in the United Kingdom contributes to 76% of the country's CO2 emissions (Baiocchi et al., 2010; Büchs & Schnepf, 2013). The sources of CO2 emissions stemming from household consumption encompass energy consumption, food waste, cooking fuel, transportation, and housing (Ala-Mantila et al., 2014; Lévay et al., 2021; Niamir et al., 2020; Purwanto et al., 2019). Household consumption significantly contributes to global carbon emissions, and altering household behavior can reduce global carbon emission regarding energy use and transitioning to low-carbon products and services (Alfredsson, 2004). However, while numerous studies have explored carbon emissions at the macro level, research at the household or micro level remains relatively limited (Seriño, 2017, 2020). Moreover, research on household carbon emissions (HCE) has predominantly been conducted in developed countries such as Belgium (Lévay et al., 2021), Japan (Hirano et al., 2016; Koide et al., 2019, 2021), China (Ding et al., 2019; Xu et al., 2016; Yuan et al., 2019; Zeqiong & Junfei, 2021), and UK (Baiocchi et al., 2010; Büchs & Schnepf, 2013). In contrast, there is still limited research on HCE in developing countries, including Indonesia.

In Indonesia, studies by Irfany & Klasen (2017) and Saras & Kristanto (2021) stand out as some of the few studies examining HCE levels and their connection with household socio-economic conditions. However, these studies' data require updating to reflect current circumstances accurately. Furthermore, previous research has primarily concentrated on analyzing overall HCE without empirically identifying the key factors influencing household carbon emissions. The emergence of the COVID-19 pandemic has also exerted a substantial influence on this situation, with Indonesia being one of the nations significantly impacted by the pandemic, leading to considerable shifts in household consumption patterns (Aktar et al., 2021; Komarulzaman et al., 2023).

This study addresses these gaps by comprehensively analyzing factors influencing household CO2 emissions. Moreover, it employs the dominance analysis method to examine the most significant determinants of household CO2 emissions empirically.

Identifying these factors that impact household carbon emissions equips decision-makers with the tools to effectively plan and implement actions to control and reduce emissions from the perspective of household consumption (Irfany & Klasen, 2017). Tailoring emissions measurement, control, and reduction strategies to the local context of each country is essential, considering that household consumption is responsible for most CO2 emissions.

Theoretical Framework

Household emissions are one form of negative externality originating from the consumer side and affecting other economic actors. Household emissions are generated by household members to fulfill their needs at a certain socio-economic level (Qu et al., 2013). The theoretical framework **(Figure 1)** employed in this research posits that HCE may be subject to influence from various factors including household (e.g., income, number of household members and household member composition), individual (e.g., age, education level, and gender), residential (e.g., residential status and residential region) socio-economic characteristics, and external economic disruptions such as the COVID-19 pandemic (Ding et al., 2019; Irfany & Klasen, 2017; Lévay et al., 2021; Saras & Kristanto, 2021; Seriño & Klasen, 2015; Aktar et al., 2021; O'Garra & Fouquet, 2022).

Diverse socio-economic conditions within households can influence variations in household consumption patterns. These differences in consumption patterns lead to discrepancies in household carbon emissions (Irfany & Klasen, 2017; Lévay et al., 2021). Conversely, individual characteristics may be associated with HCE through individual productivity and preferences influenced by educational attainment (Williamson, 2017; Lévay et al., 2021). Furthermore, numerous studies have compared household emissions generated by urban and rural households, possibly attributed to differences in consumption patterns. These disparities in consumption patterns may arise due to limited access to various commodities in rural areas (Ala-Mantila et al., 2014; Hartono et al., 2023) Among these factors, household income level stands out as the most influential factor in determining HCE, with a consistently positive relationship observed (Ala-Mantila et al., 2014; Cox et al., 2012; Irfany & Klasen, 2017; Lévay et al., 2021; Mach et al., 2018; Seriño, 2020; Yaguchi et al., 2007). This relationship implies that higher income increases consumption, elevating HCE levels. However, other studies have shown a non-linear relationship between income variables and HCE levels, aligning with the Environmental Kuznets Curve (EKC) hypothesis (Irfany & Klasen, 2017; Seriño & Klasen, 2015). This non-linear relationship suggests that as income rises, households may opt for more environmentally friendly goods, even at higher prices, due to increased consumption capacity (Seriño & Klasen, 2015).

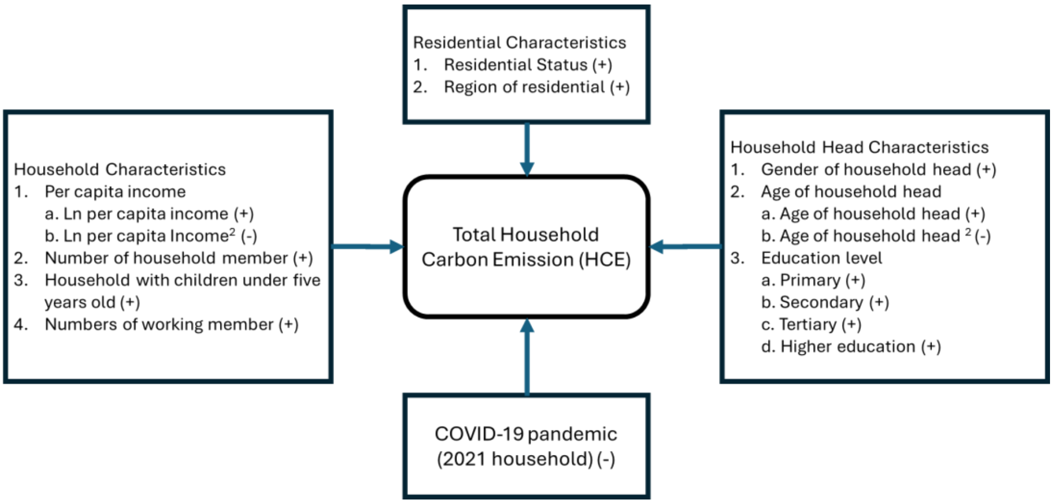


Figure 1 The relationship between household, individual, residential socio-economic characteristics, and COVID-19 pandemic on total household carbon emission

In addition to income, the number of household members emerges as another critical factor influencing HCE levels. Research indicates that an increase in household size corresponds to greater product consumption, indirectly leading to higher HCE levels (Irfany & Klasen, 2017; Lévay et al., 2021). Furthermore, the composition of household members plays a role in HCE, with the number of children and working members positively related to HCE levels (Koide et al., 2019; Lévay et al., 2021). The presence of children increases household activity, potentially leading to higher energy and food consumption. Meanwhile, more working members contribute to increased household income and consumption capacity (Koide et al., 2019; Lévay et al., 2021).

Individual characteristics, particularly household heads, influence HCE levels (Koide et al., 2019; Lévay et al., 2021; Seriño & Klasen, 2015). Previous studies have identified a quadratic relationship between HCE levels and the age of household heads (Koide et al., 2021; Lévay et al., 2021; Seriño & Klasen, 2015), suggesting that HCE initially rises with the increasing productivity of the household head but eventually declines after reaching an optimal point coinciding with decreased productivity. However, other studies have indicated a positive linear relationship between age and HCE levels, positing that growing age increases consumption needs (Adnan et al., 2018; Hirano et al., 2016). Furthermore, studies by Koide et al. (2019) and Xu et al. (2016) have suggested that households headed by males tend to produce more carbon emissions, while others have found that female-headed households lead to higher carbon emissions (Büchs & Schnepf, 2013; Irfany & Klasen, 2017; Seriño, 2017; Seriño & Klasen, 2015). These variations may stem from differing consumption behaviors between male and female-headed households. Male household heads with high mobility tend to prefer private, meaning that they prefer carbon-intensive than public transportation, while female household heads tend to have energy-intensive consumption such as heater and cooking fuel (Büchs & Schnepf, 2013; Koide et al., 2019).

The relationship between the education level of the household head and HCE levels has produced mixed results. Some studies have found a positive association (Lévay et al., 2021; Seriño, 2020; Seriño & Klasen, 2015), while others have reported the opposite (Lan et al., 2012; Mahmood et al., 2019). In contrast, specific research has suggested that the education level of the household head does not significantly impact HCE levels (Williamson, 2017; Xu et al., 2016). These discrepancies highlight the complex relationship between education and HCE, which can lead to higher consumption of environmentally harmful goods but may also promote environmentally friendly technologies and environmental awareness (Lan et al., 2012; Williamson, 2017).

Homeownership tends to be associated with higher HCE levels due to homeowners' generally greater economic capacity (Lévay et al., 2021). Additionally, disparities in HCE levels between rural and urban households have been identified, with urban households typically exhibiting higher HCE levels (Hartono et al., 2023; Seriño & Klasen, 2015). Urban households tend to have greater energy consumption and mobility (Hartono et al., 2023), while rural households may rely on conventional energy sources like oil and coal, leading to higher emissions, particularly in the energy and transportation sectors (Ala-Mantila et al., 2014, 2016; Büchs & Schnepf, 2013). This situation may be exacerbated by high-income rural communities consuming carbon-intensive products (Tian et al., 2016; Wang & Sun, 2014).

Furthermore, structural breaks, including the multidimensional crisis of the COVID-19 pandemic, have introduced significant changes in CO2 emissions. Recent research indicates a substantial decrease in global CO2 emissions, with 7.5% reduction in 2020 (Friedlingstein et al., 2020) due to pandemic-related activity restrictions, particularly in the energy and transportation sectors (Aktar et al., 2021; O'Garra & Fouquet, 2022). Public transport emissions, such as those from trains, planes, buses, and ships, witnessed significant declines during this period (O'Garra & Fouquet, 2022).

Research Method

Household Carbon Emission

Household Carbon Emission (HCE) represents the cumulative CO2 emissions that households generate through their consumption activities. At the household level, carbon emissions can be classified into two components: direct HCE (C_{dir}) and indirect HCE (C_{ind}) (Mach et al., 2018; Zeqiong & Junfei, 2021; Zhang et al., 2017). Direct HCE results directly from consumption activities and is typically associated with energy consumption, such as electricity use, heating, and transportation. On the other hand, indirect HCE arises from energy consumption in the production processes of commodities, including food, durable goods, clothing, and services (Mongelli et al., 2006). The Total HCE (C_{tot}) can be represented as the sum of these two components:

$$C_{tot} = C_{dir} + C_{ind} \quad (1)$$

This study employs an Environment Extended Input-Output (EEIO) analysis approach based on calculations by Renner et al. (2018) to calculate the influence of both direct and indirect emissions. The following equation expresses the fundamental structure of input-output analysis:

$$X = (I - A)^{-1}Y \quad (2)$$

In the equation, $\boldsymbol{X}$ represents the vector of total output, $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ represents the multiplier coefficient, also commonly referred to as the Leontief matrix, and $\boldsymbol{Y}$ represents the vector of final demands. To calculate the HCE levels, this study combines carbon intensity data from input-output analysis with expenditure data from the 2019 and 2021 National Socio-economic Surveys (SUSENAS). This research utilizes the latest available Indonesian input-output table, specifically the 2016 Input-Output Table, which includes 185 sectors and commodities from various industries in Indonesia (BPS, 2016).

This research utilizes carbon coefficients data from the Global Trade Analysis Project (GTAP) for the years 2019 and 2021 to calculate the Indirect carbon emission by using the following equation:

$$C_{ind} = c'(I - A)^{-1}Y \quad (3)$$

In this equation, $\boldsymbol{c}'$ represents the carbon coefficient vector for Indonesia's industry sectors. The carbon coefficient is calculated from all production processes, such as energy use, energy conversion, carbon intensity ratio, and emission factors from each industrial sector (Irfany & Klasen, 2017; Renner et al., 2018). The term $c'(I - A)^{-1}$ represents Carbon Intensity (CI), which accounts for direct and indirect carbon emissions. Furthermore, this study adjusts the GTAP data and IO table to reconcile differences in the number of sectors and commodities between the two datasets. This adjustment links sectors and commodities in the GTAP and IO tables. The carbon emissions for each product consumed by households are obtained using the following equation:

$$HCE_i = \sum_{j=1}^{n} CI_j \times exp_{ji} \quad (4)$$

Thus, HCE represents the total HCE generated by household (*i*). In addition, CI_j represents carbon intensity, quantifying the carbon emissions resulting from increased consumption of goods or services (*j*), and exp_{ji} represents the household expenditure (*i)* on the consumption of goods and services (*j*).

Data

This study utilizes data from the National Socio-economic Survey (SUSENAS) for 2019 and 2021. SUSENAS is published twice a year, in March and September. The March SUSENAS dataset represents the district level and covers approximately 300,000 households. In contrast, the September SUSENAS is representative at the provincial level and includes data from around 70,000 households. The 2019 data represent the socio-economic conditions of households before the onset of the COVID-19 pandemic, while the 2021 data reflect the socio-economic conditions of households during the pandemic. SUSENAS 2019 and 2021 published by BPS consist of a large-scale household data set with 315,672 households in 2019 and 340,032 households in 2021. After cleaning the data, this study used 315,668 household data in 2019 and 340,026 household data in 2021, with a few (a total of 10 households) data dropped caused of missing value on the emissions variable. SUSENAS is divided into two main parts: "Kor" and "Modul." The "Kor" section contains information about the characteristics of households and individuals residing in those households. The "Modul" section comprises three types: (1) consumption, (2) education and socio-cultural, and (3) health and housing. This research uses SUSENAS data from the "kor" section and the consumption module to conduct its analysis. The consumption module elucidates the total expenditures and household income within a specific period. The Consumption Module in SUSENAS is designed to obtain detailed information on how households allocate their income for various purposes, including food, housing, transportation, education, durable goods, and health.

Model

To investigate the relationship between socio-economic factors and HCE, the study performs an Ordinary Least Squares (OLS) regression model:

$$\ln(HCE)_i = \alpha + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \delta_i Y_i + \sum_{i=1}^{n} \gamma_i Z_i + \theta_1 Covid_i + \hat{\varepsilon}_i \text{ ....} \quad (5)$$

In the equation, $\ln(HCE_i)$ is the natural logarithm of household carbon emission, $\boldsymbol{X_i}$ is the vector of household characteristics, $\boldsymbol{Y_i}$ is the vector of individual factors, and $\boldsymbol{Z_i}$ is the vector of residential conditions. Meanwhile, $Covid_i$ represents a household dummy variable for the COVID-19 pandemic period, taking a value of 1 during the pandemic period and 0 before the pandemic. The household characteristics used in this study include per capita income, household members, households with toddlers, and the number of people working within the household. The per capita income variable is transformed into natural logarithm form, and the households with toddler variable is a dummy variable with a value of 1 if there is at least one toddler in household and 0 if there is none. The individual characteristics considered are age, gender, and education level of the household head. Gender is a dummy variable, with 1 for male household heads and 0 for female household heads. The education level is categorized into no schooling, elementary school, junior high school, senior high school, and college. The residential conditions include the region variable, taking a value of 1 for urban areas and 0 for rural areas, and the homeownership status variable, taking a value of 1 for private residences and 0 otherwise.

In this study, household emissions are categorized into several consumption categories, namely food, beverages, and tobacco (e.g., staple foods, meats, vegetables, and processed foods), housing (e.g., home maintenance and rent payments), energy (e.g., electricity, gas, and kerosene), public transportation (e.g., costs of train, bus, sea, and air travel), private transportation (e.g., motor vehicle fuel and maintenance costs), other goods (e.g., clothing and durable goods), and other services (e.g., education and health). This research divides households into five income categories to depict emission characteristics within income groups. The first group comprises households with the lowest 20 percent income, while the fifth group comprises the highest 20 percent.

Additionally, this study performs Dominance Analysis (DA) to identify the socio-economic characteristics that relatively exert the most influence on HCE levels by decomposing general fit statistics (R-square) following the approach of Azen & Budescu (2003) and Luchman (2015). DA is conducted because OLS estimation results alone cannot determine the primary socio-economic characteristics that relatively influence HCE variations. DA entails determining all model combinations of the independent variables and calculating the R-square for each combination. The additional contribution of an independent variable is defined as the increase in R-square resulting from its inclusion in a model without that variable. DA is then measured by calculating the average additional R-square for each independent variable across all possible model combinations, with the most dominant variable being the one with the highest average additional R-square.

Result and Discussion

Descriptive Analysis

In this study, 655,694 households were analyzed, comprising 315,668 households from 2019 and 340,026 from 2021. Table 1 shows an 11.54% decrease in per capita income in 2021 compared to 2019. Approximately 25% of Indonesian households have children under five years old, and a majority (84%) of household heads are male. Over two years, there was an increase in urban households, growing from 49.7% in 2019 to 56.8% in 2021.

Table 1 Summary Statistics for each variable

Variable	2019		2021	
	Mean	Std. Dev	Mean	Std. Dev
Household Carbon Emission	2,378.52	2,785.02	2,288.62	2805.29
Per capita Income	15,595	20958.69	13,795.33	14376.07
Household Size	3.66	1.63	3.59	1.56
Households with children under five years	0.26	0.44	0.25	0.43
Number of working household members	1.55	0.91	1.52	0.90
Gender of Household Head	0.83	0.36	0.85	0.35
Age of household head	49.48	0.01	48.71	0.01
Year of education	8.04	4.28	8.47	4.38
Residential status	0.82	0.37	0.81	0.39
Region	0.49	0.49	0.56	0.49
Observation	315,668		340,026	

Source: SUSENAS database, author’s computations

This research investigates the characteristics of HCE based on five per capita income groups and compares HCE levels between 2019 and 2021. The HCE level in 2019 (2,378 kgCO2eq) was generally lower than in 2021 (2,289 kgCO2). This decrease in HCE could be caused by the COVID-19 pandemic, which requires activity restrictions, reducing mobility significantly. This is illustrated in Figure 2, showing a substantial decline of -52.10% in HCE from public transportation consumption categories, followed by private transportation (3.81%) and services (-2.92%).

This pattern indicates that activity restrictions during the COVID-19 pandemic have a pronounced impact on HCE levels, particularly within the transportation consumption category. Notably, emissions increased only in the housing consumption category during the pandemic because most people stayed home. HCE from housing consumption rose by 9.19% in 2021 compared to 2019. Conversely, there was a reduction in emissions from food, beverage, and tobacco (-2.88%) and energy categories (-1.15%), most likely caused by a decrease in consumption quantity in several categories.

Figure 3 presents HCE levels based on five household income groups, ranging from the lowest 20% income group to the highest. Higher income groups correlate with higher total CO2 emissions, while CO2 emissions increased gradually from groups one to four. However, there is a significant increase in the fifth income group. This highlights that higher-income households tend to have more carbon-intensive consumption patterns (Irfany & Klasen, 2017; Seriño & Klasen, 2015).

Despite differences in the total HCE levels among income groups, similar patterns emerged in the proportion of emissions based on consumption categories within each income group. Private transportation and energy consumption categories consistently stood out as the most carbon-intensive, contributing to over 70% of total household emissions across all income groups. However, the first income group displayed some differences, with energy consumption (44%) having a higher proportion of emissions than private transportation consumption (31%) in 2019 and 2021.

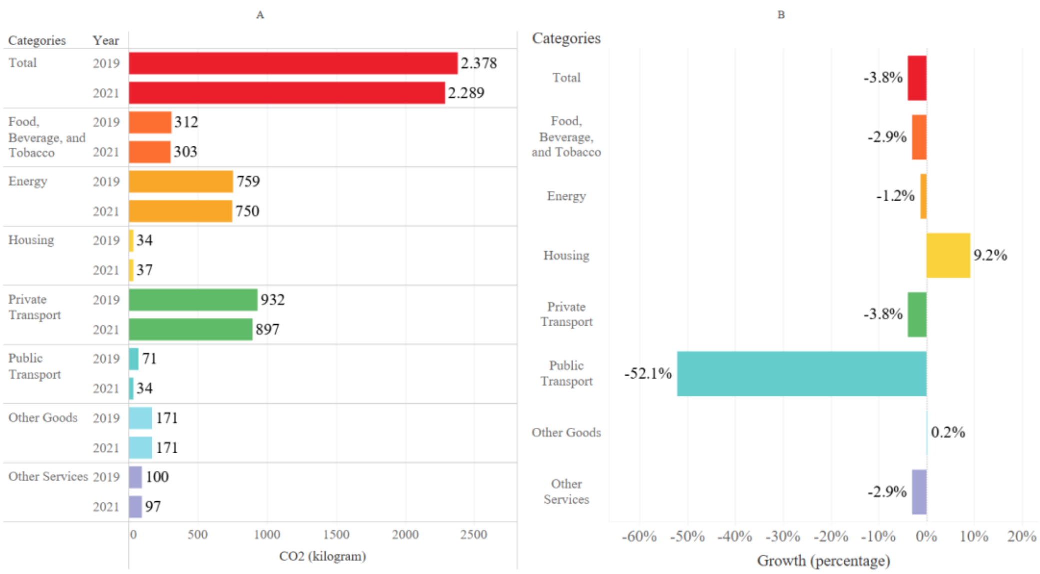
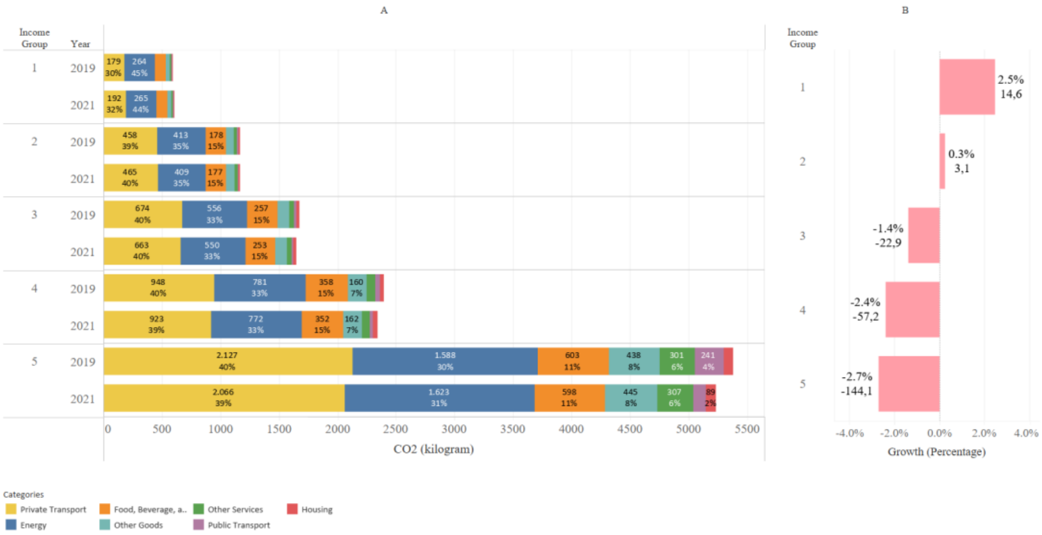


Figure 2 Average of HCE (A) and growth of HCE (B) CO2 by consumption categories
Source: SUSENAS database, author's computations



Notes: Figure (**A**) is Expressed in percentage proportion of CO_2 emission by consumption categories (e.g., food, beverage, tobacco, housing, energy, private transportation, public transportation, other goods, and other services) with a total of 100%, however, due to space constraints, only notable proportions are displayed.

Figure 3 Average of HCE (A) and growth of HCE (B) CO2 by household income level
Source: SUSENAS database, author's computations

Overall, differences were observed in the growth of CO2 emission levels within each income group from 2019 to 2021. The first- and second-income groups experienced increased emission levels, while the third, fourth, and fifth groups experienced decreased CO2 emissions. The average change in household emissions was in the first group 14.6 kgCO2, the second group 3.1 kgCO2, the third group -22.9 kgCO2, the fourth group -57.2 kgCO2, and the fifth group -144.1 kgCO2. This phenomenon suggests that higher income households were more capable of reducing their emissions during the COVID-19 pandemic than the lower income households, as they initially consumed more goods and services. On the other hand, the lowest 20% income group witnessed an increase in emissions, primarily due to higher emissions from private transportation consumption, with minimal reductions in different areas. This can be attributed to the fact that households in this income group can only afford minimal levels of goods and services. Thus, the impact of reduced consumption during the pandemic is limited.

Regression Analysis

Table 2 presents the results of the OLS estimation, exploring the relationship between household socio-economic conditions and HCE levels across various consumption categories, including food, beverage, tobacco, energy, housing, private transportation, public transportation, goods, and services.

Table 2 Pooled cross-section OLS regression results on the natural logarithm of household carbon (CO2) emission in kilogram by consumption categories

Variable	Total	Consumption Categories						
		Food	Energy	Housing	Private Transportation	Public Transportation	Other Goods	Other Services
Household characteristics								
Ln Income per capita	3.63***	4.65***	2.71***	6.77***	1.51***	-0.37***	3.00***	2.99***
Ln Income per capita^2	-0.07***	-0.11***	-0.05***	-0.16***	-0.02***	0.04***	-0.05***	-0.05***
Numbers of Household Member	0.25***	0.23***	0.21***	0.35***	0.18***	0.27***	0.28***	0.44***
Household with children under five years old (Ref. No)	0.04***	0.01***	0.06***	-0.07***	0.01***	-0.07***	0.09***	-0.03***
Numbers of working member	0.01***	0.02***	-0.03***	0.02***	0.04***	-0.04***	0.01***	-0.09***
Household head characteristics								
Gender of household head (Ref. female)	0.14***	0.12***	0.06***	0.04***	0.11***	-0.13***	0.07***	0.07***
Age of household head	17.65***	3.48***	25.25***	13.29***	8.65***	-4.33***	3.34***	21.56***
Age of household head^2	-0.18***	-0.05***	-0.20***	-0.17***	-0.10***	0.03***	-0.07***	-0.22***
Education level (Ref. lower Primary)								
Primary	0.29***	0.07***	0.46***	0.27***	0.04***	-0.19***	0.08***	0.24***
Secondary	0.34***	0.07***	0.54***	0.36***	0.05***	-0.14***	0.11***	0.27***
Tertiary	0.35***	0.05***	0.58***	0.43***	0.06***	-0.09***	0.12***	0.31***
Higher Education	0.36***	-0.001	0.60***	0.47***	0.11***	0.04***	0.14***	0.38***
Residential characteristics								
Residential Status (Ref. not owned by household)	0.03***	-0.01***	-0.01**	-0.20***	0.06***	-0.20***	0.04***	0.07***
Region (Ref. Rural)	0.08***	0.02***	0.19***	0.13***	-0.02***	-0.21***	-0.01***	0.11***
Covid-19 pandemic period (Ref. before Covid-19)	-0.07***	-0.05***	-0.06***	0.07***	-0.04***	-0.49***	-0.05***	-0.07***
Constant	-32.76***	-40.83***	-25.14***	-65.16***	-13.35***	-3.10***	-31.05***	-34.34***
Observation	655,694	655,694	654,645	628,794	507,055	480,676	655,678	647,042
R-Square	0.670	0.767	0.346	0.490	0.336	0.152	0.666	0.419

Notes: Table 2 presents the estimation results of household socio-economic factors on household carbon emission (HCE) behavior. Ref. referring to the comparison group (reference group). The HCE level variable has been transformed into a natural logarithmic form. Ln. The results show variables in a natural logarithm form. Significant level *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: SUSENAS database, author's computations

Table 3 Result of Dominance Analysis on Pooled Cross-Section OLS Regression by Consumption Categories

Variable	Total	Food	Energy	Housing	Private Transportation	Public Transportation	Other Goods	Other Services
Income per capita	79.0	70.3.	77.1	75.2	77.1	76.0	80.5	70.7
Numbers of Household Member	11.2	13.0	9.0	12.3	12.4	9.6	11.1	19.6
Household with children under five years old	0.8	9.0	0.7	0.6	0.6	0.5	1.9	1.0
Numbers of working household member	1.0	1.5	0.4	1.6	1.5	2.2	0.6	0.7
Gender of household head	1.1	1.2	0.3	0.4	0.7	0.2	0.9	0.6
Age of household head	1.3	1.2	1.4	1.4	0.7	0.3	1.2	1.4
Education level	3.5	1.7	6.6	4.7	2.7	4.5	2.7	3.6
Residential Status	0.2	0.1	0.2	1.2	0.5	0.7	0.2	0.2
Region	1.5	1.2	4.1	2.2	1.3	0.5	0.7	1.8
Covid-19 pandemic period	0.5	0.8	0.2	0.4	2.5	5.6	0.3	0.3

Source: SUSENAS database, author's computations

Household Characteristics Effect

The variable of per capita income emerges as the most influential factor on HCE levels. As shown in Table 3, per capita income is the dominant variable impacting HCE levels in all consumption categories. The relationship between per capita income, HCE levels, and most consumption categories exhibit a non-linear pattern. This includes food, beverage, tobacco, energy, housing, private transportation, public transportation, other goods, and other services. The results indicate a significant, negative coefficient for the squared income, signifying an inverted U-shaped relationship with diminishing marginal emissions (leveling off) except for the public transportation category. These findings align with previous studies, supporting the Environmental Kuznets Curve (EKC) hypothesis (Irfany & Klasen, 2017; Seriño & Klasen, 2015), indicating that it also happens in Indonesian households in most consumption categories. In simpler terms, as income increases, HCE levels rise due to higher consumption; however, at a certain income threshold, households have the financial capacity to select lower-emission goods, even at higher prices (Irfany & Klasen, 2017; Seriño & Klasen, 2015).

On the other hand, the relationship between per capita income and public transportation exhibits a U-shaped pattern, with a positive coefficient in the quadratic form of per capita income. This indicates that with increasing revenue, there is a shift in mobility from public to private transportation. At a certain income level, emissions from public transportation increase, often associated with recreation and tourism.

Table 3 reveals that the number of household members is the second most influential factor, after per capita income, on HCE levels across all consumption categories, except services, where the number of household members takes precedence. Increasing the number of household members, on average, leads to higher emissions across various consumption categories, including food, beverage, and tobacco (24%), energy (20%), housing (34%), private transportation (45%), public transportation (20%), other goods (26%), and other services (41%). This increase translates to an average overall increase in total HCE by 24%.

In addition to the number of household members, the composition of the household also impacts HCE levels, particularly in the context of energy consumption (Huang, 2015). Households with family members under five years of age tend to produce higher total HCE levels (Lévay et al., 2021) primarily due to additional emissions from energy and food consumption (Huang, 2015; Lévay et al., 2021). This aligns with the findings in Table 2, where households with children under five years old tend to generate greater HCE due to significant emissions from energy and food consumption. However, toddlers in the household negatively and significantly affect HCE levels in housing, public transportation, and other service categories. This result is consistent with existing research suggesting that having children reduces emissions in transportation consumption categories, as households with young children tend to minimize travel frequency and house renovation (Büchs & Schnepf, 2013). However, there is an increase in household emissions in the private transportation sector due to the presence of toddlers within households. This condition indicates reduced mobility within households with toddlers and a shift from public to private transportation.

The estimation results from Table 2 also indicate a positive relationship between the number of working household members and total household carbon emissions. This finding is consistent with the studies by Lévay et al. (2021), Büchs & Schnepf (2013), and Koide et al. (2019). With an increase in the number of employed individuals, household consumption capacity is expected to rise due to additional income from those employed, consequently leading to increased household emissions (Koide et al., 2019). However, as the number of working members increases, household energy consumption, such as electricity and gas usage, will likely decrease, resulting in a decrease of HCE from the energy consumption category. Nevertheless, with more individuals employed, emissions from the category of private transportation consumption also increase due to the heightened mobility of household members commuting to work (Büchs & Schnepf, 2013; Lévay et al., 2021).

Individual Characteristics Effect

As shown in Table 2, the age of the household head exhibits a non-linear relationship with HCE levels, representing an inverted U-shaped pattern with most consumption categories. This indicates that HCE levels increase with the age of the household head up to a certain point. Subsequently, HCE levels tend to decrease as the household head grows older. Young households tend to generate lower HCE levels, with HCE levels increasing as economic capabilities mature (Lévay et al., 2021). Conversely, HCE levels tend to decrease in older households due to reduced productivity and changes in household members' consumption patterns (Büchs & Schnepf, 2013).

Furthermore, gender variables have a significant favorable influence on HCE levels. Households headed by males tend to generate higher HCE than those headed by female in all consumption categories except for public transportation. This aligns with previous research, indicating that male-headed households exhibit higher mobility and more carbon-intensive consumption patterns, such as greater reliance on private vehicles and energy (Büchs & Schnepf, 2013; Koide et al., 2019; Xu et al., 2016).

On the other hand, differences in emission levels are also attributed to the economic conditions of households headed by men, which tend to be better than those headed by women (Ahmad et al., 2018; Aryal et al., 2019). Therefore, with higher economic capability, the emitted emissions also tend to be higher on average. The education level of the household head consistently emerges as one of the primary factors influencing HCE levels across all consumption categories, as seen in Table 3. Table 2 demonstrates that the education level of the household head has a positive relationship with HCE levels in most consumption categories. This finding aligns with prior studies by Seriño & Klasen (2015) and Lévay et al. (2021) that assert that a higher education level of the household head corresponds to increased HCE levels. The increase in economic capability resulting from higher education levels can be observed in the private and public transportation consumption categories. With higher levels of education, there is a shift in consumption patterns from public transportation to private transportation (Lévay et al., 2021). However, this finding contradicts other studies that suggest increased education is expected to raise environmental awareness and, at a certain level, prompt households to adopt more environmentally friendly lifestyles (Lan et al., 2012; Williamson, 2017). The shift in lifestyles can be observed in Table 2, where although HCE generally rises with the educational level of the household head, there is a point at which this increase plateaus. Notably, in the category of food, beverage, and tobacco consumption, households with higher education tend to produce fewer carbon emissions than those led by individuals who have not completed elementary school or are uneducated.

Additionally, Tables 2A and 2B reveal significant differences in the coefficient magnitudes for the variable of household head education level. The estimations indicate that the disparity in household carbon emissions among education level groups has become more pronounced in 2021 compared to 2019. This condition may arise due to a significant decrease in consumption among households with lower education levels, which tend to have lower economic capabilities (Ali et al., 2020). It suggests that education is a crucial factor in maintaining household consumption levels, with higher education levels tending to exhibit more excellent stability in consumption patterns due to higher economic capabilities (Lévay et al., 2021).

The Effects of Residential Characteristics

Households in urban regions tend to generate more HCE than their rural counterparts, primarily in the categories of energy and transportation. This difference can be attributed to higher energy consumption, such as electricity and less efficient transportation systems in urban areas, resulting in more significant emissions (Hartono et al., 2023; Seriño & Klasen, 2015). On the other hand, households in rural regions face substantial barriers to access sufficient energy consumption (Hartono et al., 2023). The disparities become more apparent when comparing the estimation results in Tables 2A and 2B, and there are differences in total household emissions between rural and urban areas before and during the COVID-19 pandemic. The estimation results for households in 2019, as shown in Table 2A, indicate that urban households tend to produce higher carbon emissions by 4%. However, the estimation results 2021 show a higher difference, with urban households emitting 13% more carbon than rural households. In addition to reduced consumption, disparities in access to various commodities, such as fuel and energy, contribute to differences in carbon emissions between urban and rural households (Aktar et al., 2021; Hartono et al., 2023).

Households with residential ownership status tend to produce higher total HCE levels across all consumption categories except housing and public transportation. This phenomenon is linked to the tendency of households with private residences to have more matured economic capabilities, allowing them to consume more goods and produce higher levels of HCE (Lévay et al., 2021). Conversely, households with residential ownership status tend to produce lower emissions from the public transportation category. This can be attributed to the residential patterns in urban areas, where industrial centers and offices are often located far from residential areas, leading to the increased use of private vehicles for mobility (Büchs & Schnepf, 2013; Koide et al., 2019). This condition is inversely proportional to rental housing, such as apartments and rental houses, which tend to be closer to industrial and office centers with more adequate public transportation facilities (Koide et al., 2019).

The study also addresses the impact of external factors, such as the COVID-19 pandemic, on household consumption patterns. A structural break, such as the pandemic, can influence household behavior and consumption patterns (Schäfer et al., 2012; Verplanken & Roy, 2016). The regression analysis shows that the COVID-19 pandemic is negatively associated with total HCE, resulting in an average decrease in HCE levels of 7.4%. It has the most significant impact on HCE in food, beverage, tobacco, energy, private transportation, public transportation, and goods and services consumption categories. This reduction is due to decreased consumption and a shift in consumption patterns towards greater environmental sustainability, especially in energy and transportation categories (Aktar et al., 2021). As highlighted by O'Garra & Fouquet (2022), the reduction in HCE level resulting from the COVID-19 pandemic was not solely attributed to a decrease in people's ability to consume. Still, it could also be attributed to changes in household consumption patterns. Table 3 reveals that the COVID-19 pandemic ranks third in terms of emissions in the public transportation consumption categories and fourth in terms of HCE in the private transportation consumption categories. This suggests that the altered circumstances stemming from the COVID-19 pandemic have notably influenced HCE, arising from private and public transportation consumption categories.

Conclusion

This study analyses the socio-economic factors influencing HCE levels for households in Indonesia, utilizing household data from the 2019 and 2021 SUSENAS. Estimating HCE levels involved a two-stage process: first, determining carbon intensity using the Environmental Extended Input-Output (EEIO) method, and second, calculating total HCE using the household expenditure approach. Through multivariate OLS analysis, the study identified significant determinants within household characteristics, individual attributes, and living conditions that impact HCE levels. A dominance analysis was also conducted to empirically determine the primary socio-economic factors influencing HCE levels.

The OLS estimation results suggest that HCE levels continue to increase with rising household income even though the Environmental Kuznets Curve (EKC) hypothesis holds true for total HCE and emissions from the food, beverage, tobacco, energy, housing, and private transportation categories. Other household characteristics, such as the number of household members and working members, exhibit a positive relationship with HCE. Households with children under five years old tend to produce higher levels of HCE. Households headed by males or those with higher levels of education tend to deliver higher levels of HCE. Meanwhile, the age of the household head exhibits a non-linear relationship with HCE levels, reflecting the age-related variation in individual productivity. The results of the dominance analysis reaffirm that income, the number of household members, and the education level of the household head are the most influential factors affecting HCE levels. Additionally, the influence of the COVID-19 pandemic is significant, particularly in the context of the transportation consumption category. On the other hand, the education level of the household head plays a crucial role in maintaining consumption levels during the COVID-19 pandemic. Therefore, efforts to enhance public education, particularly education with an environmental focus, must be continuously pursued.

Considering these findings, we offer several recommendations. Policymakers should emphasize elevating environmental awareness through eco-friendly education and supporting more sustainable household lifestyles. This is crucial, given Indonesia has set its sights on achieving high-income country status by 2045, which implies an increase in HCE levels due to growing incomes and presents a potential obstacle to achieving net-zero emissions by 2060. To address this challenge, the government must ensure that efforts to increase income do not inadvertently lead to increased household emissions. Pro-environment policies should be meticulously planned, including implementing a carbon tax, subsiding for eco-friendly products, and enhancing the mass transportation system. Policymakers can also leverage the momentum generated by the COVID-19 pandemic to encourage environmentally friendly shifts in household behaviors and choices.

Author Contributions

Conceptualisation, Methodology, Analysis, Original draft preparation, FM.A; Review and editing, F.M.A. and A.K.; Visualization, F.M.A.; Supervision, A.K. and H.D.I.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper. This research was conducted independently, and no external parties influenced the study design, data analysis, result interpretation, or the decision to publish the findings.

Appendix

Table 2A OLS regression results on the natural logarithm of household carbon (CO_2) emission in kilogram by consumption categories for 2019 Household

Variable	Total	Consumption Categories						
		Food	Energy	Housing	Private Transportation	Public Transportation	Other Goods	Other Services
Household characteristics								
Ln Income per capita	3.74***	4.18***	2.36***	6.35***	1.85***	-0.84***	2.64***	3.44***
Ln Income per capita^2	-0.08***	-0.10***	-0.04***	-0.15***	-0.03***	0.05***	-0.04***	-0.06***
Numbers of Household Member	0.26***	0.21***	0.22***	0.35***	0.19***	0.32***	0.30***	0.33***
Household with children under five years old (Ref. No)	0.03***	0.01***	0.04***	0.02***	0.02***	-0.05***	0.01***	0.05***
Numbers of working member	0.01***	0.01***	0.01***	0.01***	0.01***	-0.04***	0.01***	0.02***
Household head characteristics								
Gender of household head (Ref. female)	0.10***	0.06***	0.09***	0.11***	0.09***	0.04***	0.10***	0.13***
Age of household head	11.62***	6.10***	13.63***	9.43***	6.34***	0.02	9.18***	14.33***
Age of household head^2	-0.11***	-0.06***	-0.12***	-0.10***	-0.07***	-0.04**	-0.10***	-0.13***
Education level (Ref. lower Primary)								
Primary	0.19***	0.06***	0.29***	0.11***	0.06***	-0.14***	0.06***	0.18***
Secondary	0.20***	0.07***	0.30***	0.14***	0.07***	-0.10***	0.07***	0.19***
Tertiary	0.18***	0.07***	0.29***	0.15***	0.06***	-0.03**	0.07***	0.17***
Higher Education	0.15***	0.05***	0.24***	0.12***	0.04***	-0.02	0.04***	0.14***
Residential characteristics								
Residential Status (Ref. not owned by household)	0.02***	0.01***	-0.00	0.00	0.03***	-0.056***	0.04***	0.07***
Region (Ref. Rural)	0.04***	0.02***	0.07***	0.03***	0.01***	-0.14***	-0.002	0.06***
Constant	- 33.51***	-36.83***	- 22.03***	- 62.02***	-16.08***	0.18	- 28.18***	- 38.03***
Observation	315,668	315,668	315,006	301,439	240,773	236,582	315,654	310,969
R-Square	0.675	0.764	0.327	0.475	0.329	0.143	0.666	0.415

Notes: Table 2 presents the estimation results of household socio-economic factors on household carbon emission (HCE) behavior. Ref. referring to the comparison group (reference group). The HCE level variable has been transformed into a natural logarithmic form. Ln. This table shows variables in a natural logarithm form. Significant level *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: SUSENAS database, author's computation

Table 2B OLS regression results on the natural logarithm of household carbon (CO_2) emission in kilogram by consumption categories for 2021 Household

Variable	Total	Consumption Categories						
		Food	Energy	Housing	Private Transportation	Public Transportation	Other Goods	Other Services
Household characteristics								
Ln Income per capita	3.42***	5.77***	3.84***	7.76***	1.02***	1.68***	4.57***	0.66***
Ln Income per capita²	-0.07***	-0.15***	-0.09***	-0.20***	-0.007***	-0.01***	-0.10***	0.01***
Numbers of Household Member	0.24***	0.25***	0.19***	0.34***	0.16***	0.23***	0.26***	0.51***
Household with children under five years old (Ref. No)	0.03***	0.02***	0.07***	-0.18***	-0.005	-0.09***	0.17***	-0.12***
Numbers of working member	0.01***	0.03***	-0.06***	0.05***	0.067***	-0.04***	0.01***	-0.18***
Household head characteristics								
Gender of household head (Ref. female)	0.19***	0.18***	0.03***	-0.01***	0.13***	-0.31***	0.04***	0.03***
Age of household head	25.00***	1.35***	35.98***	20.74***	13.25***	-13.45***	-1.67***	30.90***
Age of household head²	-0.25***	-0.04***	-0.28***	-0.28***	-0.15***	0.16***	-0.04***	-0.33***
Education level (Ref. lower Primary)								
Primary	0.43***	0.08***	0.67***	0.53***	0.01**	-0.34***	0.11***	0.36***
Secondary	0.52***	0.07***	0.82***	0.71***	0.03***	-0.31***	0.13***	0.45***
Tertiary	0.57***	0.04***	0.92***	0.84***	0.06***	-0.28***	0.16***	0.55***
Higher Education	0.64***	-0.02***	1.04***	1.00***	0.15***	-0.07***	0.21***	0.79***
Residential characteristics								
Residential Status (Ref. not owned by household)	0.03***	-0.03***	-0.01**	-0.39***	0.09***	-0.33***	0.05***	0.09***
Region (Ref. Rural)	0.13***	0.03***	0.31***	0.24***	-0.06***	-0.31***	-0.02***	0.20***
Constant	-30.88***	-50.07***	-34.56***	-72.23***	-9.34***	-20.94***	-44.10***	-14.11***
Observation	340,026	340,026	339,639	327,355	266,282	244,094	340,024	336,073
R-Square	0.677	0.785	0.392	0.534	0.347	0.157	0.675	0.459

Notes: Table 2 presents the estimation results of household socio-economic factors on household carbon emission (HCE) behavior. Ref. referring to the comparison group (reference group). The HCE level variable has been transformed into a natural logarithmic form. Ln. This table shows variables in a natural logarithm form. Significant level *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: SUSENAS database, author's computations

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