Who Emits More Emission? The Association Between CO2 Emissions and Socio-economics Characteristics of Indonesian Household

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Abstract
In developed countries, a large amount of research has been done on identifying socio-economic household links. However, the study of household carbon emission (HCE) levels and related variables still needs to be created for 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 (Hannah Ritchie & Max Roser, 2020). In response to this global challenge, the Paris Agreement of 2015, which has been ratified by 191 countries (IRID, 2022)introduced the concept of net-zero emissions (NZE). NZE signifies a state in which emissions resulting from human activities are balanced by the capacity of nature to absorb them. Achieving NZE is pivotal to realizing the objectives of the Paris Agreement, which include limiting the global average temperature increase to between 1.5°C and 2°C compared to the preindustrial 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 (Myles, 2018). The swifter the reduction in CO2 emissions, the greater the likelihood of keeping the global temperature rise below 2°C. Numerous countries in Europe, North America, South America, and Oceania have initiated efforts to curtail CO2 emissions, resulting in substantial reductions over the past two decades (Hannah Ritchie & Max Roser, 2020). Nevertheless, despite these endeavours, global carbon emissions have yet to exhibit a significant decrease. In 2017, global CO2 emissions increased by 1.6% after a period of deceleration from 2014 to 2016 (Figueres et al., 2017). Other reports indicate an uptick in CO2 emissions, particularly in Asian and African nations (Hannah Ritchie & Max Roser, 2020). Consequently, the drive to mitigate CO2 emissions must engage all countries, encompassing both developed and developing nations, as well as 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, which can be reduced by altering household behaviour regarding energy use and transitioning to low-carbon products and services (Alfredsson, 2004). However, while numerous studies have explored carbon emissions within 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) and China (Ding et al., 2019; Xu et al., 2016; Yuan et al., 2019; Zeqiong & Junfei, 2021), the UK (Baiocchi et al., 2010; Büchs & Schnepf, 2013). In contrast, there is still limited research on HCE in developing countries, including Indonesia.

Various empirical studies have shown that HCE can be influenced by household characteristics (i.e., income, number of household members, household member composition, economic maturity, and residential condition) and individual characteristics (i.e., age, education level, gender, and marital status) (Ding et al., 2019; Irfany & Klasen, 2017; Lévay et al., 2021; Saras & Kristanto, 2021; Seriño & Klasen, 2015). Among these factors, household income level stands out as the most influential factor in determining HCE, 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 leads to increased consumption, thereby elevating HCE levels. However, another studies shown a non-linear relationship between income variable and HCE level, 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)

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 both 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, a higher number of working members contributes to increased household income and consumption capacity (Koide et al., 2019; Lévay et al., 2021).

Individual characteristics, particularly household heads, also exert influence on HCE levels (Koide et al., 2019; Lévay et al., 2021; Seriño & Klasen, 2015). Previous research has 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, another study has indicated a positive linear relationship between age and HCE levels, positing that growing age leads to increased 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 the

opposite, with female-headed households leading to higher carbon emissions (Büchs & Schnepf, 2013; Irfany & Klasen, 2017; Seriño, 2017; Seriño & Klasen, 2015). These variations may stem from differing consumption behaviours between male and female-headed households. Male household heads with high mobility tend to prefer private transportation, which is more 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, certain 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 nature of the relationship between education and HCE, which can lead to higher consumption of environmentally harmful goods but may also promote the use of environmentally friendly technologies and environmental awareness (Lan et al., 2012; Williamson, 2017).

Homeownership tends to be associated with higher HCE levels due to the generally greater economic capacity of homeowners (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 a 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).

In Indonesia, studies by Irfany & Klasen (2017) and Saras & Kristanto (2021)stand out as some of the few studies that have examined HCE levels and their connection with household socio-economic conditions. However, the data in these studies 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 nation's 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 conducting a comprehensive analysis of factors that influence household CO2 emissions. Moreover, it employs the dominance analysis method to empirically examine the most significant determinants of household CO2 emissions. 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.

Research Method

Household Carbon Emission

Household Carbon Emission (HCE) represents the cumulative CO2 emissions generated by households 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. Indirect HCE, on the other hand, 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:

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

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

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

Where $\boldsymbol{X}$ represents the vector of total output, $\boldsymbol{(I - A)^{-1}}$ 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).

To calculate the Indirect carbon emissions, this research utilizes carbon coefficients data from the Global Trade Analysis Project (GTAP) for the years 2019 and 2021, using the equation:

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

Where $\boldsymbol{c}'$ represents the vector of carbon coefficient for industry sectors in Indonesia. 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 both direct and indirect carbon emissions. Furthermore, this study performs adjustments to 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 equation:

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

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

Data

This study utilizes data from the National Socio-economic Survey (SUSENAS) for the years 2019 and 2021. SUSENAS is published twice a year, in March and September. The March SUSENAS dataset is representative up to the district level and covers approximately 300,000 households, whereas 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 also 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 several data have been dropped caused by missing value on 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. In conducting its analysis, this research utilizes SUSENAS data from the "kor" section and the consumption module. The consumption module elucidates the total of 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 social-economic factors and HCE, the study performs an Ordinary Least Squares (OLS) regression model:

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

Where $\ln(HCE_i)$ is the natural logarithm of household carbon emission, $\boldsymbol{X}_i$ is the vector od household characteristics, $\boldsymbol{Y_i}$ is the vector of individual characteristics, and $\boldsymbol{Z_i}$ is the vector of residential condition. $Covid_i$ 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, the number of 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 (i.e., staple foods, meats, vegetables, and processed foods), housing (i.e., home maintenance and rent payments), energy (i.e., electricity, gas, and kerosene), public transportation (i.e., costs of train, bus, sea, and air travel), private transportation (i.e., motor vehicle fuel and maintenance costs), clothing and durable goods, goods (i.e., and services (i.e., education and health). To depict emission characteristics within income groups, this research divides households into five income categories. The first group consists of households with the lowest 20 percent of income, while the fifth group comprises households with the highest 20 percent of income.

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, a total of 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 when compared to 2019. Approximately 25% of Indonesian households have children under the age of five, and majority (84%) of household heads are male. Over a two-year span, 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

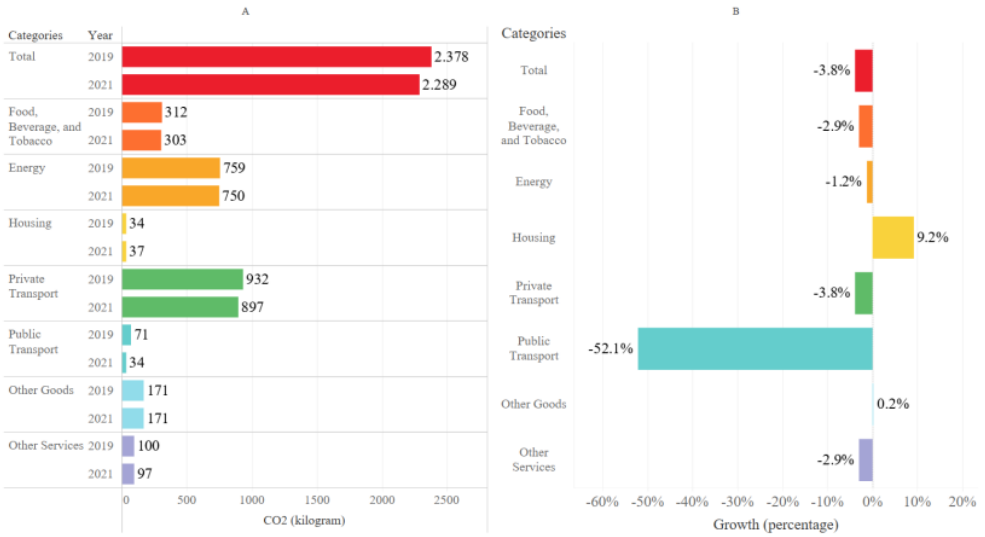
	2019		2021	
Variable	Mean	Std. Dev	Mean	Std. Dev
Household Carbon Emission	2,378.52	2,785.025	2,288.625	2805.294
Per capita Income	15,595	20958.69	13,795.33	14376.07
Household Size	3.667	1.63	3.591	1.565
Households with children under five years	0.267	0.442	0.258	0.437
Number of working household members	1.551	0.915	1.526	0.902
Gender of Household Head	0.839	0.367	0.856	0.350
Age of household head	49.488	0.013	0.048	0.0139
Year of education	8.040	4.282	8.477	4.383
Residential status	0.825	0.379	0.810	0.391
Region	0.497	0.499	0.568	0.495
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. In general, the HCE level in 2019 (2,394 kgCO2eq) was lower than in 2021 (2,289 kgCO2). This decline in HCE could be attributed to the impact of the COVID-19 pandemic, which necessitated activity restrictions, significantly reducing mobility. This is illustrated in Figure 1, 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, during the pandemic, emissions increased only in the housing consumption category, as a result of most people staying at 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%) as well as energy categories (-1.15%), likely due to decreasing of consumption quantity in several categories.

Figure 1. Average of HCE (A) and growth of HCE (B) CO2 by consumption categories

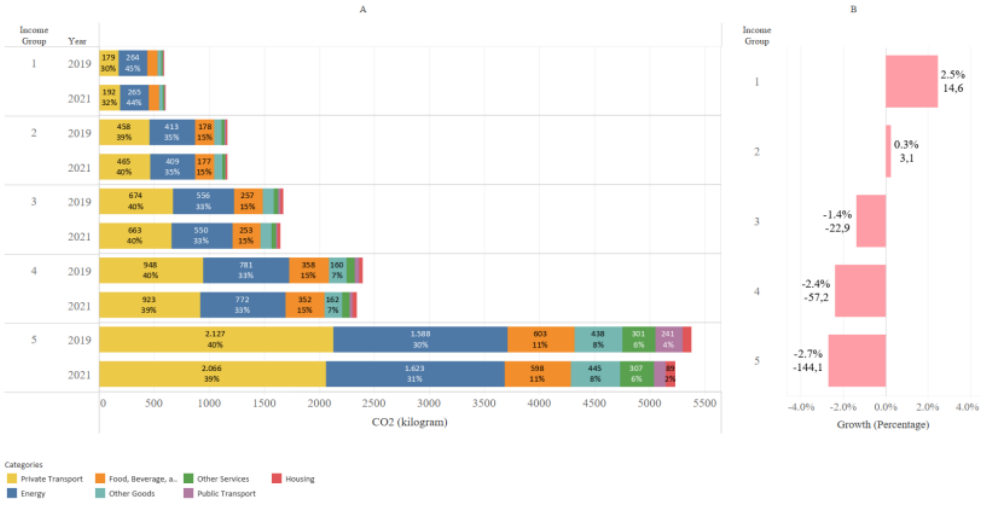


Source: SUSENAS database, author's computations

Figure 2 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, there was a significant increase in the fifth income group. This highlights that households with higher incomes 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 both 2019 and 2021.

Figure 2. Average of HCE (A) and growth of HCE (B) CO2 by household income level



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

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 a decrease in CO2 emissions. The average change in household emissions for the first group was 14.6 kgCO2, for the second group, 3.1 kgCO2, for the third group, -22.9 kgCO2, for the fourth group, -57.2 kgCO2, and for 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, 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 other 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's 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	2.322***	4.657***	2.258***	3.458***	9.633***	-3.302***	0.535***	0.486***
Ln Income per capita^2	-0.040***	-0.117***	-0.044***	-0.067***	-0.237***	0.129***	0.016***	0.023***
Numbers of Household Member	0.246***	0.247***	0.197***	0.342***	0.453***	0.202***	0.254***	0.424***
Household with children under five years old (Ref. yes)	0.036***	0.015***	0.056***	-0.086***	0.126***	-0.041***	0.155***	-0.067***
Numbers of working member	0.008***	0.019***	-0.039***	0.033***	0.129***	-0.00264	0.013***	-0.100***
Household head characteristics								
Gender of household head (Ref. female)	0.140***	0.124***	0.042***	0.040***	0.681***	-0.075***	0.070***	0.060***
Age of household head	14.010***	6.023***	21.970***	9.977***	45.88***	0.870	-0.429	19.030***
Age of household head^2	-0.144***	-0.085***	-0.167***	-0.138***	-0.526***	-0.001	-0.027***	-0.191***
Education level (Ref. lower Primary)								
Primary	0.195***	0.048***	0.420***	0.190***	0.857***	-0.110***	-0.028***	0.150***
Secondary	0.234***	0.050***	0.488***	0.288***	0.945***	-0.063***	-0.001	0.179***
Tertiary	0.250***	0.033***	0.531***	0.357***	0.923***	-0.00654	0.024***	0.219***
Higher Education	0.259***	-0.022***	0.551***	0.383***	0.832***	0.140***	0.046***	0.311***
Residential characteristics								
Residential Status (Ref. not owned by household)	0.0753***	0.021***	0.028***	-0.175***	0.321***	-0.090***	0.097***	0.146***
Region (Ref. Rural)	0.0513***	0.046***	0.154***	0.105***	0.124***	0.038***	-0.031***	0.096***

Covid-19 pandemic period (Ref. before Covid-19)	-0.074***	-0.086***	-0.073***	0.069***	-0.095***	-0.380***	-0.021***	-0.052***
Constant	-14.14***	-40.37***	-20.63***	-36.96***	-92.73***	20.82***	-9.475***	-12.75***
Observation	655,694	655,694	655,694	655,694	655,694	655,694	655,694	655,694
R-Square	0.748	0.802	0.376	0.554	0.335	0.152	0.638	0.445

Notes: Table 2 presents the estimation results of household socio-economic factors on household carbon emission (HCE) behaviour. Ref. referring to the comparison group (reference group). The HCE level variable has been transformed into a natural logarithmic form. Ln. Shows 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 and HCE levels and most consumption categories exhibits a non-linear pattern. This includes food, beverage, and tobacco, energy, housing, private transportation, and public transportation. The results indicate a significant, negative coefficient for the squared income, signifying an inverted U-shaped relationship with diminishing marginal emissions (leveling off). These findings align with previous studies, supporting the Environmental Kuznets Curve (EKC) hypothesis (Lévay et al., 2021; Seriño & Klasen, 2015), indicating that it holds true for 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 income, 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 presented 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, the presence of toddlers in the household negatively and significantly affects HCE levels in housing, public transportation, and other services categories. This result is consistent with existing research suggesting that having children in the household leads to reduced emissions in transportation consumption categories, as households with young children tend to reduce travel frequency and house renovation (Büchs & Schnepf, 2013).

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 decreased productivity and changes in household members' consumption patterns (Büchs & Schnepf, 2013). Furthermore, gender and marital status variables have a significant positive influence on HCE levels. Households headed by male tend to generate higher HCE than those headed by female in all consumption categories, except in the case of 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).

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 is in line 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. While this finding contradicted with 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 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 greater emissions (Hartono et al., 2023; Seriño & Klasen, 2015). On the other hand, households in rural regions face significant barriers to accessing sufficient energy consumption (Hartono et al., 2023). Households with residential ownership status tend to produce higher total HCE levels across all consumption categories, with the exception of 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 changes in household behaviour 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 reduction in people's ability to consume but 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 both private and public transportation consumption categories.

Conclusion

This study analyzes the socio-economic factors influencing HCE levels for households in Indonesia, utilizing household data from the 2019 and 2021 SUSENAS. The estimation of 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. Dominance analysis was also conducted to empirically identify the primary socio-economic characteristics 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 produce 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.

Considering these findings, we offer several recommendations. Policymakers should focus on 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 the implementation of a carbon tax, subsidies for eco-friendly products, and enhancements to the mass transportation system. Policymakers can also leverage the momentum generated by the COVID-19 pandemic to encourage environmentally friendly shifts in household behaviours and choices.

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