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Digital Transformation and the Environment: An Analysis of the Impact of Digital Transactions on Carbon Emissions in Indonesia

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Abstract: The rapid rise in carbon emissions due to economic expansion has accelerated global warming and climate change. Amid these challenges, digital transformation in retail and financial services has emerged as a potential solution to mitigate environmental degradation. This study analyzes the impact of digital transactions—online shopping and financial technology—on carbon monoxide emissions in Indonesia using panel data from 34 provinces between 2019 and 2022. Employing a fixed effects panel regression model, the analysis reveals that higher adoption of digital transactions significantly reduces carbon monoxide levels. The number of vehicles is positively associated with emissions, while tertiary education levels contribute to emission reduction. These findings suggest that promoting digital finance and e-commerce can support the transition toward a low-carbon economy. This study offers empirical evidence for policymakers to integrate digital transformation into environmental strategies.

Keywords: Green Economy, Carbon Emissions, Online Retail, Digital Finance

Introduction

The increase in carbon emissions, along with massive economic development, has contributed to the acceleration of global warming and climate change. According to BMKG (2023), the average temperature in Indonesia has risen by 0.30 degrees Celsius over four decades, with the highest temperature surge starting in 2008. The average temperature in 1981 was 26.6 °C, which increased to 27.00 °C in 2022, with the highest temperature anomaly occurring in 2016, reaching 27.4 °C.

The continuous rise in global temperatures has led to a series of negative impacts, including increased risks of droughts and wildfires, extreme weather events, rising sea levels, changes in planting seasons, and adverse effects on human health. Carlson et al. (2022) note that extreme weather changes have been a trigger for the emergence of the COVID-19 pandemic and suggest the possibility of new viruses or parasites emerging in the future.

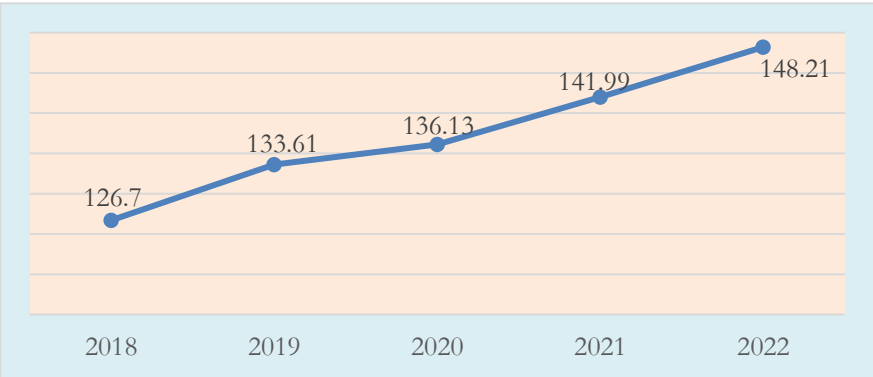
Globally, there are seven economic activities that contribute to carbon emissions. These activities include electricity generation, industry, transportation, agriculture, deforestation, residential and commercial buildings, as well as solid and liquid waste (Desrina, 2014). According to Boedoyo (2008), the largest sources of carbon emissions are the industrial sector and power plants, followed by emissions from households and transportation. However, the highest growth in carbon emissions comes from the transportation sector. This finding is consistent with studies by Hodijah, Amin, and Mubarak (2014) and Haryanto (2018), which indicate that the transportation sector is the largest contributor to carbon emissions, with carbon monoxide (CO) being the most prevalent pollutant.

Carbon monoxide is a hazardous substance due to its colorless, odorless, highly flammable, and toxic nature. It is often referred to as a "silent killer" because it easily binds with hemoglobin, thereby affecting the performance of the nervous system, heart, respiratory system, and potentially causing seizures that may lead to death (Maryanto, Mulasari, & Suryani, 2009). In addition to being produced by motor vehicles, this substance is also emitted by industrial machinery and the combustion of agricultural residues and household waste.

Economic activities have consistently grown at a rate of over five percent per year for a decade, except during the pandemic. High-intensity economic activities are naturally supported by increased energy supply, which leads to higher emissions released into the atmosphere. This is evidenced by data from Tempo (2022), which shows a significant increase in fuel consumption from 2011 to 2022. In 2011, fuel consumption reached 380 million barrels and increased to 430 million barrels by 2021.

This phenomenon is also supported by the increasing number of vehicles, even during the pandemic. In the past five years, the number of vehicles has increased by nearly 20 percent. This situation raises concerns, as a higher number of motor vehicles results in greater amounts of carbon monoxide particles circulating in the air.

Figure 1. **Number of Vehicles (Millions) in Indonesia 2018-2022**



Source: www.bps.go.id

Research in several countries has shown that online/digital shopping and financial transactions can significantly contribute to the reduction of carbon emissions (Al-Mulali, Sheau-Ting, & Ozturk, 2015). Online shopping systems gradually decrease consumer mobility to commercial centers. Buyers can select products and conduct payment transactions from anywhere and at any time without needing to interact face-to-face with sellers or distributors. According to He and Liu (2012), digital transactions can reduce carbon pollution due to increased efficiency in business processes and digital financial transactions. In addition to reducing population mobility, digital finance also decreases paper usage and promotes environmentally friendly development through green credit and green investments.

Bank Indonesia reports a significant increase in digital transaction values over the past five years. The volume of non-cash transactions through digital banking reached 1,600 trillion rupiah in 2018. By the first quarter of 2023, this figure had risen to 4,600 trillion rupiah. Similarly, from the perspective of businesses, the percentage of e-commerce operators has continuously increased, reaching 34 percent by the end of 2022.

The significant increase in digital transactions and digital finance in Indonesia has undeniably contributed to the country's economic growth. However, it also raises a critical question: can digital transactions help reduce carbon emissions in Indonesia, as has been observed in other countries? Ahiase, Nugraha, Andriana, and Sari (2024) conducted a study on the impact of digital financial inclusion on climate change in Africa. Their findings indicate that ATM usage contributes to increased consumption of renewable energy and a reduction in carbon dioxide emissions. Similarly, internet usage shows a comparable effect. A related study by Du, Hou, Zhou, and Ren (2022), using panel data from Chinese provinces, found that digital finance has a positive spillover effect in curbing environmental pollution. Digital finance was found to reduce pollution through technological innovation and the rationalization of industrial structures.

In the Indonesian context, a study by Fasa (2025) found that non-cash transactions via the digital wallet (fintech) OVO can reduce carbon dioxide emissions due to reduced cash usage, lower ATM energy consumption, and decreased demand for logistics distribution. These findings are supported by Qoriah, Safitri, Chifdzi, Nisak, and Saputri (2025), who argue that fintech contributes to carbon emission reduction through the adoption of digital technology. Moreover, fintech can also facilitate green investment through green financing for renewable energy projects.

While studies examining the impact of digital transactions and digital finance on carbon emissions have been increasingly conducted globally—especially since the COVID-19 pandemic—research in the Indonesian context has largely focused on the relationship between digital finance, carbon footprint, and the green economy. However, no study has yet explored the combined effect of online shopping and digital finance on carbon emissions in Indonesia. Therefore, this study seeks to examine both variables, guided by the research question: "What is the relationship between online shopping transactions and digital finance on carbon emissions in Indonesia?" If a significant influence is found, it will be important to determine whether digital transactions help reduce emissions or, conversely, contribute to an increase in carbon output.

Literature Review

Economic Growth and Technology

The neoclassical growth theory explains that economic growth is influenced by production factors including labor, capital accumulation, and technological advancement. Technological development distinguishes it from the Harrod-Domar growth theory. The neoclassical growth model can be expressed as follows:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$$

Description :

Y_t : Output level at year-t
A : Technology level at year-t
K_t : Capital stock at year-t
L_t : Labor amount at year-t

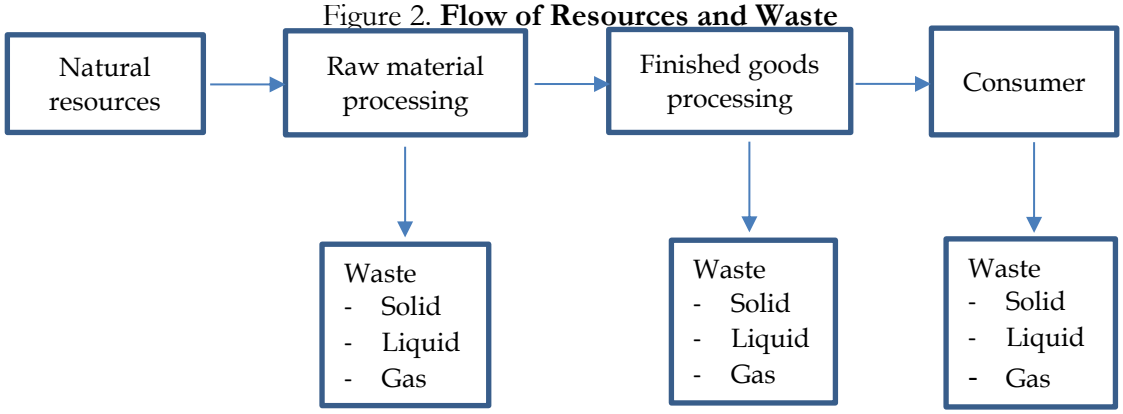
Technological advancement is considered an exogenous factor in this model. The presence of technology can enhance labor efficiency in production activities without the need to increase the labor force. Thus, the technology variable is assumed to be independent of other economic forces.

The neoclassical approach has since been refined by endogenous growth theory. Endogenous growth theory assumes that growth originates from within industries. Unlike the neoclassical theory, this approach incorporates technological processes endogenously, leading to improved production or industrial output.

Economic Growth and Environment

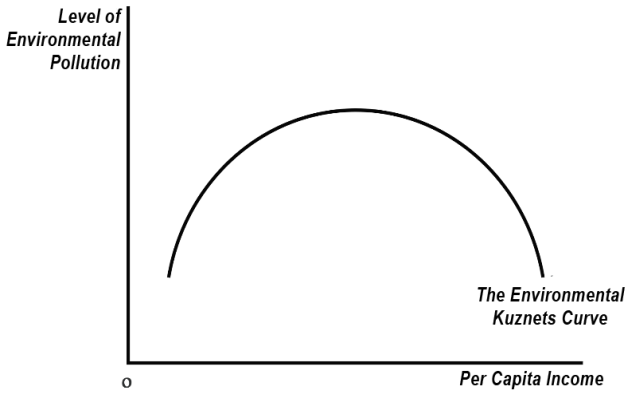
Economic activities conducted by humans have both positive and negative impacts. The positive impact of economic activities includes the fulfillment of goods and services necessary for human life. However, the negative impact is environmental damage or pollution. Economic activities require raw materials, most of which come from nature. As economic growth increases, more natural resources are used. Consequently, this leads to environmental degradation due to the excessive use of resources to meet production needs.

Figure 2. **Flow of Resources and Waste**



In addition to the excessive use of natural resources, economic activities also contribute to environmental pollution. Economic activities, from production processes to consumption, generate waste. The waste produced can be in the form of solids, liquids, or gases. All of this waste eventually becomes a burden on the environment. To date, a significant amount of waste is still discarded directly into nature without undergoing any filtration process (Baskoro, 2008).

Figure 3. **The Environmental Kuznets Curve**



The relationship between the environment and economic growth in the long term can be explained by the Kuznets Environmental Curve. Kuznets argued that when a region's income is low, the government's focus is primarily on increasing income without considering environmental damage. As a result, per capita income growth is accompanied by increased environmental degradation. This process occurs during the transition from the agricultural sector to the industrial sector. Subsequently, as the transformation shifts from the industrial sector to the service sector, air pollution tends to decrease while per capita income continues to grow (Panayotou, 1993).

Digital technology holds the potential to reshape the relationship between economic growth and environmental outcomes, particularly in the context of the Environmental Kuznets Curve (EKC). As previously discussed, the initial stages of economic development are often accompanied by environmental degradation, including increased carbon emissions. However, once a certain income threshold is reached, digital technology can be leveraged to mitigate these emissions. Digital systems can replace energy-intensive manual processes, thereby enhancing energy efficiency. The digital economy promotes resource efficiency through automation, supports the management of renewable energy systems, and facilitates innovations such as electric vehicles and the sharing economy—all of which contribute to the reduction of carbon emissions.

Previous Research

Weideli and Cheikhrouhou (2013) examined the carbon footprint comparison of shopping processes through simulations of ten different purchasing methods. The results indicated that online shopping is the most environmentally friendly option. However, this depends on the customer's location and transportation choices. Online shopping is effective for customers living in suburban areas, but for urban residents, traditional shopping methods are more effective compared to online shopping.

Van Loon, Deketele, Dewaele, McKinnon, and Rutherford (2015) conducted a similar study in the United Kingdom. E-commerce transactions were considered more environmentally friendly because online shopping can encourage consumers to reduce trips to purchase complementary goods and maximize the number of items purchased.

Al-Mulali et al. (2015) also conducted a study on online shopping in 2015. The analysis covered 77 developed and developing countries over the period from 2000 to 2013. The results showed that online shopping significantly reduces carbon dioxide levels in developing countries. However, in developed countries, online shopping does not have a significant impact.

Studies on financial technology and environmental pollution have also been conducted by several researchers. Wan, Pu, and Tavera (2023) state that technological innovations in the financial sector can reduce pollution. Similarly, Muganyi, Yan, and Sun (2021) mention that financial technology has a positive impact on environmental protection by contributing to the reduction of sulfur dioxide emissions. Financial technology promotes sustainable development by reducing costs, mitigating information asymmetry, and valuing natural assets (Cen & He, 2018). The rapid adoption of financial technology over the past decade, driven by the availability of internet and mobile technology, has enabled financial institutions to provide services that are accessible at any time (Durai & Stella, 2019).

However, other research presents contrasting findings. The role of technology is seen as having both beneficial and detrimental effects on achieving green economic development. Technological advancements have led to pollution, global warming, ozone depletion, and large-scale exploitation of natural resources (Mumtaz & Smith, 2019). This is consistent with the Kuznets Curve, which suggests that technological progress can contribute to environmental degradation in developing countries (Febriana, Diartho, & Istiyani, 2019).

In addition to the variable of digital financial transactions, carbon emission reductions can also be influenced by factors such as the level of industrialization, population density, number of vehicles, and education level. Muganyi et al. (2021) state that the level of industrialization has a positive and significant impact on sulfur emissions in the air. This is consistent with the research by K. Ahmed, Shahbaz, and Kyophilavong (2016), which found that increased industrialization, along with population growth, has contributed to higher greenhouse gas levels in the atmosphere and impacts climate change. This finding is also supported by Du et al. (2022), where population growth affects increased energy and resource consumption, leading to environmental damage.

In contrast to industrialization, agricultural activities have an opposite effect on emissions released into the air. A study by Farhan (2021) in Asian countries found that the agricultural sector has a negative impact on per capita carbon emissions. This finding is similar to that of Pant (2009), who analyzed data from 120 countries provided by the World Bank. The analysis showed that agricultural land, irrigation, forest areas, and biomass energy use contribute to the reduction of carbon emissions.

In developing countries, impoverished populations are often compelled to use natural resources excessively to survive. Research conducted in 22 developing countries from 1990 to 2016 indicates that the level of education among the population mitigates the impact of poverty on methane (CH4) levels. Additionally, education has a significant negative

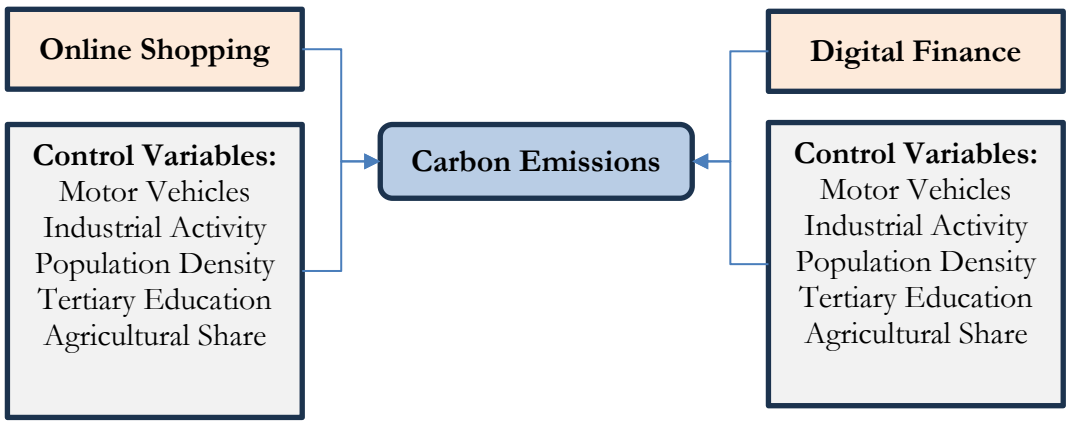
correlation with environmental degradation (Subramaniam, Masron, & Policy, 2020). Education serves as a tool to enhance community capacity to address environmental damage (Dong, Ishikawa, Liu, & Hamori, 2011).

Furthermore, aside from the industrial sector, the transportation sector is also a major contributor to carbon emissions. In Japan, the transportation sector accounts for 18 percent of carbon emissions, with 85 percent originating from land transport. Carbon emissions from land transport are highly dependent on the number of vehicles, distance traveled, and the type of fuel used (Watabe, Leaver, Ishida, & Shafiei, 2019). Motor vehicle exhaust accounts for 60-70 percent of air pollution (Nurdjanah, 2014). In some regions, vehicle emissions are the primary source of carbon emissions (Sutanhaji, Anugroho, & Ramadhina, 2018). Therefore, an increase in the number of operational vehicles will result in higher emissions.

Conceptual Framework and Hypotheses

Based on the literature review presented earlier, the relationships among the variables can be mapped as follows:

Figure 4. **Conceptual Framework**



Based on the conceptual framework presented in Figure 4, the analysis is conducted using panel regression methods. The research hypotheses are as follows:

a. Digital finance has a negative effect on carbon emissions.
b. Online shopping has a negative effect on carbon emissions.

Methods

This study uses panel data, which is secondary data covering all provinces in Indonesia for the period from 2019 to 2022. Details of the variables used are provided in Table 1. The analytical method used in this study is panel regression analysis. Panel regression is a method employed to examine the influence of a set of independent variables on a dependent variable, with data that combines both time series and cross-sectional dimensions. There are three methods used to estimate the regression model with panel data, which include:

a. Common Effect Model
b. Fixed Effect Model
c. Random Effect Model

Table 1. **Variables Used**

No	Variable Name	Unit	Source
1	Carbon monoxide levels	Mol/m²	Big Data - Sentinel 5
2	Percentage of ecommerce	Percent	BPS
3	Percentage of online financial transactions	Percent	BPS
4	Ratio of population to vehicles	-	BPS
5	Share of agriculture	Percent	BPS
6	Population density	people/km²	BPS
7	Percentage of population with tertiary education	Percent	BPS
8	Share of agriculture	percent	BPS

To determine the appropriate model, two estimation techniques can be employed. The first method involves conducting the Chow Test to choose between the Common Effect Model and the Fixed Effect Model. If the Chow Test indicates that the Fixed Effect Model is more appropriate than the Common Effect Model, the analysis proceeds with the Hausman Test. The purpose of this test is to determine whether the Fixed Effect Model or the Random Effect Model is more suitable.

In addition to selecting the best model, panel regression also requires testing for classical assumptions and model adequacy. These tests include checking for multicollinearity, autocorrelation, and heteroscedasticity. The model adequacy is assessed through the F-test (simultaneous) and t-test (partial) to evaluate the significance of each regression coefficient.

The panel regression model for carbon monoxide emissions is examined from two aspects: online shopping activities and online financial transactions, along with control variables. The model can be expressed as follows:

Model 1:

$$Ln\ CO_{it} = \beta_0 + \beta_1 Log\ of\ ecommerce_{it} + \beta_2 Log\ of\ Vehicles_{it} + \beta_3 Log\ of\ Industry_{it} + \beta_4 Log\ of\ Population_{it} + \beta_5 Log\ of\ Education_{it} + \beta_6 Log\ of\ Agriculture_{it} + \mu_{it}$$

Model 2:

$$Ln\ CO_{it} = \beta_0 + \beta_1 Log\ of\ efinance_{it} + \beta_2 Log\ of\ Vehicles_{it} + \beta_3 Log\ of\ Industry_{it} + \beta_4 Log\ of\ Population_{it} + \beta_5 Log\ of\ Education_{it} + \beta_6 Log\ of\ Agriculture_{it} + \mu_{it}$$

Description:

CO	:	Carbon Monoxide Levels in Province i in Year t
E-commerce	:	Percentage of Ecommerce users (buyer & seller) in Province i in Year t
Vehicles	:	Population-to-Vehicle Ratio in Province i in Year t
Industry	:	Share of the Manufacturing Sector in the GDP of province i in year t
Population	:	Population Density in Province i in Year t
Education	:	Percentage of the Population with Tertiary Education in Province i in Year t
Agriculture	:	Share of the Agricultural Sector in the GDP of Province i in Year t
E-Finance	:	Percentage of Digital Financial Transaction Users in Province i in Year t

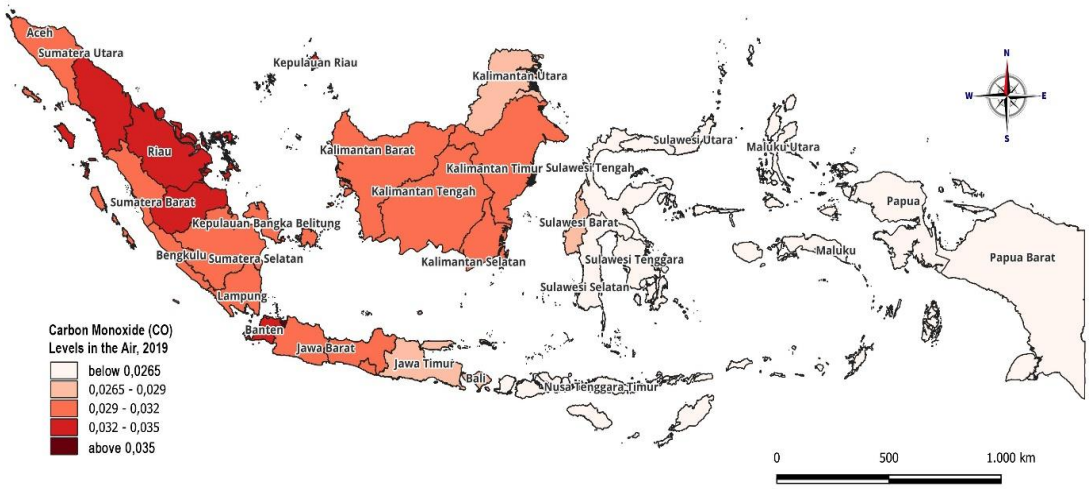
Findings

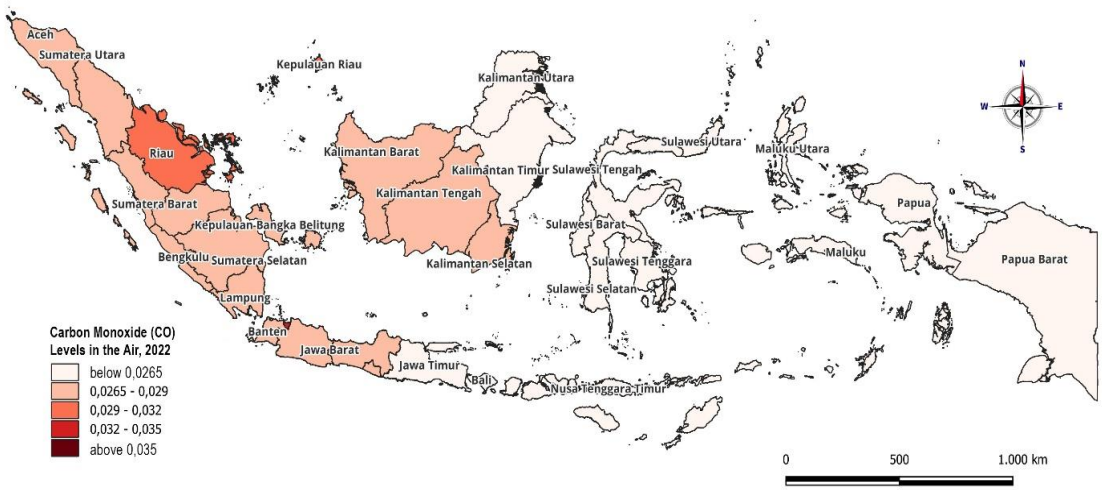
Descriptive Analysis

The COVID-19 pandemic has had a significant impact not only on humans but also on environmental conditions. Restrictions on human activities or mobility to prevent the spread of the virus have resulted in a reduction in carbon emissions during the pandemic. This is illustrated in Figure 5.

The highest levels of carbon monoxide (CO) occurred in 2019, indicated by the darkest red color. The darker the red, the higher the CO levels. Conversely, lighter areas signify lower CO concentrations compared to surrounding regions.

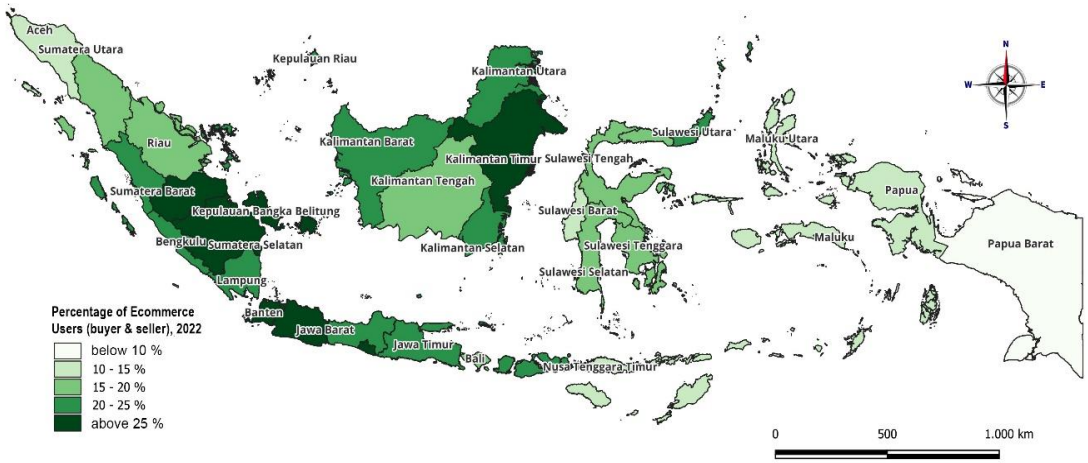
Figure 5. **Spatial Map of CO Levels by Province 2019 & 2022**





The highest CO levels were observed in the islands of Java and Sumatra, particularly in DKI Jakarta, during the observation period. The regions with dark red colors gradually diminished from 2020 to 2022. Conversely, areas with lighter colors increased during this period. The lighter-colored regions are predominantly located in Central and Eastern Indonesia. Indirectly, this phenomenon indicates that the reduction in human activities has contributed to a decrease in CO levels over the past four years.

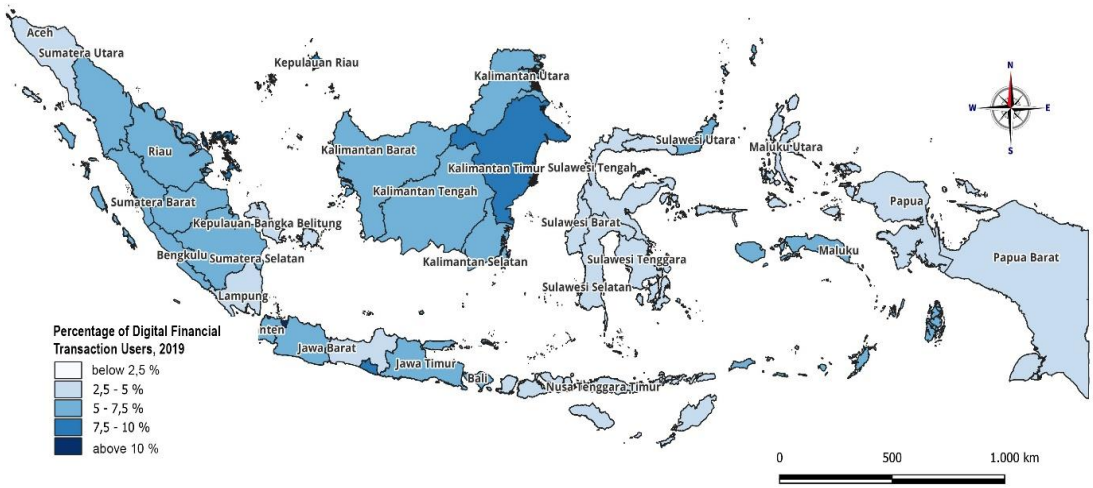
Figure 6. **Percentage of Ecommerce Users (user & seller) by Province 2019 & 2022**

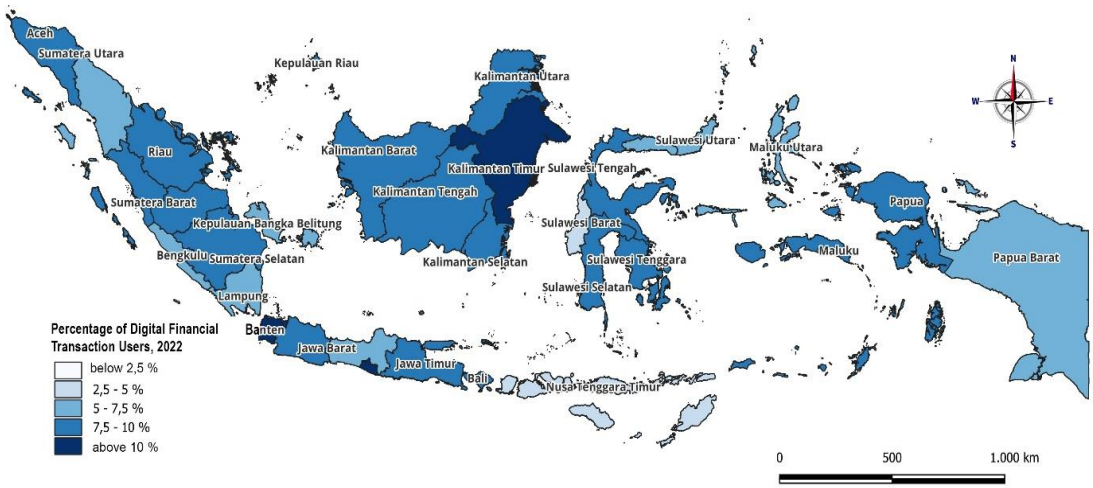


The restricted activities during the pandemic did not deter the population from engaging in economic transactions. This is evident from the increase in the percentage of people engaging in online shopping from 2019 to 2022, as shown in Figure 6. In several regions on the islands of Java, Sumatra, and Kalimantan, the color has darkened in 2022 compared to 2019. The darker the color, the higher the number of people participating in online transactions.

The increase in online trading participants has also led to a rise in digital financial transactions. This is comprehensively illustrated in Figure 7. Darker blue areas indicate higher percentages of online financial transaction users compared to regions with lighter blue shades. Unlike the online trading map, the increase in online financial transaction users is relatively uniform, except in the NTB and NTT regions. The highest increases are observed in West Java, DKI Jakarta, and the Special Region of Yogyakarta. When viewed by island, the most significant increases are in Kalimantan, Java, and Sumatra.

Figure 7. **Percentage of Digital Financial Transaction Users by Province in Indonesia, 2019 & 2022**





Empirical Results

In the initial stage of panel regression analysis, a test was conducted to select the best model between the Common Effect Model and the Fixed Effect Model using the Chow Test, with the following results:

Table 2. **Chow Test Results**

Effect Test	Statistic	d.f	Prob*)
Model 1			
Cross Section F	25.1870	(33.96)	0.0000
Cross Section Chi Square	308.4198	33	0.0000
Model 2			
Cross Section F	24.5504	(33.96)	0.0000
Cross Section Chi Square	305.3026	33	0.0000

* Significance level = 5 %

Based on the results presented in Table 2, the significance values are less than 0.05 for both models. This indicates that the Fixed Effect Model (FEM) is preferable compared to the Common Effect Model (CEM). The next step is to compare the Fixed Effect Model with the Random Effect Model. The testing tool used for this comparison is the Hausman Test, with results presented in Table 3.

Table 3. **Hausman Test Results**

Test Summary	Chi-Sq.Statistic	Chi-Sq d.f	Prob*
Model 1			
Cross Section random	65.293	6	0.0000
Model 2			
Cross Section random	66.237	6	0.0000

* Significance level = 5 %

The Hausman Test results show that the significance values for both models are less than 0.05. This indicates that the Fixed Effect Model (FEM) is preferable to the Random Effect Model for analyzing the relationship between a set of independent variables and the dependent variable in this study. Based on the Chow and Hausman Tests, it can be concluded that the Fixed Effect Model is the most suitable panel regression model for analyzing the relationship between carbon monoxide levels and digital transactions, including online shopping and online financial transactions.

Once FEM was selected as the analysis tool, classical assumption testing and model feasibility tests were conducted. Given the selection of FEM as the analysis method, the classical assumption tests performed include tests for heteroscedasticity, multicollinearity, and normality.

The next step, after meeting the classical assumptions, is to test the model's feasibility. The results of the model feasibility tests for Model 1 and Model 2 are presented in Table 4. Based on the F-statistics obtained, the models are statistically significant at less than 0.01, indicating that these models are suitable for use.

Table 4. **Statistics for Regression Model 1 and Regression Model 2**

Dependent Variable: Carbon Monoxide Levels			
(1)		(2)	
Constant (Intercept)	0.0073	Constant (Intercept)	0.0697
Log of Ecommerce	-0.0053**	Log of Efinance	-0.0039**
Log of Vehicles	0.0264***	Log of Vehicles	0.0282***
Log of Industry	0.0001	Log of Industry	0.0011
Log of Population	-0.0082	Log of Population	-0.0094
Log of Education	-0.0214***	Log of Education	-0.0206**
Log of Agriculture	0.0022	Log of Agriculture	0.0021
Observations	136	Observations	136
R Squared	0.929	R Squared	0.929
Adjusted R-Squared	0.9	Adjusted R-Squared	0.9
Prob F statistics	0.000	Prob F statistics	0.000

*p<0.1; **p<0.05 ; ***p<0.01

The relationship between carbon monoxide concentration—as the dependent variable—and online shopping, online financial transactions, along with control variables, is presented in Table 4. A closer examination reveals that the coefficient for carbon monoxide concentration and online shopping is -0.0053, indicating a negative and statistically significant relationship. This suggests that an increase in online shopping activity is associated with a reduction in carbon monoxide levels in the atmosphere, or in other words, a decline in carbon emissions.

A similar result is found in the relationship between carbon monoxide concentration and online financial transactions. The estimated regression coefficient is -0.0039 and statistically significant, indicating that online finance also has a direct and significant inverse relationship with carbon monoxide levels.

Further analysis of the control variables reveals that only two of them have statistically significant effects. These are the number of vehicles and the level of education. The regression coefficients for the logarithm of vehicle ownership are 0.0264 in the first model and 0.0282 in the second model. This positive relationship implies that a higher number of vehicles used by the population leads to higher levels of carbon emissions.

In contrast, the education variable shows a negative and statistically significant effect, with coefficients of -0.0214 and -0.0206, respectively. This suggests that higher levels of educational attainment among the population contribute to reduced carbon emissions. This phenomenon may occur because individuals with higher education levels tend to have greater awareness and knowledge regarding environmental issues, thus supporting efforts to reduce pollution.

Discussion

The massive development of information technology has caused disruptions in human social and economic life. With the advent of computers and the internet, economic activities are now conducted not only in the physical world but also through digital media. According to previous studies, the use of this technology can have both negative and positive impacts on the environment.

A 2007 study by Gartner indicated that information and communication technology (ICT) accounts for two percent of global carbon dioxide emissions. This figure is comparable to the emissions produced by the aviation sector. The emissions from ICT are attributed to the high electricity consumption for PCs, servers, cooling systems, telephones, mobile phones, LANs, and printers. This consumption is predicted to continue increasing until 2015 (Gelenbe & Caseau, 2015). According to O. Mohiuddin, Mohiuddin, Obaidullah, Ahmed, and Asumadu-Sarkodie (2016), increased electricity consumption leads to higher electricity production, and whether the production uses coal, natural gas, or oil, all generate carbon emissions. A 1 percent increase in electricity production is expected to raise emission levels by thirteen percent in the long term.

In contrast to the findings of M. Mohiuddin (2014), the use of information technology for shopping and financial transactions in Indonesia has an opposite effect. This means that as the percentage of the population engaging in online shopping and financial transactions increases, the levels of carbon emissions, specifically carbon monoxide, decrease. This conclusion is consistent with the research conducted by Xue, Feng, Chen, and Li (2022),

Shao, Cheng, Wang, and Li (2022), Z. Ahmed and Le (2021), Li et al. (2021) and Zhao, Yang, Li, Liu, and Li (2021).

Digital economies can enhance economic performance while simultaneously reducing energy consumption and carbon emissions (Zhang & Liu, 2022). This is due to the shift from traditional to digital/online shopping systems, which has decreased the mobility of residents using motor vehicles (Weideli, 2013; Loon et al., 2014; Al Mulali, 2015). Additionally, the role of digital financial technology in reducing carbon emissions includes the decrease in paper usage, cost reductions due to shorter business processes, and reduced information asymmetry (Cen & He, 2018; He & Liu, 2012; Weideli & Cheikhrouhou, 2013). However, in Indonesia, the adoption of digital transactions—both in shopping and finance—remains relatively low. According to data from Statistics Indonesia (BPS), only around 23 percent of the population made online purchases in 2024. Meanwhile, the proportion of the population accessing digital financial services stood at just 11.57 percent.

Similar to digital transactions, the percentage of the population with tertiary education also has a negative impact on carbon emissions. Data processing indicates that individuals with education beyond high school contribute to the reduction of CO levels in Indonesia. According to Dong et al. (2011), education is a tool that can enhance societal capacity to prevent and address environmental damage. Additionally, Subramaniam and Masron (2018) suggest that education levels can mitigate the impact of poverty on environmental degradation. This is because individuals in lower economic groups often overuse natural resources.

Unlike digital transactions, the number of vehicles has a significant positive impact on carbon emissions. The greater the number of vehicles owned by a resident, the higher the carbon emissions released into the air. This finding aligns with the conclusions of Hodijah et al. (2014) and Haryanto (2018), which indicate that the transportation sector is a major contributor to carbon emissions.

Population density, industrial share, and agricultural share also affect carbon emissions. However, in this study, these three variables did not show a significant impact on the carbon emissions in the air. This is justifiable given that during the pandemic, the government implemented Large-Scale Social Restrictions (PSBB) to limit mobility. Consequently, economic activities were temporarily halted across Indonesia. As a result, the industrial share, agricultural share, and population density had no significant effect on carbon emissions during the study period.

Conclusion

This study examines the impact of online shopping and digital financial transactions, along with a set of control variables, on carbon monoxide (CO) levels as a carbon pollutant in Indonesian provinces. The investigation into digital economy and carbon emissions has become a significant topic of discussion internationally since the onset of the COVID-19 pandemic. The results reveal that online shopping consistently has a significant negative effect on CO levels in the air. Similarly, digital financial transactions also have a significant impact on CO levels. This inverse relationship indicates that the transition to digital platforms may contribute to a reduction in airborne carbon emissions.

However, not all control variables in the model have an impact on carbon emissions. Population density, the share of manufacturing industry, and agriculture in this study do not show a significant effect on CO levels. In contrast, the number of vehicles and the percentage of the population with tertiary education significantly influence CO levels during the study period. These findings reinforce the role of the transportation sector as a major emitter of carbon emissions, while education plays a crucial role in enhancing public awareness of environmental conditions.

Based on the findings of this study, the following policy recommendations can be proposed: enhancing educational attainment, particularly tertiary education, has been shown to have a negative effect on carbon emissions. In addition, integrating digital and environmental literacy into educational curricula and public awareness campaigns is essential to strengthen understanding of the benefits of digitalization for sustainable development. The government, with support from financial institutions, should promote the use of digital transactions—such as e-commerce and digital financial services—across all regions of Indonesia, particularly in areas with low digital penetration. One approach is to expand the implementation of QRIS as a digital payment method. This is crucial, as the findings indicate that increased digital transactions are significantly and negatively associated with carbon monoxide (CO) emissions, thus supporting the transition toward a low-carbon economy. Affordable and secure e-commerce platforms should be developed for MSMEs, accompanied by guidance and support to accelerate their digital transformation, particularly in trade-related transactions. The government, in collaboration with the private sector, should invest in the development of digital technology infrastructure and telecommunication service providers, such as the construction of Base Transceiver Stations (BTS). This will expand access to financial and digital commerce services as part of a broader strategy to reduce emissions through digital transformation. Incentives such as shipping discounts or subsidies for using eco-friendly digital platforms should be provided to consumers and small and medium enterprises (SMEs) that shift to digital transactions. This is based on the evidence that online consumer behavior contributes to reduced physical mobility and, in turn, lower emissions. Given the significant contribution of motor vehicles to rising CO emissions, control measures are needed, including the development of integrated and environmentally friendly public transportation systems, as well as policies to restrict the use of private vehicles in designated zones. The government should support the development of more secure and resilient digital technology systems to address concerns about cybercrime among producers and consumers. This is critical to building trust and ensuring the security of digital transactions in order to enhance digital financial inclusion.

In addition to policy recommendations, the following suggestions for future research can be proposed: extend the data series, this study is limited by the data used, covering only a four-year period. Future research could include a longer time series to better understand the relationships between variables in both the short term and long term. Consider replacing the share of the manufacturing industry variable with the number of industries based on their scale of operations to improve the validity of the results. Additionally, incorporating other variables that were not covered in this study could enrich the analysis of similar topics.

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