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# Navigating the Trade-Environment Nexus: Moderating Effect of Digital Payments, Urbanization, and Fiscal Policies

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Received: March 20, 2025; Received in revised form: May 24, 2025; Accepted: May 26, 2025; Available online: June 30, 2025

**Abstract:** This paper investigates the nexus between trade and environmental sustainability, focusing on Asia and Africa, using CO<sub>2</sub> emissions as the key variable and testing the moderating effects through digital payments, urbanization, and government expenditure. The diagnostic test validates the appropriateness of the data. The fixed-effects, random-effects, and GLS estimation baselines show that trade growth reduces the emissions of CO<sub>2</sub> significantly, especially for countries with higher emissions. On the other hand, digital payments and urbanization are significantly and positively related to emissions. Government expenditure shows a mixed effect, but its interaction with trade is likely to amplify the environmental benefit of trade. Quantile regression presents some robustness checks, which provide evidence of the heterogeneity of these effects. While the relationship of population and emissions stands out to be statistically significant at higher quantiles, the relationship of GDP and inflation does not show any significant or consistent impact. The instrumental variables (IV) analysis also ensures that potential omitted variable bias and endogeneity issues are addressed. Therefore, the results emphasize the complex interaction between economic factors and sustainability. The study has a crucial policy implication, especially for high-emitting countries, that balances trade, digitalization, and urbanization to achieve sustainable development.

**Keywords:** CO<sub>2</sub>; Moderating Effect; Digital Payments; Quantile Regression; Environmental Sustainability

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## 1. Introduction

Fossil fuel combustion is the prime catalyst for economic growth, but this process emits CO<sub>2</sub>, which very strongly contributes to the degradation of the environment. These days, countries in Asia and Africa increasingly suffer from the struggle between global warming and sustainable economic development. In 1900, over 90 percent of all emissions came either from Europe or the US; as late as 1950, each emitted over 85 percent yearly. But in recent decades, this has dramatically changed. In the second half of the 20<sup>th</sup> century, there was an explosive increase in the rest of the world, particularly across Asia and, most significantly, China [1]. It is imperative to seek to isolate growth in the economy from CO<sub>2</sub> emissions across Asia and the Pacific, which account for 60% of the world's CO<sub>2</sub> emissions

[2]. In the meantime, most of the African countries, although not heavily industrialized, still experience population growth, and this has increased the energy demand that is mostly satisfied through the burning of fossil fuels. More than 50 percent of the top 20 polluters in Africa have shifted to more highly carbon-intensive methods [3]. On the economic side, only two countries, South Africa and Tanzania, have been able to decouple economic growth from CO<sub>2</sub> emissions [4].

Trade growth may result in increased transportation and manufacturing, which will eventually raise the consumption of natural resources and likely increase CO<sub>2</sub> emissions [5, 6]. According to scholars [7, 8], digital payments foster financial development that, in turn, helps lower CO<sub>2</sub> emissions. In Asia, a greater number of transactions are taking place online that foster the growth of the manufacturing sector, and it may have a significant impact on emissions. The growing number of digital payments lays the pathways for sustainable trade growth in Africa. A study discovered that for readily available funding sources, consumers are more likely to make investments and have the opportunity to use environmentally friendly energy sources [9]. Digital platforms allow quicker interactions between buyers and sellers [10, 11]. The use of digital payments is more widely recognized and favored by the legislative and financial institutions [12]. The speed and reliability of transaction systems make trade more efficient, which ensures the growth of an economy [13].

Urbanization can be a moderating variable in the relationship between trade growth and CO<sub>2</sub> emissions. While the effects of higher population density, infrastructure construction, and transportation demand in an urban setup increase energy demand and are CO<sub>2</sub>-emitting sources. On the other hand, it can also facilitate more efficient energy use and access to greener technologies in dense areas at a reduced per capita level. Gnangoin et al. [14] noted in their study that, while assessing CO<sub>2</sub>, urbanization may perform as a complementary lever. In another study, Chang et al. [15] recorded that the environmental problems are worsening due to economic growth and urbanization. Emissions may increase if spending is used to induce industry growth without environmental controls. Bulut et al. [16] applied panel cointegration analysis to depict some useful information about government spending; as such, they showed that sustainable government spending policies contribute to economic growth while causing minimum harm to the environment.

There are a few studies that examine the accompanying environmental effects, more specifically, CO<sub>2</sub> emissions. Most of the literature on these issues either investigates the economic benefits of digital payments [17, 18] or examines the environmental impacts [19, 20] of trade independently but not in an integrated way in a comparative cross-regional context. This study presents new avenues through which trade, apart from moderating effects by digital payment, urbanization, and government expenditure, potentially influences environmental sustainability. Generally, carbon emissions across economies of varying diversity are missing in the existing literature. Therefore, the study will act as a bridge to address the substantial knowledge gaps identified among policymakers and businesses on how growth in trade, digital payments, urbanization, and government expenditure align with environmental goals that foster a more sustainable digital economy.

The objective of this study will be to analyze trade growth, digital payments, urbanization, government expenditure, and CO<sub>2</sub> emissions in Asia and Africa, thereby providing an interaction and moderating effect of the variables on environmental sustainability. Therefore, this study will highlight the trends and discrepancies that may exist; this could help policy analysts, business executives, and environmentalists develop appropriate strategies that ensure a balance between trade growth and environmental sustainability. Businesses, both new and old, are motivated to succeed by

efficient financial systems, and digital payment systems are likely to remain at the heart of future economic development [21]. This study tries to fill the knowledge gap through the assessment of the dual roles that digital payments, urbanization, and government expenditure have on trade facilitation and trade facilitation has on the environment in Asia and Africa.

The results will be instructive in identifying the extent to which trade growth can impact CO<sub>2</sub> emissions along with the moderating effects of digital payment, urbanization, and government expenditure, and, in effect, engender sustainable economic growth. Other determinants, such as population growth, educational attainment, inflation, etc., will also be analyzed in the attempt to explain the socioeconomic conditions for the adoption of trade growth and its impacts on the environment. Such findings might be useful for policymakers, business leaders, and environmental activists. It will also give a way forward on how to align the moderating variables with sustainable trade practices that will help in the promotion of economic growth while limiting environmental harm. It is particularly important in the emerging countries of today since trade is becoming fundamental to their economies, and their climate is significantly changing.

## 2. Literature Review

Trade growth and increasing emissions of carbon dioxide are associated with many theories, like the "pollution haven hypothesis" as well as the "environmental Kuznets curve." The former argues that economies with weaker environmental regulations tend to have more harmful industries, whereas the latter supports the theory that emissions surge with economic growth till a certain threshold point; thereafter, emissions fall as economies grow. In this way, the moderating influences of government expenditure, urbanization, and digital payments balance the trade-environment connection, either enhancing or reducing its effects on environmental sustainability. Prior studies have led to findings that are not entirely satisfactory for the formulation and implementation of appropriate environmental regulations. Each of the categories below may be employed to discuss previous empirical research.

### 2.1. Trade and Environmental Sustainability

The relationship between environmental sustainability and trade development is complex and multidimensional. Increased trade corresponds to higher energy consumption needed for increased production, which will therefore lead to higher CO<sub>2</sub> emissions [22]. Dlamini et al. [23] mentioned that trade development in the long run negatively influences the environment. A study by Sun et al. [24] postulated that trade openness reduces the emission of CO<sub>2</sub>. Similarly, it was reported by Essandoh et al. [25] that trade decreases CO<sub>2</sub> emissions in developed nations. Trade has a negligible to zero effect on the emission of CO<sub>2</sub> in Bangladesh [26]. In addition, two studies conducted by Haug and Ucal [27] and Hasanov et al. [28] depicted the uncertain effects of trade on CO<sub>2</sub> emissions. These conflicting impacts through trade on CO<sub>2</sub> emissions do require further investigation.

There is a bidirectional causal association between trade growth and CO<sub>2</sub> emissions [29]. In another study, Iorember et al. [30] analyzed African OPEC economies, focusing on the effect of trade, income, and energy consumption on environmental sustainability. They fail to draw a clear finding about the effect of trade on CO<sub>2</sub> emissions. Similar to this study, there are some related articles, including [31–36]. Most of their findings are still unclear and focused on the association among economic growth, renewable energy consumption, foreign direct investment, industrialization, and

CO<sub>2</sub> emissions. The current study is significantly different from prior studies in terms of scope, area of focus, periodicity, and methodology.

### 2.2. Digital Payments as A Moderator

Digital payments refer to all payments using digital resources, including digital currency, mobile electronic wallets, online payments, and mobile money transactions [37]. Digital payment is one of the main forces driving the rapid growth of trade and the economy. The use of digital payments promotes economic expansion [18]. In recent years, the rise of digital finance has substantially boosted financial services' availability and affordability, mostly for people who used to be economically excluded, thus ensuring a positive effect on economic growth [17]. In a study, Ibrahim [38] specifies a positive connection between economic betterment and digital payment. Utilizing the fixed effect plus Driscoll-Kraay panel-adjusted estimators [39] found that a surge in digital payments has a beneficial impact on economic expansion.

During an investigation on the nexus between financial inclusion and CO<sub>2</sub> emissions, V. L. T. Le & Pham [40] stated that digital payments affect CO<sub>2</sub> emissions. It increased the efficiency in trade by facilitating financial transactions, which in turn also led the higher energy consumption and CO<sub>2</sub> emissions. Mobile payments increase CO<sub>2</sub> emissions by encouraging consumer spending [41]. On the other hand, digital payments lower CO<sub>2</sub> emissions by reducing the production and transportation of physical cash. Per capita GDP improves dramatically due to digital financial inclusion, thus reducing CO<sub>2</sub> emissions [42]. Digital payments moderate the trade-CO<sub>2</sub> emissions relationship in two ways. First, it reduces transaction costs and increases access, which can increase trade activities and subsequently raise emissions. Secondly, transparency and efficiency in digital transactions encourage eco-friendly initiatives and minimize carbon footprints.

### 2.3. Urbanization as A Moderator

Urbanization reshapes the production, consumption, and transportation patterns; thus, it significantly influences trade growth. Urbanization can affect the patterns of trade since it changes the relative concentration of production factors in an economy and therefore enlarges, or even reverses, what is normally predicted by the model of factor abundance [43]. In a study, Surec & Katircioğlu [44] found a significant positive association between urbanization and trade growth. In another study, Thia [45] stated that trade opportunities and the service sector develop with increased urbanization. In Asia, there is an adverse association between urbanization and trade between nations, especially for non-grain sectors [46].

Urbanization is also an important moderator between trade growth and environmental sustainability relationships. In a study, Mignamissi & Djeufack [47] investigated the effect of urbanization on environmental pollution and concluded that in African countries from the year 1980 to 2016, urban populations were the key emitter of greenhouse gases. Applying a panel study in Sub-Saharan Africa (SSA) over the period from 1984 to 2016, Salahuddin et al. [48] identified the urban population as a key determinant of environmental pollution. Anwar et al. [49] noticed a long-term correlation between urbanization and CO<sub>2</sub> emissions in Asia, but Sufyanullah et al. [50] reported a short-term, unilateral connection. The detrimental environmental impacts associated with trade development may be reduced or increased via urbanization.

### 2.4. Government Spending as A Moderator

Government spending may act as a key catalyst for trade growth. It can increase trade through basic investment in infrastructure and innovation for doing business. Investments that emphasize growth in industries over sustainability issues will boost CO<sub>2</sub> emissions. Empirical studies indicate that due to increased government spending, exchange rate changes have a separate impact on exports and imports. Both the Eurozone and Turkey have shown an upward association between higher expenditures by governments and greater imports [51, 52]. According to Mushtaq et al. [53], government expenditure has the potential to substantially foster economic growth, which in turn stimulates exports. Domestic biases increase due to government procurement policies that stimulate trade [54].

Government spending is one of the main causes of CO<sub>2</sub> emissions, and its impact depends on the pattern of resource allocation. Spending on clean energy projects, energy efficiency, and environmental protection can reduce CO<sub>2</sub> directly by supporting environmentally friendly practices and technologies. In their research, Hazem et al. [55] and Oh [56] find that government spending has an immediate negative impact on the release of CO<sub>2</sub> emissions. In another study, Bouchoucha et al. [57] stated that fiscal spending connects with renewable as well as non-renewable energy sources and can reduce carbon dioxide emissions. Mukherjee and Chakraborty [58] claim that increased CO<sub>2</sub> emissions could result from subsidies that promote industrial development. Similar to this, H. P. Le & Ozturk [59] concluded that governmental expenditure can increase CO<sub>2</sub> emissions because it promotes economic activity that needs greater consumption of energy.

Overall, the above literature suggests that the debate on the relationship between trade growth and environmental sustainability is still unclear. Therefore, the current study aims to explore the impact of trade growth on CO<sub>2</sub> emissions and the moderating effect of digital payments, urbanization, and government spending on this association.

## 3. Methodology

### 3.1. Data

**Table 1.** Data and Sources.

Variables	Measurement	Sources
<i>Dependent</i>		
CO <sub>2</sub>	Natural log of CO <sub>2</sub> emission (Mt CO <sub>2</sub> /yr)	EDGAR
<i>Independent</i>		
Trade	Trade (% of GDP)	WDI
DP	Natural log of digital payments (Billion \$)	Statista
Urb	Urban population (% of total population)	WDI
GE	General government final consumption expenditure (% of GDP)	WDI
GDP	GDP growth (annual%)	WDI
Pop	Population growth (annual%)	WDI
Inf	Inflation, consumer prices (annual%)	WDI
Exg	Official exchange rate (LCU per US\$, period average)	WDI

The paper employed a balanced panel dataset from 2017 to 2023. A total of 50 countries are taken into consideration for analysis, including 25 from Asia and 25 from Africa, representing

heterogeneous economic and demographic contexts. CO<sub>2</sub> emission is the dependent variable and is used as a proxy for environmental sustainability, the data was taken from the Emissions Database for Global Atmospheric Research (EDGAR).

The independent variables include trade, urbanization (Urb), and government expenditure (GE); all the data are from the World Development Indicators (WDI). Another explanatory variable is digital payment (DP) in billion U.S. dollars, which is obtained from Statista and includes both digital commerce (online payments for goods and services) and mobile payments. Besides, the study considered GDP growth, population growth, inflation growth, and exchange rate. These data are also from WDI. In such a way, the current study analyzes how socioeconomic and environmental drivers of CO<sub>2</sub> vary both in time and across regions.

### 3.2. Method and Models

Initially, to check multicollinearity, a Pearson correlation matrix and variance inflation factor are conducted, and for stationarity, it utilizes the Levin-Lin-Chu unit root test. In the baseline model estimation, the paper estimates random effects, fixed effects, and generalized least squares panel regression models to take care of the cross-country and time-series variations in the CO<sub>2</sub> emissions. The moderating effects are explored by introducing the interaction terms among the variables into the models. In addition, for robustness, quantile regression across the 10<sup>th</sup> to 90<sup>th</sup> percentile is deployed, which captures the effects that may vary at higher and lower levels of emissions. The following baseline models are used to identify the impact of trade growth on environmental sustainability, along with other independent variables.

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \mu_i + \epsilon_{it} \tag{1}$$

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \alpha_i + \epsilon_{it} \tag{2}$$

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \epsilon_{it} \tag{3}$$

The following models are used to identify the moderating effect of digital payments, urbanization, and government expenditure,

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \sum_{j=1}^3 \gamma_j M_{j,it} + \mu_i + \epsilon_{it} \tag{4}$$

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \sum_{j=1}^3 \gamma_j M_{j,it} + \alpha_i + \epsilon_{it} \tag{5}$$

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \sum_{j=1}^3 \gamma_j M_{j,it} + \epsilon_{it} \tag{6}$$

To ensure the baseline relationship and for robust findings the following quantile regression models are used,

$$Q_T(CO_{2it}) = \beta_{T,0} + \sum_{k=1}^8 \beta_{T,k} X_{k,it} + \epsilon_{T,it} \quad (7)$$

With a moderating effect;

$$Q_T(CO_{2it}) = \beta_{T,0} + \sum_{k=1}^8 \beta_{T,k} X_{k,it} + \sum_{j=1}^3 \gamma_{T,j} M_{j,it} + \epsilon_{T,it} \quad (8)$$

where,

- $CO_{2it}$  : Dependent variable (CO<sub>2</sub> emissions for country i at time t)
- $X_{k,it}$  : Independent variables (k=1, 2, ...,8)
- $M_{j,it}$  : Moderating variables (j=1,2,3)
- $\beta_0, \beta_k$  : Intercept and coefficients of independent variables, respectively
- $\gamma_j$  : Coefficients of moderating variables
- $\alpha_i$  : Fixed effect for country i (used in FE models)
- $\mu_i$  : Random effect for country i (used in RE models)
- $\epsilon_{it}$  : Error term
- T : Quantile level (T = 0.1, 0.2, ..., 0.9)

To address potential endogeneity, the following instrumental variable regression models are used, where endogenous regressors are instrumented using appropriate lagged instruments.

$$CO_{2it} = \beta_0 + \sum_{k=1}^8 \beta_k X_{k,it} + \epsilon_{it} \quad (9)$$

With a moderating effect;

$$CO_{2it} = \beta_0 + \sum_{k=1}^{11} \beta_k X_{k,it} + \epsilon_{it} \quad (10)$$

These models offer an inclusive framework through which the impacts of both direct and moderating influences of CO<sub>2</sub> emissions could be analyzed while allowing for possible heterogeneity across countries and time. Additionally, the estimation has gone through robustness checks and diagnostic tests for reliable and valid empirical results.

#### 4. Research Result Analysis

##### 4.1. Descriptive Statistics, Correlation Matrix and Unit Root Tests

Table 2 provides the descriptive statistics that demonstrate the variability and key insights, and provides the stages for analyzing their interconnected dynamics.

For clarification and to reveal the relationship between trade and environmental sustainability, it is mandatory to analyze the variability and distribution of the key variables. Diversity in environmental sustainability is demonstrated in the mean of the dependent variable (CO<sub>2</sub> emissions), which is 3.731. In addition, evaluating the environmental impact of trade (mean 28.731% of GDP) is

crucial. Urbanization and digital payments, at a mean of 56.358% and 1.423, respectively, reflect varied levels of adoption that might influence the trade-environment relationship. Government expenditure, at a mean of 14.763% of GDP, reflects fiscal planning concerning sustainability. The mean value of population growth (2.006%) along with exchange rate variation with a mean value of 93.715, additionally contextualizes the sample set with sustainability. On the other hand, economic variability is illustrated through GDP growth at a mean of 2.805% and inflation at 11.742%. Thus, the statistics frame the investigation of the trade effect on environmental sustainability and the moderating effects, showing diversity in trade, government expenditure, and digital payments.

**Table 2.** Descriptive Statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max
CO <sub>2</sub>	350	3.731	2.058	-.655	9.451
Trade	350	28.731	18.079	2.21	32.98
DP	350	1.423	1.821	-2.303	8.1
Urb	350	56.358	23.631	12.71	100
GE	350	14.763	5.939	2.36	36.14
GDP	350	2.805	3.787	-12.05	11.92
Pop	350	2.006	3.269	-4.17	34.24
Inf	350	11.742	29.998	-2.81	59.09
Exg	350	93.715	101.207	0.3	120

**Table 3.** Correlation Matrix and VIF.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	VIF
(1) CO <sub>2</sub>	1.000									
(2) Trade	0.016 (0.763)	1.000								1.67
(3) DP	0.903*** (0.000)	0.033 (0.542)	1.000							1.39
(4) Urb	0.404*** (0.000)	0.556*** (0.000)	0.323*** (0.000)	1.000						2.12
(5) GE	-0.069 (0.199)	0.091* (0.088)	-0.113** (0.035)	0.298*** (0.000)	1.000					1.39
(6) GDP	0.000 (0.995)	-0.057 (0.284)	0.025 (0.643)	-0.160*** (0.006)	-0.274*** (0.000)	1.000				1.13
(7) Pop	-0.205*** (0.000)	-0.106** (0.047)	-0.213*** (0.000)	0.003 (0.956)	-0.120** (0.025)	-0.002 (0.970)	1.000			1.16
(8) Inf	-0.034 (0.526)	-0.144*** (0.007)	-0.047 (0.384)	-0.033 (0.565)	-0.189*** (0.000)	-0.163*** (0.002)	0.170*** (0.001)	1.000		1.16
(9) Exg	0.096* (0.096)	-0.032 (0.580)	0.002 (0.971)	0.014 (0.803)	0.007 (0.907)	-0.033 (0.575)	-0.013 (0.820)	0.033 (0.567)	1.000	1.00

Note(s): p values in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

The correlation matrix (Table 3) shows a significant relationship among the key explanatory variables and helps to simplify the dynamics between trade growth and environmental sustainability.

The result indicates that the direct impact of trade growth on CO<sub>2</sub> emissions is limited. The CO<sub>2</sub> emission positively and significantly correlates with digital payments of 0.903,  $p < 0.01$ , and urbanization of 0.404,  $p < 0.01$ , showing their threats to environmental sustainability. Trade is positively and moderately correlated with urbanization at 0.556,  $p < 0.01$ . The CO<sub>2</sub> negatively correlates with population growth of -0.205,  $p < 0.01$ , and government expenditure with the GDP growth of -0.274,  $p < 0.01$ . The variance inflation factor (VIF) values for all the variables are below the threshold value of 5, and they range from 1.00 to 2.12. Among the variables, the highest VIF is for urbanization, but it is still within the acceptable range. Thus, the findings show that there is no issue of multicollinearity, hence a robust analysis. The findings significantly capture the trade environmental dynamics and the moderating effect of the sustainable development policies.

Table 4 demonstrates the Levin, Lin, and Chu (LLC) unit root test analysis. Stationarity is essential because non-stationarity can lead to misleading regression results. The null hypothesis specifies that the variable has a unit root, while the alternative hypothesis suggests the variable does not contain a unit root, hence stationary. The test statistics and p-values provide evidence against the null hypothesis of a unit root. The unit root testing validates that every variable is stationary, confirming analysis of regression is not spurious. Among the variables, CO<sub>2</sub>, trade, digital payments, spending by governments, GDP growth, increases in population, and inflation are all significant at  $p < 0.01$ , and nearly all of the indicators are stationary in their level form. However, the currency exchange rate is stationary after first differencing, whereas urbanization is stationary in lag transformation. These findings support the suitability of the variables for the study of trade-environment dynamics and their moderating effect.

**Table 4.** Unit Root Test (LLC).

Variables	Transformation	Test Statistic	P Value	Stationary
CO <sub>2</sub>	No	-22.8069	0.000	Yes
Trade	No	-67.0903	0.000	Yes
DP	No	-11.1712	0.000	Yes
Urb	Lagged	-40.032	0.000	Yes
GE	No	-13.8119	0.000	Yes
GDP	No	-9.8642	0.000	Yes
Pop	No	-15.1288	0.000	Yes
Inf	No	-8.6531	0.000	Yes
Exg	First difference	-18.8096	0.000	Yes

Note(s): LLC: Levin, Lin, and Chu.

## 4.2. Analysis and Discussion

### 4.2.1. Regression Output

The regression results (Table 5) reflect mixed relationships of the independent variables with CO<sub>2</sub> emissions (used as a proxy for environmental sustainability) without considering the moderating effects. Trade has a significant negative association with CO<sub>2</sub> emissions in our GLS model (coefficient = -0.0028, p-value = 0.006), which implies that trade growth has a beneficial impact on the environment as it reduces CO<sub>2</sub> emissions. The fact may be for greener trade practices and improvement in technology. Digital payment (DP) is significantly and positively related to CO<sub>2</sub>

emissions, especially in GLS at p-value < 0.001, showing that increased digitalization might be one of the reasons for increased emissions, possibly due to higher energy consumption in digital infrastructure. It can be observed that the GLS model represents urbanization (Urb) very positively (coefficient = 0.0207, p-value < 0.001), hence confirming that urbanization is usually accompanied by environmental degradation due to increased resource use and emissions. Government expenditure (GE) showed a significant negative connection in the GLS model (coefficient = -0.0297, p-value < 0.001), confirming that fiscal policies may positively affect environmental sustainability.

**Table 5.** RE, FE and GLS Regression.

Variables	Random Effects (1)	Fixed Effects (2)	GLS (3)
Trade	0.0001 (0.0007)	0.0008* (0.0005)	-0.0028*** (0.0010)
DP	0.0327* (0.0170)	0.0478*** (0.0162)	0.8466*** (0.0245)
Urb	0.0153*** (0.0055)	-0.0069 (0.0069)	0.0207*** (0.0021)
GE	0.0008 (0.0034)	0.0021 (0.0024)	-0.0297*** (0.0045)
GDP	0.0044*** (0.0016)	0.0045*** (0.0011)	0.0019 (0.0022)
Pop	-0.0000 (0.0027)	0.0009 (0.0019)	-0.0072 (0.0085)
Inf	-0.0003 (0.0003)	-0.0001 (0.0002)	-0.0003 (0.0008)
Exg	0.0000 (0.0000)	0.0000 (0.0000)	0.0001*** (0.0000)
Constant	2.8007*** (0.3279)	3.9504*** (0.3723)	2.2635*** (0.1096)
R <sup>2</sup>	0.2656	0.0064	
Significance	Wald chi <sup>2</sup> (8) = 42.64 Prob > chi <sup>2</sup> = 0.0000	F (8,242) = 5.32 Prob>F= 0.0000	Wald chi <sup>2</sup> (8) = 3430.13 Prob > chi <sup>2</sup> = 0.0000
Hausman Test	chi <sup>2</sup> (8) = 15.87 Prob > chi <sup>2</sup> = 0.0443		
BPLM test	chi <sup>2</sup> (01) = 399.27 Prob > chi <sup>2</sup> = 0.0000		
Modified Wald test	chi <sup>2</sup> (50) = 1500.05 Prob > chi <sup>2</sup> = 0.0000		
Wooldridge test	F (1,49) = 35.344 Prob > F = 0.0000		

Note(s): BPLM: Breusch-Pagan Lagrange Multiplier Test. Standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

On the other hand, variables like GDP, population, inflation, and exchange rate are showing little to no significant association with CO<sub>2</sub> emissions, suggesting that these variables are minor drivers of environmental sustainability. Hausman test analysis supports the fixed effect model, so unobserved individual effects are associated with the regressors. The modified Wald test, the BPLM

test, and the Wooldridge test indicate the presence of heteroskedasticity and autocorrelation, which indicates that the GLS regression model is superior for addressing these issues and making robust results.

**Table 6.** RE, FE and GLS Regression with Moderating Effects.

Variables	Random Effects (4)	Fixed Effects (5)	GLS (6)
Trade	-0.0014 (0.0024)	-0.0012 (0.0017)	0.0014 (0.0034)
DP	0.0584** (0.0239)	0.0739*** (0.0209)	0.9368*** (0.0379)
Urb	0.0135** (0.0059)	-0.0107 (0.0071)	0.0194*** (0.0026)
GE	-0.0011 (0.0058)	-0.0008 (0.0041)	-0.0235** (0.0108)
Trade.DP	-0.0003 (0.0002)	-0.0003* (0.0002)	-0.0010** (0.0004)
Trade.Urb	0.0000 (0.0000)	0.0000 (0.0000)	-0.0000** (0.0000)
Trade.GE	0.0000 (0.0000)	0.0000 (0.0000)	0.0001 (0.0001)
GDP	0.0048*** (0.0016)	0.0049*** (0.0011)	0.0039* (0.0023)
Pop	0.0002 (0.0028)	0.0012 (0.0019)	-0.0141* (0.0080)
Inf	-0.0003 (0.0003)	-0.0001 (0.0002)	-0.0014 (0.0009)
Exg	0.0000 (0.0000)	0.0000 (0.0000)	0.0001*** (0.0000)
Constant	2.9010*** (0.3553)	4.1767*** (0.3869)	2.0726*** (0.2060)
R <sup>2</sup>	0.2883	0.0001	
Significance	Wald chi <sup>2</sup> (8) = 45.57 Prob > chi <sup>2</sup> = 0.0000	F (11,239) = 4.45 Prob>F= 0.0000	Wald chi <sup>2</sup> (11) = 2349.77 Prob > chi <sup>2</sup> = 0.0000
Hausman Test	chi <sup>2</sup> (8) = 16.72 Prob > chi <sup>2</sup> = 0.1163		
BPLM test	chi <sup>2</sup> (01) = 359.38 Prob > chi <sup>2</sup> = 0.0000		
Modified Wald test	chi <sup>2</sup> (50) = 22469.65 Prob > chi <sup>2</sup> = 0.0000		
Wooldridge test	F (1,49) = 32.731 Prob > F = 0.0000		

Note(s): BPLM: Breusch-Pagan Lagrange Multiplier Test. Standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

The results (Table 6) provide valuable insight about the relationship between trade growth and environmental sustainability, also showing the moderated effects of digital payments, urbanization, and government expenditure. From the result, we found that trade has inconsistency across different

models (insignificant negative in the FE, RE model but insignificant positive in the GLS model), implying that trade alone has no direct impact on environmental sustainability.

Digital payment, as well as urbanization, consistently exhibit significant and positive effects on CO<sub>2</sub> emissions, specifically in the GLS model (coefficient = 0.9368, p < 0.001 for DP and coefficient = 0.0194, p < 0.001 for Urb). Contrary to that, government expenditure is found to be significantly and negatively associated with CO<sub>2</sub> emissions, suggesting that sustainable investment can be beneficial for the environment. Although the moderating effect of government expenditure (Trade.GE) is not significant in the models. The moderating effect of digital payment and urbanization (Trade.DP and Trade.Urb) both have a significant negative association with CO<sub>2</sub> emissions, implying both moderate the trade environment dynamics significantly. The diagnostic tests confirm the presence of heteroskedasticity and autocorrelation. Thus, again, the GLS model ensures robust findings.

4.2.2. Robustness Check

Table 7. Quantile Regression (7).

Variables	Lower Order			Middle Order			Upper Order		
	10 <sup>th</sup>	20 <sup>th</sup>	30 <sup>th</sup>	40 <sup>th</sup>	50 <sup>th</sup>	60 <sup>th</sup>	70 <sup>th</sup>	80 <sup>th</sup>	90 <sup>th</sup>
Trade	-0.0017 (0.0025)	-0.0038* (0.0021)	-0.006*** (0.0017)	-0.005*** (0.0016)	-0.005*** (0.0016)	-0.0064*** (0.0018)	-0.007*** (0.0016)	-0.009*** (0.0015)	-0.0100*** (0.0015)
DP	0.960*** (0.0622)	0.950*** (0.0534)	0.893*** (0.0419)	0.923*** (0.0404)	0.948*** (0.0408)	0.925*** (0.0454)	0.945*** (0.0392)	0.919*** (0.0379)	0.914*** (0.0383)
Urb	0.0121** (0.0058)	0.019*** (0.0050)	0.0241*** (0.0039)	0.0211*** (0.0038)	0.0187*** (0.0038)	0.0212*** (0.0042)	0.0237*** (0.0036)	0.0284*** (0.0035)	0.0260*** (0.0036)
GE	-0.0075 (0.0186)	-0.0058 (0.0160)	-0.0229* (0.0125)	-0.0207* (0.0121)	-0.0146 (0.0122)	-0.0232* (0.0136)	-0.0209* (0.0117)	-0.037*** (0.0114)	-0.0364*** (0.0115)
GDP	-0.0183 (0.0258)	-0.0107 (0.0222)	-0.0047 (0.0174)	-0.0151 (0.0168)	-0.0103 (0.0169)	-0.0087 (0.0188)	0.0085 (0.0163)	0.0013 (0.0158)	-0.0089 (0.0159)
Pop	-0.0199 (0.0302)	-0.0020 (0.0259)	-0.0223 (0.0203)	-0.0224 (0.0196)	-0.0364* (0.0198)	-0.0293 (0.0220)	-0.0421** (0.0190)	-0.0422** (0.0184)	-0.0486*** (0.0186)
Inf	0.0011 (0.0031)	-0.0016 (0.0027)	-0.0042** (0.0021)	-0.0023 (0.0021)	-0.0001 (0.0021)	0.00063 (0.0023)	0.0003 (0.0020)	-0.0008 (0.0019)	-0.0004 (0.0019)
Exg	0.0004** (0.0002)	0.0003* (0.0002)	0.0003** (0.0001)	0.0002** (0.0001)	0.0002* (0.0001)	0.0007*** (0.0001)	0.0005*** (0.0001)	0.0005*** (0.0002)	0.0005*** (0.0002)
Constant	0.795** (0.373)	0.922*** (0.320)	1.533*** (0.251)	1.722*** (0.242)	1.956*** (0.244)	2.188*** (0.272)	2.318*** (0.235)	2.724*** (0.227)	3.195*** (0.230)
Obs	300	300	300	300	300	300	300	300	300

Note(s): Standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

The quantile regression analysis (Table 7) brings out the differential impact of the key variables on environmental sustainability across quantiles. Trade shows an increasingly negative relationship with emissions, starting to be significant from the 30<sup>th</sup> percentile onward, which indicates that trade growth is beneficial for sustainability more in high-emission countries. Emissions and digital payments have always shown a positive and significant relationship. This may indicate that with more implications of the digital revolution, the higher the resultant emissions. The coefficient of

urbanization has consistently shown a positive and much higher magnitude in almost all the quantiles, showing that as growth becomes more comprehensive, it deteriorates environmental sustainability. Government expenditure is mixed but was positive and statistically significant at high quantiles; hence, it has the potential for the attainment of sustainability in countries where emissions have risen. The table shows that among the other results, GDP, population, and inflation reveal varying impacts at high quantiles, while the state of GDP and inflation reveals a weak or nil impact. Consequently, this will make policy intervene in high-emission countries, where the effects of trade, urbanization, and government spending are significant, to enhance prospects for environmental sustainability.

**Table 8.** Quantile Regression with Moderating Effects (8).

Variables	Lower Order			Middle Order			Upper Order		
	10 <sup>th</sup>	20 <sup>th</sup>	30 <sup>th</sup>	40 <sup>th</sup>	50 <sup>th</sup>	60 <sup>th</sup>	70 <sup>th</sup>	80 <sup>th</sup>	90 <sup>th</sup>
Trade	-0.041*** (0.0114)	-0.044*** (0.0106)	-0.037*** (0.0091)	-0.029*** (0.0092)	-0.026*** (0.0089)	-0.018* (0.0093)	-0.004 (0.0095)	-0.004 (0.0084)	0.003 (0.0083)
DP	1.008*** (0.111)	0.851*** (0.103)	0.882*** (0.0892)	0.880*** (0.0891)	0.904*** (0.0862)	0.921*** (0.0905)	1.020*** (0.0928)	0.929*** (0.0820)	0.985*** (0.0805)
Urb	0.0016 (0.0067)	0.0084 (0.0062)	0.0104* (0.0054)	0.0131** (0.0054)	0.0110** (0.0052)	0.017*** (0.0055)	0.0207*** (0.0057)	0.0297*** (0.0050)	0.0330*** (0.0049)
GE	-0.094*** (0.0311)	-0.112*** (0.0288)	-0.106*** (0.0250)	-0.083*** (0.0250)	-0.078*** (0.0242)	-0.066*** (0.0254)	-0.0344 (0.0260)	-0.0504** (0.0230)	-0.0405* (0.0226)
Trade.DP	0.0002 (0.00174)	0.0029* (0.00161)	0.0014 (0.0014)	0.0008 (0.0014)	0.0011 (0.0013)	0.0005 (0.0014)	-0.0008 (0.0014)	-0.0003 (0.0012)	-0.0010 (0.0012)
Trade.Urb	0.0002** (-0.0009)	0.0001 (-0.0001)	0.0001* (-0.0001)	0.0001 (-0.0007)	0.0001 (-0.0001)	0.00001 (-0.0001)	-0.00003 (-0.0008)	-0.00006 (-0.0006)	-0.00009 (-0.0007)
Trade.GE	0.0016*** (0.0004)	0.002*** (0.0004)	0.002*** (0.0004)	0.0011*** (0.00036)	0.0011*** (0.0003)	0.0008** (0.0004)	0.0002 (0.00038)	0.00013 (0.00033)	-0.0002 (0.00033)
GDP	-0.0101 (0.0208)	-0.00828 (0.0193)	-0.00295 (0.0168)	-0.0105 (0.0168)	-0.0116 (0.0162)	-0.0110 (0.0170)	0.0129 (0.0175)	0.00314 (0.0154)	-0.0187 (0.0151)
Pop	0.0170 (0.0246)	-0.00168 (0.0228)	-0.0138 (0.0198)	-0.0185 (0.0198)	-0.0201 (0.0191)	-0.0229 (0.0201)	-0.0339 (0.0206)	-0.0400** (0.0182)	-0.050*** (0.0179)
Inf	0.0026 (0.00261)	0.00014 (0.0024)	0.0017 (0.0021)	-0.00030 (0.00210)	0.00035 (0.00203)	0.00051 (0.0021)	0.00141 (0.00219)	-0.00033 (0.00194)	0.00166 (0.00190)
Exg	0.00039** (0.00015)	0.0003** (0.0002)	0.0003** (0.0002)	0.00027** (0.00012)	0.0002** (0.00012)	0.0016*** (0.0012)	0.0005*** (0.00013)	0.0006*** (0.00011)	0.0004*** (0.00011)
Constant	2.600*** (0.646)	3.277*** (0.598)	3.214*** (0.520)	3.080*** (0.519)	3.195*** (0.502)	2.878*** (0.527)	2.281*** (0.541)	2.606*** (0.478)	2.587*** (0.469)
Obs	300	300	300	300	300	300	300	300	300

Note(s): Standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Quantile regression analysis with moderating effects (Table 8) largely confirms the results from the baseline model. Trade consistently shows a negative effect on CO<sub>2</sub> emissions, which is significant across all quantiles, similar to the baseline model, thus proving that trade growth is supportive of

sustainability, especially for high-emitting countries. The moderating role of digital payments also supports baseline findings, where higher digitalization contributes to emissions growth, which is also tempered by trade at low quantiles. Urbanization reinforces emissions growth as well, and its magnitude grows stronger for the higher quantiles, a situation that supports what was obtained from the baseline model.

The interaction between (Trade.Urb) and the influence of government expenditure further reinforces the conclusions of the baseline model by showing that government spending is so important in high-emission countries to address CO<sub>2</sub> emissions. All in all, the moderating effects add to the robustness of the baseline model and confirm that trade, urbanization, and government expenditure play an indispensable role in environmental sustainability.

4.2.3. Instrumental Variables (IV) Estimation

Table 9. Instrumental Variables (IV) Regression (2SLS).

Variables	Coefficient (9)	Coefficient (10)
Trade	-0.0054*** (0.0011)	-0.0269* (0.0141)
DP	0.9552*** (0.0381)	0.9573*** (0.0735)
Urb	0.0194*** (0.0032)	0.0129*** (0.0050)
GE	-0.0118 (0.0093)	-0.0714*** (0.0269)
Trade.DP		0.0004 (0.0011)
Trade.Urb		0.0000 (0.0000)
Trade.GE		0.0010** (0.0004)
GDP	-0.0119 (0.0113)	-0.0112 (0.0115)
Pop	-0.0360*** (0.0105)	-0.0257*** (0.0097)
Inf	0.0001 (0.0014)	0.0004 (0.0013)
Exg	0.0011*** (0.0003)	0.0013*** (0.0003)
Constant	1.6971*** (0.1853)	2.8434*** (0.7131)
R <sup>2</sup>	0.8526	0.8621
Significance (First-Stage F-statistic)	Wald chi <sup>2</sup> (8) = 1451.54 Prob > chi <sup>2</sup> = 0.0000	Wald chi <sup>2</sup> (8) = 1606.04 Prob > chi <sup>2</sup> = 0.0000
Shea's Partial R-squared:		
Trade	0.9491	0.2471
DP	0.9511	0.7761
Urb	0.9796	0.6996
Endogeneity Test	chi <sup>2</sup> (3) = 15.96 (p = 0.001) F (3,238) = 7.90 (p = 0.000)	chi <sup>2</sup> (3) = 17.58 (p = 0.000) F (3,235) = 7.92 (p = 0.000)

Note(s): Standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Instrumental variables estimation (Table 9) provides a comprehensive analysis and deeper insights into the relationship among the variables in our analysis. The value of Shea's partial R-squared in the first stage IV analysis provides strong evidence that the instrument is strong and relevant. In both models, the significant F statistics suggest the use of this instrument. The variability in the coefficient value across the variables implies that there may be other factors that can alter the trade environment nexus. The endogeneity test further confirms the validity of IV and ensures that potential omitted variable bias is addressed. The findings are also consistent with our baseline as well as our robustness model. This consistency further ensures the robustness of our analysis and findings.

## 5. Conclusion

The findings confirm that trade growth significantly reduces the level of CO<sub>2</sub> emissions in the Asian and African regions, especially in highly emitting countries, hence its contribution to increasing environmental sustainability. This outcome is consistent across the baseline model as well as quantile regression estimation, hence adding to the robustness of the analysis. More interesting insights from moderating effects show that although digital payments have a direct positive impact on emissions, at lower quantiles, the interaction between (Trade.DP) reduces such impact; that is, trade could offset part of the environmental costs brought about by digitalization. Urbanization also presents an increasing impact along all quantiles, with higher impacts for higher emission levels, and reflects the challenges in terms of sustainability that rapid urban growth brings with it. Government expenditure has a direct emission-reducing effect at lower quantiles but mixed effects at higher quantiles. The interaction between trade and government expenditure (Trade.GE) points to the potential of fiscal measures in leveraging the environmental sustainability of trade growth, especially in high-emission countries. The results are closely aligned in both the baseline and quantile analyses, hence robust, and underline the need for targeted policies that balance trade, digitalization, and urbanization to attain sustainability. Further, the IV analysis addressed the potential omitted variables bias and endogeneity issue.

These results provide critical implications for policymakers to achieve sustainable development. The government should reduce trade barriers to promote free trade across boarder. Policymakers need to promote environmentally friendly technology and goods. Their proposed and implemented investment priority should be based on green logistics. They should also use trade strategically as a means for the mitigation of emissions while responding to the environmental consequences of digitalization and urbanization. The findings of this study detail real-life pathways to integrate economic growth with environmental sustainability and, therefore, feed into global efforts toward mitigating climate change.

The study is, however, limited to the data accuracy as collected from secondary sources. Long-term implications of such moderators as digitalization and urbanization are also yet to be realized. Future studies may also conduct in-depth sub-regional analysis, and the studies might engage in more dynamic models or add further variables to obtain more accurate perceptions about sustainable outcomes.

**Contributions:** Shakil Ahmed Sabuz: Conceptualization; Methodology; Data curation; Formal analysis; Writing – original draft; Visualization.

Nusrat Tasnim: Literature review; Writing – review and editing; Interpretation of results; Supervision; Both authors reviewed and approved the final version of the manuscript.

**Acknowledgments:** The authors acknowledge each other's contributions to this paper. They also acknowledge the anonymous reviewer for their valuable feedback and suggestions.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

- [1] Ritchie, H., & Roser, M. (2024). CO<sub>2</sub> emissions. Our World in Data. <https://ourworldindata.org/co2-emissions> (Accessed: 19 November 2024).
- [2] Pagaduan, J., & Hugot, J. (2023). Strategies for rapidly decoupling carbon dioxide emissions from GDP in Asia and the Pacific. Asian Development Blog. <https://blogs.adb.org/blog/strategies-rapidly-decoupling-carbon-dioxide-emissions-gdp-asia-and-pacific> (Accessed: 19 November 2024).
- [3] De Melo, J., & Solleder, J. (2023). The landscape of CO<sub>2</sub> emissions across Africa: A comparative perspective. *World Economy*, 46, 3392-3418. <https://doi.org/10.1111/twec.13498>
- [4] Wang, J., Shan, Y., Cui, C., Zhao, C., Meng, J., & Wang, S. (2024). Investigating the fast energy-related carbon emissions growth in African countries and its drivers. *Applied Energy*, 357, 122494. <https://doi.org/10.1016/j.apenergy.2023.122494>
- [5] Li, Z., & Wang, J. (2022). The dynamic impact of digital economy on carbon emission reduction: Evidence from city-level empirical data in China. *Journal of Cleaner Production*, 351, 131570. <https://doi.org/10.1016/j.jclepro.2022.131570>
- [6] Nguyen, T. T., Pham, T. A. T., & Tram, H. T. X. (2020). Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries. *Journal of Environmental Management*, 261, 110162. <https://doi.org/10.1016/j.jenvman.2020.110162>
- [7] Bekhet, H. A., Matar, A., & Yasmin, T. (2017). CO<sub>2</sub> emissions, energy consumption, economic growth, and financial development in GCC countries: Dynamic simultaneous equation models. *Renewable and Sustainable Energy Reviews*, 70, 117-132. <https://doi.org/10.1016/j.rser.2016.11.089>
- [8] Le, T. -H., Le, H. -C., & Taghizadeh-Hesary, F. (2020). Does financial inclusion impact CO<sub>2</sub> emissions? Evidence from Asia. *Finance Research Letters*, 34, 101451. <https://doi.org/10.1016/j.frl.2020.101451>
- [9] Kara, A., Zhou, H., & Zhou, Y. (2021). Achieving the United Nations' sustainable development goals through financial inclusion: A systematic literature review of access to finance across the globe. *International Review of Financial Analysis*, 77, 101833. <https://doi.org/10.1016/j.irfa.2021.101833>
- [10] Abeliantsky, A. L., & Hilbert, M. (2017). Digital technology and international trade: Is it the quantity of subscriptions or the quality of data speed that matters? *Telecommunications Policy*, 41, 35-48. <https://doi.org/10.1016/j.telpol.2016.11.001>
- [11] Demirkan, H., Goul, M., Kauffman, R. J., & Weber, D. M. (2009). Does distance matter? The influence of ICT on bilateral trade flows. *Electronic Commerce Research and Applications*, 8(4), 246-259. <https://doi.org/10.1016/j.elerap.2008.09.001>.
- [12] Bhuiyan, M. R. I., Akter, M. S., & Islam, S. (2024). How does digital payment transform society as a cashless society? An empirical study in the developing economy. *Journal of Science and Technology Policy Management*, 2024. Ahead of print. <https://doi.org/10.1108/JSTPM-10-2023-0170>.
- [13] Aldaas, A. (2021). A study on electronic payments and economic growth: Global evidences. *Accounting*, 7(2), 409-414. <https://doi.org/10.5267/j.ac.2020.11.010>
- [14] Gngoin, T. Y., Kassi, D. F., & Kongrong, O. (2022). Urbanization and CO<sub>2</sub> emissions in Belt and Road Initiative Economies: Analysis of the mitigating effect of human capital in Asian countries. Preprint. <https://doi.org/10.21203/rs.3.rs-2030777/v1>
- [15] Chang, G., Yasin, I., & Naqvi, S. M. M. A. (2024). Environmental sustainability in OECD nations: The moderating impact of green innovation on urbanization and green growth. *Sustainability*, 16, 7047. <https://doi.org/10.3390/su16167047>
- [16] Bulut, U., Ongan, S., Dogru, T., Işık, C., Ahmad, M., Alvarado, R., Amin, A., & Rehman, A. (2023). The nexus between government spending, economic growth, and tourism under climate change: Testing the

- CEM model for the USA. *Environmental Science and Pollution Research*, 30, 86138-86154. <https://doi.org/10.1007/s11356-023-28319-w>
- [17] Ahmad, M., Majeed, A., Khan, M. A., Sohaib, M., & Shehzad, K. (2021). Digital financial inclusion and economic growth: Provincial data analysis of China. *China Economic Journal*, 14, 291-310. <https://doi.org/10.1080/17538963.2021.1882064>
- [18] Ozturk, I., & Ullah, S. (2022). Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? An empirical analysis. *Resources, Conservation & Recycling*, 185, 106489. <https://doi.org/10.1016/j.resconrec.2022.106489>
- [19] Li, X., Liu, J., & Ni, P. (2021). The impact of the digital economy on CO<sub>2</sub> emissions: A theoretical and empirical analysis. *Sustainability*, 13, 7267. <https://doi.org/10.3390/su13137267>
- [20] Mukalay, N. M., & Inglesi-Lotz, R. (2023). Digital financial inclusion and energy and environment: Global positioning of Sub-Saharan African countries. *Renewable and Sustainable Energy Reviews*, 173, 113069. <https://doi.org/10.1016/j.rser.2022.113069>
- [21] Tay, L. -Y., Tai, H. -T., & Tan, G. -S. (2022). Digital financial inclusion: A gateway to sustainable development. *Heliyon*, 8, e09766. <https://doi.org/10.1016/j.heliyon.2022.e09766>
- [22] Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Wireko, S. A., & Dogbe, C.S.K., (2021). Innovation, trade openness and CO<sub>2</sub> emissions in selected countries in Africa. *Journal of Cleaner Production*, 281, 125143. <https://doi.org/10.1016/j.jclepro.2020.125143>
- [23] Dlamini, Z., Nzimande, N., Biyase, M., Khobai, H., Manguzvane, M., & Gumede, S. (2024). Carbon emissions and growth: The role of trade and urbanization in Sub-Saharan Africa. *International Journal of Energy Economics and Policy*, 14, 605-614. <https://doi.org/10.32479/ijeeep.15940>
- [24] Sun, H., Clotey, S. A., Geng, Y., & Fang, K. (2019). Trade openness and carbon emissions: Evidence from Belt and Road countries. *Sustainability*, 11, 2682. <https://doi.org/10.3390/su11092682>
- [25] Essandoh, O. K., Islam, M., & Kakinaka, M. (2020). Linking international trade and foreign direct investment to CO<sub>2</sub> emissions: Any differences between developed and developing countries? *Science of the Total Environment*, 712, 136437. <https://doi.org/10.1016/j.scitotenv.2019.136437>
- [26] Rahman, M. M., & Alam, K. (2021). Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. *Renewable Energy*, 172, 1063-1072. <https://doi.org/10.1016/j.renene.2021.03.103>
- [27] Haug, A. A., & Ucal, M. (2019). The role of trade and FDI for CO<sub>2</sub> emissions in Turkey: Nonlinear relationships. *Energy Economics*, 81, 297-307. <https://doi.org/10.1016/j.eneco.2019.04.006>
- [28] Hasanov, F. J., Liddle, B., & Mikayilov, J. I. (2018). The impact of international trade on CO<sub>2</sub> emissions in oil exporting countries: Territory vs consumption emissions accounting. *Energy Economics*, 74, 343-350. <https://doi.org/10.1016/j.eneco.2018.06.004>
- [29] Rahman, M. M., & Alam, K. (2022). CO<sub>2</sub> emissions in Asia-Pacific region: Do energy use, economic growth, financial development, and international trade have detrimental effects? *Sustainability*, 14, 5420. <https://doi.org/10.3390/su14095420>
- [30] Iorember, P. T., Gbaka, S., Jelilov, G., Alymkulova, N., & Usman, O. (2022). Impact of international trade, energy consumption and income on environmental degradation in Africa's OPEC member countries. *African Development Review*, 34, 175-187. <https://doi.org/10.1111/1467-8268.12629>
- [31] Ansari, M. A, Haider, S., & Khan, N. A. (2020). Does trade openness affects global carbon dioxide emissions: Evidence from the top CO<sub>2</sub> emitters. *Manag Environ Qual Int J*, 31, 32-53. <https://doi.org/10.1108/MEQ-12-2018-0205>
- [32] Asongu, S. A., & Odhiambo, N. M. (2021). The green economy and inequality in Sub-Saharan Africa: Avoidable thresholds and thresholds for complementary policies. *Energy Exploration & Exploitation*, 39, 838-852. <https://doi.org/10.1177/0144598720984226>
- [33] Azam, M., Rehman, Z. U., & Ibrahim, Y. (2022). Causal nexus in industrialization, urbanization, trade openness, and carbon emissions: Empirical evidence from OPEC economies. *Environmental Development and Sustainability*, 24, 13990-14010. <https://doi.org/10.1007/s10668-021-02019-2>
- [34] Dogan, E. (2015). The relationship between economic growth and electricity consumption from renewable and non-renewable sources: A study of Turkey. *Renewable and Sustainable Energy Reviews*, 52, 534-546. <https://doi.org/10.1016/j.rser.2015.07.130>
- [35] Dogan, E., & Seker, F. (2016). The influence of real output, renewable and non-renewable energy, trade, and financial development on carbon emissions in the top renewable energy countries. *Renewable and*

- Sustainable Energy Reviews, 60, 1074-1085. <https://doi.org/10.1016/j.rser.2016.02.006>
- [36] Kasman, A., & Duman, Y. S. (2015). CO<sub>2</sub> emissions, economic growth, energy consumption, trade, and urbanization in new EU member and candidate countries: A panel data analysis. *Economic Modelling*, 44, 97-103. <https://doi.org/10.1016/j.econmod.2014.10.022>
- [37] Alkhowaiter, W. A. (2020). Digital payment and banking adoption research in Gulf countries: A systematic literature review. *International Journal of Information Management*, 53, 102102. <https://doi.org/10.1016/j.ijinfomgt.2020.102102>
- [38] Lee, M.W., Yap, M.M., & Goh, K. L. (2022). Malaysian Domestic Bond Market Experience: Lessons for Emerging Economies. *Capital Markets Review*, 30(2), 1-8.
- [39] Patra, B., & Sethi, N. (2024). Does digital payment induce economic growth in emerging economies? The mediating role of institutional quality, consumption expenditure, and bank credit. *Information Technology for Development*, 30, 57-75. <https://doi.org/10.1080/02681102.2023.2244465>
- [40] Le, V. L. T., & Pham, K. D. (2024). The impact of financial inclusion and digitalization on CO<sub>2</sub> emissions: A cross-country empirical analysis. *Sustainability*, 16, 10491. <https://doi.org/10.3390/su162310491>
- [41] Li, T., Jiang, Y., & Zhao, Y. (2024). Does mobile payment foster low-carbon lifestyles? Evidence from Alipay's "collecting five blessings" campaign. *Journal of Cleaner Production*, 463, 142513. <https://doi.org/10.1016/j.jclepro.2024.142513>
- [42] Zheng, H., & Li, X. (2022). The impact of digital financial inclusion on carbon dioxide emissions: Empirical evidence from Chinese provinces data. *Energy Reports*, 8, 9431-9440. <https://doi.org/10.1016/j.egy.2022.07.050>
- [43] Brakman, S., & van Marrewijk, C. (2013). Lumpy countries, urbanization, and trade. *Journal of International Economics*, 89, 252-261. <https://doi.org/10.1016/j.jinteco.2012.05.004>
- [44] Surec, Y., & Katircioğlu, S. (2020). The role of urbanization in the international trade of services. *Management Decision Economics*, 41, 943-951. <https://doi.org/10.1002/mde.3149>
- [45] Thia, J. P. (2016). Trade and urbanization. *World Economy*, 39, 853-872. <https://doi.org/10.1111/twec.12312>
- [46] Yuan, Z., & Guanghua, W. (2015). International trade and the urbanization of developing countries: Evidence from Asia. *Social Sciences in China*, 36(2), 186-204. <https://www.tandfonline.com> (Accessed: 23 December 2024). <https://doi.org/10.1080/02529203.2015.1029679>
- [47] Mignamissi, D., & Djeufack, A. (2021). Urbanization and CO<sub>2</sub> emissions intensity in Africa. *Environmental Economics and Policy Studies*, 65(9), 1660-1684. <https://doi.org/10.1080/09640568.2021.1943329>
- [48] Salahuddin, M., Ali, M.d.I., Vink, N., & Gow, J. (2019). The effects of urbanization and globalization on CO<sub>2</sub> emissions: Evidence from Sub-Saharan Africa (SSA) countries. *Environmental Science and Pollution Research*, 26, 2699-2709. <https://doi.org/10.1007/s11356-018-3790-4>
- [49] Anwar, A., Sinha, A., Sharif, A., Siddique, M., Irshad, S., Anwar, W., & Malik, S. (2022). The nexus between urbanization, renewable energy consumption, financial development, and CO<sub>2</sub> emissions: Evidence from selected Asian countries. *Environmental Development and Sustainability*, 24, 6556-6576. <https://doi.org/10.1007/s10668-021-01716-2>
- [50] Sufyanullah, K., Ahmad, K. A., & Sufyan Ali, M. A. (2022). Does emission of carbon dioxide impact urbanization? An empirical study of urbanization, energy consumption, economic growth, and carbon emissions-Using ARDL bound testing approach. *Energy Policy*, 164, 112908. <https://doi.org/10.1016/j.enpol.2022.112908>
- [51] Çebi, C., & Çulha, A. A. (2014). The effects of government spending shocks on the real exchange rate and trade balance in Turkey. *Applied Economics*, 46, 3151-3162. <https://doi.org/10.1080/00036846.2014.922673>
- [52] Konstantakopoulou, I. (2017). The effects of government expenditure on imports in the Eurozone reconsidered: Evidence from panel data. *Applied Economics*, 49, 3231-3239. <https://doi.org/10.1080/00036846.2017.1418081>
- [53] Mushtaq, M., Nazir, R., Bashir, I., Ahmed, S., & Nadeem, M. (2021). Panel cointegration analysis of government spending, exports, imports, and economic growth. *Economic Research International*, 2021, 346139.
- [54] Gourdon, J., & Messent, J. (2019). How government procurement measures can affect trade. *Journal of World Trade*. <https://kluwerlawonline.com/api/Product/CitationPDFURL?file=Journals\TRAD\TRAD2019029>. pdf (Accessed: 24 December 2024). <https://doi.org/10.1787/d1ab07b8-en>
- [55] Hazem, N., Taha, N. M., & Hussein, I. A. E. (2024). The impact of government expenditure on

- environmental degradation in MENA countries: An empirical investigation. *International Journal of Sustainable Economics*, 16, 90-112. <https://doi.org/10.1504/IJSE.2024.135205>
- [56] Oh, J. (2023). The effects of local government expenditures on carbon dioxide emissions: Evidence from the Republic of Korea. *Sustainability*, 15, 14913. <https://doi.org/10.3390/su152014913>
- [57] Bouchoucha, N., Ghandri, M., & Yahyaoui, I. (2024). Linking non-renewable and renewable electricity and government expenditures to environmental degradation: Evidence from 10 newly industrialized countries. *International Journal of Energy Economics and Policy*, 14, 301-306. <https://doi.org/10.32479/ijeeep.15688>
- [58] Mukherjee, S. & Chakraborty, D. (2014). Relationship between fiscal subsidies and CO<sub>2</sub> emissions: Evidence from cross-country empirical estimates. *Economic Research International*, 2014, 346139. <https://doi.org/10.1155/2014/346139>
- [59] Le, H. P., & Ozturk, I. (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO<sub>2</sub> emissions in the presence of the environmental Kuznets curve. *Environmental Science and Pollution Research*, 27, 22680-22697. <https://doi.org/10.1007/s11356-020-08812-2>



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(Executive Editor: Jin-mo Li)