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DIGITALIZATION AND SUSTAINABLE AGRICULTURE: A PATH TO CARBON-NEUTRAL FARMING IN E7 ECONOMIES

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Abstract
This study explores the dynamic relationship between key macroeconomic factors Consumer Price Index, digitalization, financial development, human development, and carbon dioxide emissions (share of agriculture) in the E7 economies. Using data from 1991 to 2022 and applying the Pooled Mean Group Autoregressive Distributed Lag model, the research examines both the direct effects of these variables on CO_2 emissions and the moderating role of digitalization in mitigating inflationary pressures. The results highlight a positive correlation between CPI, digitalization, and financial development with increased CO_2 emissions, whereas the interaction of digitalization and CPI offers a potential avenue for emission reduction. The study emphasizes the need for sustainable agricultural practices, such as precision farming and renewable energy adoption, to counteract the environmental impact of economic growth. The findings underscore the need for policies promoting technological efficiency and sustainable growth to combat climate change, emphasizing digitalization's role in balancing economic progress with environmental sustainability.
Keywords: *sustainable agriculture, carbon neutral farming, digitalization, regulatory proposals, E7 economies*

INTRODUCTION
In many developing countries, key demographic factors such as population growth, declining mortality rates, and increasing life expectancy indicate sustained population expansion throughout the 21st century. Agriculture remains a dominant economic sector, providing livelihoods for over one-third of the global population, particularly in Asia (FAO, 2017). However, environmental challenges such as groundwater contamination, biodiversity loss, resource depletion, and forest degradation necessitate a shift toward sustainable agricultural practices. Consequently, research on agricultural sustainability, particularly in E7 economies, has gained significant attention, as these nations play a vital role in global food production and trade.
Agriculture is energy-intensive, relying heavily on fossil fuels, electricity, and natural gas for machinery, heating, cooling, and lighting. Additionally, energy is indirectly consumed in fertilizer, machinery, and chemical production, contributing 14–30% of global greenhouse gas (GHG) emissions (Reynolds & Wenzlau, 2012). Sustainable agricultural practices, such as precision farming, organic agriculture, and agroforestry, can help reduce these emissions while enhancing productivity and resource efficiency. Transitioning to renewable energy in agriculture is crucial for sustainable growth, particularly in developing economies. The global economy is projected to grow at an average annual rate of 2.5% between 2016 and 2050, with E7 economies (China, India, Brazil, Russia, Mexico, Indonesia, and Turkey) expected to expand at 3.5% annually, compared to 1.6% for G7 nations (PWC, 2017). Notably, developing countries surpassed developed nations in renewable energy investments for the first time in 2015, highlighting the increasing role of sustainability in economic growth (Bloomberg New Energy Finance, 2016).
In the context of E7 economies, agricultural sustainability is influenced by rapid urbanization, changing consumption patterns, and environmental policies. Nations like Brazil and Indonesia face challenges related to

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deforestation and land-use change, while China and India struggle with soil degradation and water scarcity. Addressing these issues requires integrating sustainable farming techniques with technological advancements, financial development, and policy support. Prioritizing renewable energy can modernize agricultural sectors, supporting economic and environmental sustainability (Kaygusuz et al., 2007). Over the past decade, climate change concerns, sustainability initiatives, and regulatory policies have prompted a shift toward ecologically responsible growth strategies (Khan & Hassan, 2019; Falcone, 2023; Jie et al., 2023; Roussel et al., 2024; Farhadi & Zhao, 2024). The urgency to reduce GHG emissions has led to a research focus on information and communication technology (ICT) and digitalization as key tools for energy efficiency and cleaner energy generation (Dabbous & Barakat, 2023; Charfeddine & Umlai, 2023; Al Masri & Wimanda, 2024).

Beyond climate mitigation, digitalization and ICT facilitate trade openness, financial development, electricity consumption, and governance improvements, ultimately fostering human development, particularly in developing nations. For E7 countries, digital agriculture, leveraging AI, IoT, and blockchain, can improve resource efficiency, optimize supply chains, and enhance climate resilience. Precision agriculture, coupled with financial and policy support, enables smallholder farmers to adopt eco-friendly practices and integrate into global markets. Since clean energy production is vital to sustainability (William & Adam, 2018; Jaiswal et al., 2022), technological advancements in renewable energy and ICT also contribute significantly to human capital development (Diaz & Weber, 2020; Lancia et al., 2022).

This study has three primary research implications. First, it addresses a gap in empirical literature by examining macroeconomic factors' impact on climate change mitigation, focusing on how interaction terms influence carbon emissions. Specifically, it analyzes the effects of the consumer price index (CPI), digitalization (Digi), financial development (FD), and human development (HD) on climate change. Additionally, it investigates how digitalization moderates the relationship between CPI and carbon emissions intensity.

By integrating sustainable agricultural practices with digitalization, renewable energy, and financial innovation, policymakers can foster environmentally responsible agricultural growth while enhancing economic resilience in E7 economies. Understanding the interplay between these factors is crucial for achieving long-term sustainability goals in the face of climate change challenges.

Figure 1 illustrates CO2 emissions (share of agriculture) trends in E7 economies from 1990 to 2022. Russia and China exhibit distinct patterns, with Russia's emissions declining and stabilizing, while China's emissions have steadily increased. Other countries, including India, Brazil, and Turkey, show relatively lower but consistent CO2 emission growth over time.

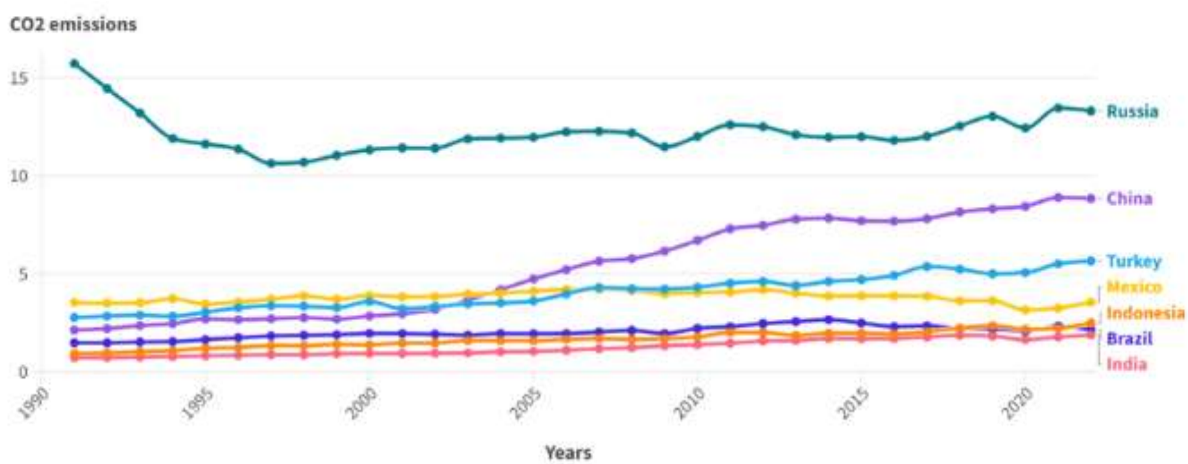

Figure 1: CO2 Emissions (share of agriculture sector) trends in E7 Countries
Source: Authors' own elaboration

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LITERATURE REVIEW

The relationship between macroeconomic factors and environmental concerns has gained significant attention in recent years. Numerous studies have examined the link between various economic variables and carbon emissions, yielding mixed results. Some studies highlight positive impacts, while others indicate negative consequences. This research focuses on digitalization, financial development, human development, and the Consumer Price Index (CPI) within the framework of climate change mitigation. Specifically, it explores digitalization's moderating role in the CPI-carbon emissions nexus.

DIGITALIZATION AND CO_2 EMISSIONS NEXUS

Digitalization integrates digital technologies into industries, affecting carbon emissions in both positive and negative ways. Some research suggests digitalization improves carbon productivity by promoting energy efficiency and industrial transformation (Ahmad & Ali, 2019; Qi et al., 2023). Digital technologies enhance resource utilization effectiveness, leading to better energy consumption and carbon neutrality (Saia, 2023; Ma et al., 2022). However, expanding digital infrastructure also increases energy demand, particularly in data centers and communication technology (Petrakis, 2021; Ke et al., 2022).

While digitalization helps some countries decouple economic growth from emissions (Zulfiqar et al., 2023), others experience reinforced emissions due to energy-intensive digital solutions (Ramos-Meza et al., 2021). In China, an inverted U-shaped relationship suggests that emissions rise with digitalization before declining as technologies mature (Ma et al., 2023). Digital transformation also aids corporate pollution abatement by enhancing productivity and efficiency (Adha et al., 2023).

Regional and industrial variations in the impact of digitalization on carbon emissions necessitate further research. Studies suggest that less developed regions benefit more than industrialized ones (Tang et al., 2024). Differences across industries, such as manufacturing and services, further highlight the need for granular analysis (Lin & Huang, 2023). Additionally, low-carbon technologies, financial digitalization, and digital enablers in global value chains require further investigation to fully understand digitalization's environmental impact (Hieu et al., 2023).

HUMAN DEVELOPMENT INDEX (HDI) AND CO_2 EMISSIONS NEXUS

Human development significantly influences environmental quality. Developed nations are more effective in controlling carbon emissions than developing ones (Ali et al., 2021; Porro & Gia, 2021; Li et al., 2022; Sharma & Das, 2024). Social inclusion is a key driver of carbon emissions levels (Zhang, 2021; Martí et al., 2022; Dima, 2022; Situngkir, 2024).

Research suggests that increasing HDI improves environmental quality. Studies on BRICS countries show that higher HDI and stricter environmental policies enhance ecological sustainability (Hossain & Chen, 2021; Durbin & Filer, 2021). Similarly, studies on G7 countries find a positive correlation between improved human amenities and environmental quality (Zhang et al., 2024).

The relationship between HDI, energy consumption, and economic growth has been examined in emerging economies, revealing a negative correlation between HDI and emissions (Rahman et al., 2021). In OECD countries, natural resource rents and energy efficiency measures have been linked to lower carbon emissions (Lin, 2021; Li et al., 2023). These findings suggest that economic development strategies must integrate sustainable policies to minimize environmental degradation.

FINANCIAL DEVELOPMENT AND CO_2 EMISSIONS NEXUS

Financial development plays a crucial role in controlling carbon emissions by improving resource allocation (Khan & Ozturk, 2021). However, research remains divided on whether financial development mitigates or exacerbates emissions. Some studies suggest that financial development decreases emissions by supporting sustainable investments, while others argue it increases emissions through industrial expansion. Research on highly polluted countries confirms that financial systems play a critical role in environmental sustainability (Abid et al., 2022). Studies on China highlight that financial development enhances regional environmental quality but may have negative spillover effects on surrounding areas (Rafique et al., 2020; Allen, 2021).

Research on African economies (1990–2020) suggests that financial efficiency can help achieve environmental sustainability (Habiba & Xinbang, 2022). Similarly, studies on BRICS and G7 countries show that financial development, technology, and foreign direct investment (FDI) are negatively correlated with emissions (Anwar et al., 2022).

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CONSUMER PRICE INDEX (CPI) AND CO_2 EMISSIONS NEXUS

The link between CPI and carbon emissions remains underexplored. However, economic stability and consumer behavior significantly influence environmental quality. For instance, research on global wealth and consumption patterns shows that increased wealth imposes environmental burdens (Chishti et al., 2023; William, 2023).

The relationship between CO_2 emissions and inflation dynamics highlights the need for economic policies that balance environmental sustainability and price stability. Vision 2030's strategic alignment emphasizes reducing CO_2 emissions while managing labor force participation, foreign direct investment, and trade openness to sustain economic growth and control inflationary pressures (Zheka & Vishnevsky, 2022; Bilal et al., 2024).

Studies suggest that CPI fluctuations impact environmental quality. Research on 40 Asian countries (1990–2018) finds that inflation instability positively affects environmental quality by lowering investment and consumption (Zhou et al., 2022). Additionally, in Pakistan, asymmetric ARDL analysis indicates that negative inflation shocks increase CO_2 and N_2O emissions, while positive shocks have no significant long-term impact (Walsh, 2022; Tariq et al., 2023).

Digitalization also influences the CPI-emissions relationship. Digital platforms promote sustainable consumption, reducing demand for carbon-intensive products and stabilizing CPI. However, increased energy use from digital infrastructure may offset these benefits (Chen et al., 2023). Studies indicate that digitalization impacts CPI and emissions differently across economies: developing nations experience higher initial emissions due to energy-intensive infrastructure, while developed nations benefit from efficiency improvements (Wang et al., 2023)

ECONOMETRIC MODEL, DATA AND METHODS

DATA

This study analyzes the correlation between macroeconomic indicators and climate change, focusing on Digitalization (Digi), Financial Development (FD), Human Development (HD), and Consumer Price Index (CPI). It examines digitalization's moderating with CPI on CO_2 emissions link across E7 countries from 1991 to 2022. Data were sourced from World Development Indicators, Global Atmospheric Research, International Monetary Fund, and United Nations. A digitalization index was created using PCA, and all variables were log-transformed to address heteroscedasticity and data abnormalities.

MODEL SPECIFICATIONS

Based on the literature review, the econometric model for this study was selected and then modified from that used for the top ten countries in terms of renewable energy consumption (Chishti & Dogan, 2024). However, this study will include a host of economic indicators, and test the moderating role of digitalization. To accomplish the primary goal of this research the following functional model structure has been designed:

$CO_2 = f(CPI, Digi, FD, HD, Digi*CPI)$

$$CO_{2it} = \propto_{1it} + \propto_{cit} CPI_{it} + \propto_{dit} Digi_{it} + \propto_{fit} FD_{it} + \propto_{hit} HD_{it} + \propto_{dcit} Digi * CPI_{it} + \epsilon_{it} \ldots \quad (1)$$

Table 1: Variables of the study and their descriptions

Variable	Symbol	Measurement	Source
CO_2 emissions (share of agriculture)	CO_2	Mt Per Capita	GAR
Consumer Price Index	CPI	Annual %	WDI
Digitalization	Digi	• Fixed telephone subscriptions (per 100 people) • Mobile cellular subscriptions (per 100 people) • Individuals using the Internet (% of population)	Authors' calculations; WDI
Financial Development	FD	Financial Development Index	IMF
Human Development	HD	Human Development Index	UN

In the model, CO2 is the regressand variable. At the same time, the consumer price index (CPI), digitalization (Digi), financial development (FD), and human development (HD) are the regressor variables, with an interaction term introduced to identify the moderating role of digitalization with the consumer price index (Digi*CPI). The error term ϵ_{it} is an idiosyncratic error term, independent and identically distributed. It follows the usual assumption of a standard normal distribution with mean zero and constant variance. Here i represents the considered countries, t stands for a period, $\propto_{1it}$ it is the intercept, while $\propto_{cit}$, $\propto_{dit}$, $\propto_{fit}$, $\propto_{hit}$, $\propto_{dcit}$ are the long-run elasticity estimates of CO_2 for the explanatory variables, such as CPI, Digi, FD, HD, and the interaction term, respectively.

METHODOLOGY

The study investigates the short- and long-run relationships between selected economic variables and their moderating role across E7 countries (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) from 1991 to 2022. Given globalization and technological integration, these economies exhibit interdependencies, referred to as cross-sectional dependence (CSD). To confirm CSD, four tests are employed: the CD test (Pesaran et al., 2004), BP LM test (Hahn & Shi, 2021), scaled LM test (Pesaran et al., 2004), and bias-corrected scaled LM test (Baltagi et al., 2012).

The study also applies the slope heterogeneity test to assess variations in the data. Stationarity is examined using second-generation cross-sectional Augmented Dickey-Fuller unit root tests, as well as CADF and CIPS tests (Pesaran, 2007). Once CSD and stationarity are confirmed, cointegration analysis is conducted using Pedroni's (2004) residual-based approach and Westerlund's (2007) panel cointegration test. These methods allow for both within- and between-dimension assessments, considering heterogeneity among panel members.

To estimate short- and long-run coefficients, the study employs the Pooled Mean Group (PMG) approach within the ARDL bounds testing framework, which accommodates CSD, heterogeneity, and mixed integration orders (I(0) and I(1)). This method is superior to conventional techniques such as ARDL, FMOLS, and DOLS (Chishti & Dogan, 2024). Lastly, causal interactions between variables are analyzed using the Panel Causality test (Dumitrescu & Hurlin, 2012), which provides insights into the nature and direction of relationships in a balanced and heterogeneous panel dataset.

RESULTS

The current research analyzed the effect of CPI, Digi, FD, and HD on CO_2 emissions in the sampled E7 economies. Moreover, it explored the moderating role of digitalization and the consumer price index on CO_2 emissions for the period 1991–2022.

CROSS-SECTIONAL DEPENDENCE AND SLOPE HETEROGENEITY RESULTS

Regarding the cross-sectional dependence test applied in the context of the present study, the Breusch and Pagan Lagrange Multiplier (LM) test was used since it was formulated by (Hahn & Shi, 2021). These results are summarized in Table 3 where rejection of the null hypothesis of no CD is numerically highly significant at 1% for both the individual and collective cases and all methods of CD. This means that the panel series under examination is characterized by a rather severe CD problem. The next step following confirmation that CD exists amongst the study variables is the use of the test for homogeneity of the slope coefficients (Pesaran & Yamagata, 2008). Table 4 shows the significant slope heterogeneity test results (p = 0.000) indicate that relationships between variables vary across E7 countries. This suggests the need for models that account for country-specific differences rather than assuming uniform effects.

Table 3: Cross-sectional dependence test

Variables	B-P LM	PS LM	BCS LM	PCD
CO_2	287.566*	41.132*	41.019*	12.033*
CPI	121.232*	15.466*	15.353*	9.535*
Digi	493.210*	72.863*	72.750*	22.162*
FD	372.0316*	54.165*	54.052*	18.7947*
HD	645.715*	96.395*	96.282*	25.407*

*Note: B-P LM: Breusch–Pagan LM test; PS LM: Pesaran Scaled LM; BCS LM: Bias-Corrected Scale; PCD: Pesaran CD test; * represents 1% significance level*

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Table 4: Slope heterogeneity test

	Δ		ΔAdjusted
Model	10.944*	(0.000)	12.382* (0.000)

*Note: * represents significance level at 1%*

UNIT ROOT RESULTS

The results of the second-generation panel unit root tests are shown in the next Table 5. The order test results reveal that some variables possess features of I(0) as well as I (1) which implies that some of them are stationary at a level and first difference respectively. The evidence presented also shows that none of the series are stationary at Further I(2). From these findings, the study validates that for the series under investigation, the PMG-ARDL approach can be used to establish the short and long-run coefficient estimates.

Table 5: Panel unit root test results

Variables	CIPS		CADF		Order of Integration
	Level	Δ	Level	Δ	
CO_2	-2.20	-3.88*	-3.39	-3.21***	I(1)
CPI	-3.07*	---	-3.88**	---	I(0)
Digi	-2.57*	---	-3.11***	---	I(0)
FD	-3.17	-3.23*	-0.05	-4.24***	I(1)
HD	-2.44	-3.92*	-2.36	-5.38*	I(1)

*Note: *, **, and *** represents 1 %, 5 %, and 10 % levels of significance*

COINTEGRATION RESULTS

The next objective was to identify the long-run relationships among the considered variables. To achieve this, we utilized several cointegration tests, including those by (Westerlund, 2007; Pedroni, 2004). The results of these tests, presented in Table 6, confirm the presence of long-run relationships among the variables, indicating that they move together over the long term. Specifically, at the 5% significance level, four out of seven statistics show significant results. Additionally, the Westerlund tests were conducted to further validate the findings, which also support the existence of cointegration among the variables. Overall, both tests confirm a long-run cointegration relationship among the variables.

Table 6: Padroni and Westerlund Cointegration tests

Pedroni				
	Statistic	p-Value	Within Weight	p-Value
Within dimension				
Panel v-Statistic	-2.572	0.995	-2.452	0.992
Panel rho-Statistic	0.021	0.508	-1.420	0.594
Panel PP-Statistic	-2.066	0.019**	-1.748	0.040**
Panel ADF-Statistic	-2.201	0.013**	-1.980	0.023**
Between dimensions				
Group rho-Statistic	1.579	0.942		
Group PP-Statistic	-1.420	0.077***		
Group ADF-Statistic	-1.882	0.029**		
Westerlund				
	1.407	0.079***		

*Note: **, and *** represents 5 %, and 10 % levels of significance*

LONG-RUN AND SHORT-RUN RESULTS OF PMG-ARDL

The upper panel of Table 7 presents the long-run PMG-ARDL coefficients, while the lower panel displays the short-run coefficients for the dependent variable, CO_2 emissions (share of agriculture), in relation to the

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independent variables, including the consumer price index (CPI), digitalization (Digi), financial development (FD), human development (HD), and the interaction term (Digi*CPI) for the E7 economies. The selected PMG-ARDL (2,1,1,1,1,1) model is based on optimal lag lengths, ensuring the best fit for the data.
In the long run, several key variables exhibit significant relationships with CO_2 emissions (share of agriculture). The Consumer Price Index (CPI) has a positive and statistically significant impact, with a coefficient of 0.2271. This suggests that a 1% increase in CPI is associated with a 0.2271% rise in CO_2 emissions, indicating that inflationary pressures may contribute to higher agricultural emissions. Similarly, digitalization (Digi) shows a substantial positive effect, with a coefficient of 0.9045, implying that a 1% increase in digitalization is linked to a 0.9045% increase in agricultural CO_2 emissions. This highlights the environmental trade-offs associated with technological advancements in the agricultural sector. Financial development (FD) also positively influences CO_2 emission, with a coefficient of 0.2901, suggesting that financial sector growth may drive carbon-intensive agricultural activities.

Table 7: Long-run and Short-run estimates of PMG-ARDL

Dependent Variable: CO_2 (2,1,1,1,1,1)				
Variable	Coefficient	Std. error	t-stat	p-value
Long-run coefficients				
CPI	0.2271	0.0525	4.3204*	0.0000
Digi	0.9045	0.2202	4.1066*	0.0001
FD	0.2901	0.1456	1.9927**	0.0480
HD	0.4922	0.4372	1.1258	0.2619
DI*CP	-0.1940	0.0542	-3.5743*	0.0005
Short-run coefficients				
CPI	-0.0663	0.0426	-1.5558	0.1217
Digi	-0.2468	0.1349	-1.8291***	0.0692
FD	0.0600	0.0633	0.9475	0.3448
HD	1.6006	0.8818	1.8151***	0.0713
DI*CP	0.0544	0.0361	1.5057	0.1341
ECM(-1)	-0.1344	0.0638	-2.1052**	0.0368
C	0.1121	0.0677	1.6568	0.0997

*Note: *, **, and *** represents 1 %, 5 %, and 10 % levels of significance*

In contrast, the interaction term (Digi*CPI) has a negative coefficient of -0.1940, indicating that the combined effect of digitalization and CPI may help mitigate CO_2 emissions. This interaction effect is statistically significant, highlighting the complex dynamics between economic factors and agricultural emissions.
In the short run, the impact of these variables on CO_2 emissions is less pronounced. The CPI, digitalization, and financial development have coefficients of -0.0663, -0.2468, and 0.0600, respectively, none of which are statistically significant, indicating that these factors do not have an immediate effect on agricultural CO_2 emissions. However, human development (HD) shows a positive and significant impact in the short run, with a coefficient of 1.6006. The interaction term (Digi*CPI) also exhibits a slight positive effect, but it is not statistically significant.
Importantly, the error correction term ECM (-1) is negative and statistically significant, with a coefficient of -0.1344. This confirms a stable long-term relationship between the variables, with a 13.44% speed of adjustment back to equilibrium each year following a disturbance.

CAUSALITY RESULTS

The results show several significant unidirectional causalities (see Table 8) running from CO_2 to CPI, Digi to CO_2, CO_2 to FD, HD to CO_2, CO_2 to Di*CP, HD to CPI, Digi to CPI, Di*CP to CPI, HD to FD, Digi to FD, Di*CP to FD, and Digi to Di*CP. Additionally, the study noted bidirectional causality between HD and CO_2, in E7 economies from 1991 to 2022.

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DISCUSSION AND CONCLUSION

The findings of this study contribute significantly to the understanding of how macroeconomic variables, including consumer price index (CPI), digitalization (Digi), financial development (FD), and human development (HD), affect carbon dioxide (CO_2) emissions (share of agriculture) in the E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey). This section contextualizes the results within the broader literature and discusses potential policy implications.

Table 8: Dumitrescu and Hurlin panel causality results

Null Hypothesis	W-stat	Zbar-stat	p-value	Causality
CPI → CO_2	3.5270	1.5093	0.1312	
CO_2 → CPI	3.3699	3.5649	0.0004*	Uni-directional
Digi → CO_2	5.2244	3.4026	0.0007*	
CO_2 → Digi	3.0126	0.9356	0.3495	Uni-directional
FD → CO_2	2.7386	0.6298	0.5288	
CO_2 → FD	7.7501	6.2199	5.e-10*	Uni-directional
HD → CO_2	6.8534	5.2197	2.e-07*	
CO_2 → HD	4.3678	2.4472	0.0144***	Bi-directional
Di*CP → CO_2	3.5530	1.5383	0.1240	
CO_2 → Di*CP	6.9108	5.2837	1.e-07*	Uni-directional

*Note: *, **, and *** represents 1 %, 5 %, and 10 % levels of significance.*

POSITIVE LONG-RUN EFFECTS OF CPI, DIGITALIZATION, AND FINANCIAL DEVELOPMENT ON CO_2 EMISSIONS

One of the key findings from the long-run results is the positive and statistically significant relationship between CO_2 emissions, digitalization, and the development of the financial sector. Specifically, the econometric results suggest that a 1% rise in financial development is associated with a 0.2271% increase in CO_2 emissions. This finding aligns with prior research highlighting how financial expansion can drive agricultural intensification, mechanization, and resource consumption, leading to higher carbon emissions from the sector (Adeleye et al., 2022; Ronaghi & Scorsone, 2023). As financial access improves, agricultural enterprises may increase production through mechanized farming, fertilizer application, and irrigation, which contribute to emissions.

However, this necessitates the adoption of sustainable financial models that encourage green investments in agriculture, such as low-carbon farming technologies, precision agriculture, and organic farming incentives. Integrating sustainability linked financing mechanisms can help mitigate the adverse environmental impact of financial growth while ensuring productivity improvements.

Furthermore, digitalization has a measurable long-term positive impact on CO_2 emissions with a coefficient value of 0.9045, suggesting that while technological progress enhances agricultural productivity, it also carries environmental costs. The increasing adoption of precision farming, automated irrigation, and digital supply chain management expands energy use, potentially leading to greater emissions. This aligns with the view that while digital technologies can optimize resource use and improve efficiency, their overall impact on agricultural emissions depends on the energy sources powering them (Saqib et al., 2023).

To counteract the negative environmental effects, agricultural digitalization strategies must integrate renewable energy solutions, such as solar-powered irrigation and energy-efficient farm machinery. Governments and stakeholders should promote smart farming techniques that enhance resource efficiency while minimizing carbon footprints, ensuring that digital transformation leads to both economic and environmental gains.

THE MODERATING ROLE OF DIGITALIZATION AND CPI ON CO_2 EMISSIONS

The detailed discovery highlighted how digitalization reduced the effects of inflation on CO_2 emissions. When combined, adopting new technologies and rising prices lowered agricultural CO_2 emissions by -0.1940. This important finding helps policymakers understand digitalization's role in offsetting some environmental impacts of cost changes. By integrating advanced techniques into agricultural practices, economies can improve efficiency, reduce energy use, and cut emissions. Existing research has shown technology's dual role, where advancements drive both economic growth and environmental benefits, aligning with this study’s findings (Balogun & Oloja-Ojabo, 2023; Ngo & Nguyen, 2022).

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This highlights the need for policies that promote low-carbon innovations in digital agriculture, such as AI-driven climate-smart farming, soil health monitoring, and carbon sequestration practices. Encouraging farmers to adopt climate-resilient crops and sustainable land management techniques through digital platforms can significantly enhance long-term agricultural sustainability while keeping emissions in check.

HUMAN DEVELOPMENT AND ITS IMPACT ON CO_2 EMISSIONS

The positive and significant effect of human development on CO_2 emissions, particularly in the short run (coefficient: 1.6006), suggests that as human development progresses, agricultural activities become more energy-intensive, leading to higher emissions. In developing economies, improvements in human development and modernization of the agricultural sector increase reliance on mechanization and chemical inputs, which are often driven by carbon-intensive energy sources.

To mitigate these effects, investment in sustainable agricultural education and capacity-building programs is essential. Training farmers in eco-friendly practices, such as organic farming, regenerative agriculture, and agroforestry, can help transition agricultural activities toward low-emission models. Additionally, integrating clean energy solutions, such as bioenergy and wind-powered irrigation, into agricultural expansion efforts can support sustainability without compromising productivity.

The rise in emissions during the development phase highlights the necessity of promoting sustainable agricultural practices and integrating clean energy solutions into agricultural expansion efforts (Zhang et al., 2024; Wang et al., 2023). A balanced approach that combines economic growth with ecological preservation will be key in ensuring long-term agricultural sustainability in the E7 economies.

THEORETICAL IMPLICATIONS

The findings of this study offer important theoretical implications for understanding the complex relationships between macroeconomic variables and CO_2 emissions. One key contribution is the integration of digitalization as a moderating factor that can influence the traditional link between inflation (CPI) and environmental degradation. This expands current theories by suggesting that digital technologies, when effectively utilized, have the potential to mitigate the environmental impacts typically associated with economic growth, such as increased energy consumption and emissions. The interaction between digitalization and CPI highlights a more nuanced view of technological advancement, which can both drive emissions and simultaneously offer solutions for reducing them. Additionally, the study challenges simplistic interpretations of financial development by showing that while it fosters economic growth, it also leads to increased carbon emissions in the long run, especially in emerging economies. The bidirectional relationships observed between financial development, human development, and environmental outcomes point to the need for financial systems that support sustainable investments. Overall, this study extends existing environmental economic theories by emphasizing the multifaceted role of digitalization and financial development in shaping the environmental trajectory of rapidly growing economies.

POLICY IMPLICATIONS

This research has several policy implications as highlighted below: First, the significant and positive correlation between inflation (CPI), digitalization, and financial development with CO_2 emissions suggests that strategic policies should be implemented to decouple economic growth from environmental degradation. Government officials in E7 economies should focus on promoting efficiency-enhancing technologies that reduce emissions without hindering production. Specifically, leveraging the moderating effect of digitalization on the relationship between inflation and CO_2 emissions presents a valuable opportunity to mitigate the environmental impact of inflationary pressures. Second, human development as a concept has a positive effect on emissions in the short-run as it promotes the integration of sustainability into human development. Budgets for education, health, and infrastructure need to be matched with programs that seek to minimize the use of fossil energy and encourage the use of renewable energy which is key to sustainable development.

Lastly, the study focuses the importance of collaborative efforts across the globe to deal with climate change as the E7 countries under review industrialize and digitize to have higher emissions of GHG. In this regard, the policymakers should aim to foster complementary activities that permit both economic growth and environmental conservation.

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