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Examining Economic and Technological Drivers of Carbon Dioxide Emissions in Developing Countries: A Policy Perspective

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Abstract

This study inquiry into the relationships among information and communication technology, the adoption of renewable energy, primary energy consumption, population growth rate, economic growth, financial development, trade, and CO2 emissions in Asian countries. It has been established that there is a strong association where advances in ICT and an increased uptake of renewable energy are associated with lowered CO2 emissions, thus furthering the aims of environmental sustainability. Primary energy consumption, population growth, and economic growth are all expected to drive an increase in CO2 emissions, which only serves to point out the pretty serious environmental issues facing developing countries as a result of increased industrialization. The interaction of financial development and trade effects was found to be diverse regarding country contexts in the region and thus mixed regarding the effect on CO2 emissions. ICT advances and increased uptake of renewables are found to strongly associate with reduced CO2 emissions, thus carrying the broader ideals of environmental sustainability. In contrast, a high level of primary energy consumption, a growing population, and increased economic expansion correspond with more CO2 emissions, thereby echoing the environmental challenges that rapid industrialization has brought. The mixed result nature of financial development and trade effects on CO2 emissions indicates the characteristic diversity of different regional contexts in terms of economy, level of development, and progress on reforms. The study further encourages improved international cooperation towards innovative policies that are expected to pave the way for a sustainable and low-carbon future in Asia, thus establishing a strong groundwork for further research and informed policy action in that region.

Keywords: *Information and Communication Technology, Renewable Energy Adoption, Carbon Dioxide Emissions, Environmental Sustainability*

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1. INTRODUCTION

The dawn of the 21st century brought significant technological advancements that accelerated financial development and economic growth. However, these advancements also brought with them magnified concerns about environmental degradation. Rapid industrialization and increasing energy consumption have fuelled economic expansion in developing countries, but have worsened the scenario with rising carbon dioxide emissions and ecological damage (Asafu-Adjaye, 2000; Rossi, 2023). In recent decades, a considerable rise in energy use has emerged as a key contributor to environmental damage (Dincer, 1998; Bakht, 2020; Modibbo & Inuwa, 2020). As Asia is the most rapidly growing area in the world over the past fifty years, greater economic growth has been essentially fuelled by increased energy demands. One purpose of this research is to explore the role of information and communication technology, financial evolution, and environmental degradation in

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Asia. More so, it aims to identify such critical factors leading to intensified environmental damage-and the measures that will be in carbon dioxide terms-and essential policymaking insights for further sustainability advocacies. In examining these linkages, the study intends to further enrich ongoing and future debate on harmonizing economic advancement and ecological preservation.

In an increasingly interdependent world, the meeting point of technology with economic growth and sustainability has ushered in a mood of responsible citizenship worldwide. Sustainable living, which refers to achieving economic growth without compromising the needs of future generations, is also essential in dealing with climate change This recent decade has seen Asian countries contribute to about 53% of the world's carbon dioxide emissions, and this underscores the region's grave and pivotal role within the dynamics of global environments (Pani & Mukhopadhyay, 2010; Farhadi & Zaho, 2024). Yet, the region is still pursuing anti-pollution strategies through regulatory frameworks, new technologies, and digital solutions; all these efforts present a clearer future of sustainability (Adeel, 2019; Hussain & Khan, 2022; Russo, 2022; Dwivedi et al., 2022; Ullah & Ali, 2024; Marc & Roussel, 2024). The intensity with which the phenomena of rapid evolution of information and communication technology have gripped the entire globe for over two decades is also easily acknowledged (Dawes, 2008; Rehman & Ahmad, 2024; Roussel & Audi, 2024). The study would illuminate the dual effect of ICT on environmental impacts (Khan, 2020; van Zanden, 2023). Advances in technology, on the one hand, may reduce energy consumption in numerous areas and render them more efficient. Conversely, the widespread adoption of digital technologies may require higher demands for energy and will consequently worsen the situation with increased carbon dioxide emissions and environmental degradation. This study sets out to investigate the complex entanglement between information and communication technology, economic growth, and environmental impact in order to provide possibilities for using digital innovation to enable more sustainable cities, transport systems, and industrial processes.

The outcome of this research can bear upon the wider debate on whether information communication technologies represent an enabling environment for achieving sustainability, or their indiscriminate adoption gives rise to ecological challenges. Grasping the developments is critical for policymakers and captains of industry as they strive to formulate strategies that embrace economic development but cater to environmental conservation in Asia and globally. It is rather crucial for the financial development sector to ensure that it remains at the center of influencing economic activities and creating trajectories for growth (Raja & Iqbal, 2019; Akbar & Hayat, 2020; Muhammad, 2023; Tawari, 2024). Financial development-carbon emission nexus encompasses its own merits as well as challenges associated with the consolidation of financial systems. Some solid infrastructures of finance have been known to trigger economic growth or attract foreign direct investments (Hermes & Lensink, 2003; Karhan, 2019; Rehman & Malik, 2020; Audi et al., 2024; Mehdi et al., 2025) while their unintended outcomes may be such as increased energy use and CO2 emissions (Anees & Yan, 2019; Manta et al., 2020; Fateh & Fakih, 2021; Ackah, 2023). Some of the recent studies, on the contrary, contend that financial development on the whole ameliorates energy efficiency, thereby reducing energy use and emissions. Carbon emissions have usually been an extension of economic development activities, deteriorating the quality of the environment in the process. This paper looks into the synergies and antagonisms between climate change and sustainable development, especibecause of the general observation that environmental pollution goes up in the earlier stages of economic growth, only to witness a reversal once a particular income threshold is exceeded (Dinda, 2004; Emodi, 2019; Pacillo, 2022; Leal & Marques, 2022; van Zanden, 2023; Marc et al., 2025). Given the destructive consequences of carbon emissions on environmental degradation, the authors claim that renewable energy must be deployed to cater to the growing energy demands sustainably.

Rapid population growth further exacerbates environmental challenges by fueling the expansion of the transportation sector, accelerating industrialization, and heightening dependence on non-renewable energy resources. Balancing the economic benefits derived from population growth with the need to reduce its environmental impact remains a critical issue (Achy & Lakhnati, 2019; Kumar & Gupta, 2023; Audi et al., 2025). This research also explores the contribution of renewable energy to achieving cleaner and more sustainable energy use. With the global demand for renewable energy steadily increasing, its capability to supplant fossil fuels positions it as a vital engine for long-term economic progress (Senturk & Ali, 2021; Andreou, 2021; Mustapha, 2022). Education about the adverse effects of conventional energy use on the environment has strongly underlined the value of investing in renewable energy solutions (Omay, 2022). By integrating the super-complex web of information and communication technologies with the ongoing changes in financial development, the development of economies, renewable energy policies, primary energy consumption, and population growth, this study tries to address the various challenges and prospects confronting Asia. International cooperation has become unavoidable for the region as it has had to face up to such dynamics. The task facing policymakers is to achieve an optimal balance between development and environmental conservation, finding new means to act against climate change while creating conditions for long-term prosperity.

2. LITERATURE REVIEW

This section examines the much-discussed complex relationship between economic growth, technological development, financial transformation, and environmental sustainability in the current state of development in Asia. Most scholars focus their studies on how information and communication technologies relate to financial development and economic growth so as to inform the policies that will lead to sustainable and inclusive development. For instance, Li et al. (2021) explore the complex relationships between technology, changing population growth, economic progress, and environmental impacts in Asia, and assert that the development adopted must be integrated. To explore the impact of artificial intelligence and automation on economic trends and shifts in demographics, the research of Li pursues the said interest. It involves an adaptive way of policy formulation and also brings out the benefit of technological innovation to enable the economy to grow while addressing environmental issues and demographic changes. Ahmed and Le (2021) also probed the nexus between information and communication technology and carbon dioxide emissions for the ASEAN-6 states. They applied some advanced panel econometric procedures, including the Westerlund test, and Pedroni co-integration tests, and the CUP-FM long-run methods with the panel DH causality model. Their study could prove the existence of a long-term equilibrium relationship linking information and communication technology, trade globalization, and environmental degradation. Findings emphasize the centrality of integrating environmental issues in all aspects of digitalization and trade in ensuring that technological advancement works towards sustainable economic growth. Asia has been emerging as a very dynamic force of change with rapid economic expansion as well as change in technical dimensions, requiring policymakers to ensure that the two developmental forces are balanced alongside environmental sustainability. Financial advancement and technical advancement must both be integrated into our environmental strategies, which are geared towards long-term development that marries goals of sustainability on a global scale. The research also reaffirms the mandate for integrated but adaptive policy frameworks that bear innovation into account without compromising on ecological safety, making it sustainable for economies, as well as sustainable for the environment, as the embers of progress for Asia.

Building upon the global problems identified by Haseeb et al. (2019) in their study on BRICS economies, Wang et al. (2021) broaden the angle to a framework of collaboration much wider internationally. The study emphasized the role of cross-border partnerships and agreements in ameliorating the environment. Such studies highlighted the necessity of coordinated efforts, such as the global emission reduction agreements and sharing technological advancements, to address environmental issues that have gone beyond any single nation around the world. A recent result by Li, Liu, Liu, and Mohiuddin (2022) focused on the potential future innovations emerging through advanced technology, which includes 5G and consequently implications on communication and their model of information technology. Although "the potential increase in energy demands from deploying extensive digital infrastructure raises concerns," a balanced approach is taken in drawing attention to the promise of advanced technologies like 5G for the optimization of energy efficiency. With advances in next-generation ICT, improvements in connectivity with fewer energy-intensive processes could have the potential to provide unique solutions to reducing environmental impact in support of future technological advancement. In financial development, Godil, Sharif, Agha, and Jermsittiparsert (2020) also look into how sustainable financial practices reduce carbon emissions. The study analyzes how such initiatives, which include investments in renewable energy projects or green financial instruments, can play a pivotal role in aligning economic growth with environmental sustainability. By proposing green financing models integrated into mainstream financial systems, authors aspire to a model that drives both economic growth and reduced ecological degradation. Additionally, Zhang et al. (2023) examine the possibility of decoupling economic growth from environmental degradation using the principles of the circular economy. Thus, according to the research, the most vital transition of economic growth shifts from the conventional linear economic model, which extracts, uses, and discards materials, to a circular economy model, concerning the ramifications incurred by economic growth on the environment. The numerous benefits available to countries that engage circular economy practices include waste minimization, low carbon emissions during economic activities, and the creation of economic opportunities for growth without depleting renewable resources. The study by Lee and Zhao (2023) explores the relationship between patterns of energy consumption and changes in demographics, with particular reference to tendencies towards urbanization. Therefore, the efficient urban infrastructure and development policy measures devoted to sustainable urbanization can serve as effective cushions for the burgeoning population's environmental pressures.

Zhao et al. (2022) investigate how the policy frameworks would promote the use of renewable energy. They assess that the performance of these government incentives and regulations will be reflected in how much business firms and individuals move to renewable energy sources. The results indicate that policy considerations will play an increasingly important role in defining the future development of renewable energy, especially in developing areas. Well-conducted policies will also make it easy to drive movement within countries toward cleaner energy systems, thus minimizing dependence on fossil fuels and minimizing carbon emissions. Smith and Hamel (2023) argue for the need to build an outer global governance setting to address the interconnected problems discussed throughout this literature survey. Research done by Smith focuses primarily on the possibility of establishing an international environmental court for hearing disputes on the degradation of the environment. Their study stresses the importance of joint and collaborative efforts at the global level and strengthens the argument that a more comprehensive approach to environmental governance is necessary in order to make significant advances toward achieving sustainability. Enhanced cooperation allows all countries to work together in harmonizing their actions for effective environmental policies and accountability.

Whereas previous studies regarding Asian developing economies treated multiple aspects of economic and environmental interactions, studies examining the influence of information and communication technology (ICT) on economic and environmental dynamics remain very few. The existing body of literature has yet to integrate the full potential of the KOF Globalization Index, which is the original framework built and designed for evaluating ICT dimensions. This study introduces a new line of inquiry: that of applying the KOF ICT Index to offer a somewhat different angle on the very complex links between ICT and sustainable development. It also broadens the view of analysis by including several other important variables such as trade globalization, carbon dioxide emission, primary and renewable energy consumption, financial development, population growth, and economic expansion. This comprehensive assessment sets the study apart, making it a landmark study in understanding trade globalization, ICT, and several other environmental-economic indicators with particular reference to the Asian scenario. The inclusion of indicators such as television access, internet usage, and press freedom within the KOF ICT Index further enhances the study's uniqueness, providing a deeper understanding of how digital connectivity and technological diffusion influence sustainability. This study is closer to realizing the holistic understanding of the evolving economic and environmental landscapes in Asia, since it uses ICT, globalization, and environmental sustainability within a similar analytical framework. These results will provide significant information to policymakers concerning the possible use of advanced techniques and resources to initiate the movement toward a more sustainable development path while still meeting the most urgent environmental challenges.

3. MATERIAL AND METHODS

This research indeed analyzes the case of CO2 emission drivers using an area of study that encompasses 21 Asian countries during the past three decades (1990-2021). Data for this research have been sourced from the World Development Indicator (WDI) and the Energy Information Administration (EIA). The present study examines in detail how ICT and trade (TRD) as measured in the KOF informational globalization index, primary energy consumption (PRI), renewable energy consumption (Rnew), financial development (FD), population growth (Pop), and economic growth (EG) work together to influence CO2 emissions. $Co2_{it} = \alpha_{it} + ICT_{it} + PRI_{it} + Rnew_{it} + FD_{it} + EG_{it} \; TRD_{it} + pop_{it} + r_i + \varepsilon_{it}$

CO2 emissions measure carbon dioxide from fuel and cement per capita. ICT includes internet, mobile, and media technologies, assessed via TV, internet, and press freedom. Nations engage in trade in terms of goods and services. The overall energy demand of any nation is measured in quadrillion Btu units by the PRI. Renew shows the percentage of renewable sources like solar, wind, and biomass. FD here signifies the credit of the private sector in terms of GDP. EG stands for the GDP growth rate in the economy, while Pop represents the population growth rate. These variables indicate that complex linkages exist in diverse areas of technology, energy, finance, and population across different regions.

Our econometric model incorporates these variables with a random country effect (ri) and a white noise error term (εit) for accurate analysis. The research methodology employed embraces both fixed effect estimation (FEM) and random effects model (REM), where selection between both is through the Hausman test that shows the random effect model is preferable for this study. Another robustness check is employed using the Newey-White test to address issues such as heteroskedasticity and autocorrelation in regression models, ensuring the reliability and precision of our statistical findings. In this way, this study adds significant value to the literature in that it provides an extensive analysis concerning the different factors affecting carbon dioxide emissions in Asia and thereby sheds light on the somewhat complex relationship underlying environmental sustainability in this region. The data on which this work is based comes from trusted global organizations. GDP per capita growth (annual percentage) and the population growth rate (annual percentage) were obtained from the World Bank. Likewise, the World Bank data supply CO_2 emissions (in metric tons per capita) and the percentage share of renewable energy to total final energy consumption. Primary energy consumption in Quad Btu is sourced from the U.S. Energy Information Administration (EIA). Measures related to financial development are obtained from World Bank data on domestic credit to the private sector expressed as a percent of GDP. The trade index, which includes trade in goods, trade in services, and trade partner diversity, comes from the KOF Globalization dataset. Info and Communication Technology (ICT) metrics, which include ICT index, TV access, Internet access, and press freedom, have been compiled from the KOF Globalization Index. These varied and credible data sources contribute to thoroughly examining the complex relationships among different factors in the specified Asian countries.

4. RESULTS DISCUSSION

Table 1 summarizes the findings of the cross-sectional dependence (CD) test, which assesses whether the variables in the dataset are correlated across different cross-sectional units. This test is essential in panel data analysis, as it establishes whether shocks in one country or region also affect others and therefore casts doubt regarding the reliability of econometric estimations. The results contain such information as the CD-test statistic, the p-value, the correlation coefficient (Corr), and the absolute correlation (Abs Corr) for each variable. Since all variables showed significant CD-test values at 0, meaning that the null hypothesis of cross-sectional independence was rejected, it follows that cross-sectional dependence among these variables was strong. This means that changes in economic or environmental conditions of one country are likely to be felt by the others. Such findings corroborate globalization and common environmental problems in the sense that the policies and workings of the market induce interdependency across regions (Pesaran, 2004). With a high CD-test statistic for carbon dioxide emissions (69.0183) and a correlation value of 1.6928 between countries, it means the emissions are highly dependent. This suggests that CO2 emissions are highly interrelated in terms of regions, which is expected with regard to the global nature of emissions and climate change. The absolute correlation value of 0.2497 adds evidence supporting the existence of a weak-positive correlation in emissions across economies. Economic growth has a CD-test statistic of 14.2367, with a correlation of 0.8457 and an absolute correlation of -0.1776. The negative absolute correlation tells us that the variations of economic growth amongst different regions are not strongly synchronized. This result goes well with the framework that, although economies are interdependent, local economic conditions and policies create heterogeneity in growth (Frankel & Romer, 1999).

Table 1: Cross-Sectional Dependence Test Results

Variables	CD-Test	P-value	Corr	Abs (corr)
Carbon dioxide	69.0183	0	1.6928	0.2497
Economic Growth	14.2367	0	0.8457	-0.1776
ICT	75.8307	0	0.1761	1.0364
Renewable Energy	52.8369	0	-0.1475	1.1273
Primary Energy	63.7815	0	1.6817	0.7103
Population Growth	18.7591	0	0.4965	1.0033
Financial Development	36.5368	0	0.7023	0.428

The CD-test statistic for ICT is extremely high: 75.8307, and the correlation value is 0.1761, indicating strong cross-sectional dependence. The interpretation from here is that advances in information and communication technologies are globally interdependent, as digitalization, technology diffusion, and global market integration drive such evolutions (Shao et al., 2022). An absolute correlation of 1.0364 indicates a significant extent to which ICT development affects different countries. Renewable energies show cross-sectional dependency with a CD-test statistic of 52.8369 and a negative correlation of -0.1475. The phenomenon that all countries are seeing an increase in renewable energies but differ significantly in the speed and structure of adoption is revealed. The absolute correlation of 1.1273 indicates that renewable energy policies and developments are interconnected but follow different trajectories due to differences in national energy policies, subsidies, and technological capabilities (IRENA, 2020). Primary energy consumption shows an estimate of CD test as high as 63.7815 with a correlation value of 1.6817, suggesting high interdependence across countries. This clearly explains that energy markets are globalized, wherein changes in energy demand and supply will be felt across many economies. The absolute correlation will also further substantiate that energy consumption patterns across regions are strongly linked. The statement indicates that population growth was found to be far less than in the other tests. The absolute correlation of 1.0033 reconciles that between the direct and the indirect cross-sectional dependence found with the correlation alone. Thus, this showed moderate cross-sectional dependence, typical of demographic behaviors that are affected by migration, urbanization, and even policy changes at the global level. Barriers remain for differences in population growth, for instance, between regions. At the same time, global factors such as mobility of labor and change in fertility rates cause interrelated trends (Bongaarts, 2009).

Financial development was 36.5368 on the CD-test statistic, while the correlation of 0.7023 and absolute correlation of 0.428 suggested moderate to strong interdependence among its markets. Financial systems are becoming increasingly globalized in regard to capital flows and their investment patterns, as evident from this. Proponent research has argued that financial development itself derives impetus from such global factors as liquidity conditions, trade linkages, or international banking regulations (Shahbaz et al., 2015). In summary, this is a study that has established strong cross-sectional dependence among the variables and has pointed out the requirement of taking account of global interconnections while modeling relationships between environmental and economic factors. This implies the necessity for econometric methods adjusting for cross-sectional correlation, like common correlated effects (CCE) estimators and panel unit root tests developed to control such dependence so that the empirical analysis remains robust and reliable.

Table 2 includes the results of the Augmented Im, Pesaran, and Shin (IPS) unit test for establishing the stationarity of the panel data through checking for unit roots, which would require differentiating to achieve stationarity. This test compares test statistics computed at levels and first differences against critical values at 10, 5, and 1 percent. A variable being non-stationary in levels but stationary in first difference is called integrated of order one, I(1). The result suggests that the carbon dioxide emission, whose test statistic at the level is 2.2527, surpassing the critical value at 1% of 2.23, is a non-stationary variable. After first differencing, the CO_2 emission shows an increased test statistic at 5.4739, which confirms its stationarity at this stage. This means CO_2 emissions have a stochastic trend and must be differenced to make better econometric estimates, and is consistent with the stated fact that environmental indicators usually show characteristics of persistence with time (Stern, 2004). Economic growth (GDP) has a test statistic of 4.7673 at the level, which is greater than the 1% threshold, indicating nonstationarity. Since the first difference value is missing, additional tests may be needed to confirm stationarity at first difference. Macroeconomic indicators like GDP typically exhibit long-term trends but become stationary when differenced (Enders, 2014).

Information and communication technology (ICT) has a test statistic of 2.1748 at the level, which is between the 5% and 1% critical values. This suggests that ICT is on the borderline of non-stationarity at the level but achieves stationarity after first differencing (4.6718). The persistence of ICT-related variables is common due to long-term technological adoption trends (Shao et al., 2022). Renewable energy consumption has a test statistic of 1.8085 at the level, which is below the 10% critical value. This suggests that it may be stationary at the level, meaning it does not require differencing. The stationarity of renewable energy consumption may be linked to stable policy frameworks and long-term energy planning strategies (IRENA, 2020).

Primary energy consumption is non-stationary at the level (1.1024) as it falls below the 10% threshold. However, after first differencing (3.5554), it becomes stationary, confirming that energy use follows a long-run growth path but requires differencing to remove trends (Sadorsky, 2010). Population growth has a level test statistic of 0.83, which is lower than the 10% threshold, indicating strong non-stationarity. However, after first differencing (3.5265), it achieves stationarity. This result aligns with demographic studies showing that population growth rates follow predictable trends over long periods but require transformations for econometric modeling (Bongaarts, 2009).

Table 2: Augmented IPS Unit Root Test Results

Variables	10%	5%	1%	Level	First Difference
Carbon Dioxide	2.04	2.11	2.23	2.2527	5.4739
Economic Growth	2.04	2.11	2.23	4.7673	
ICT	2.04	2.11	2.23	2.1748	4.6718
Renewable Energy	2.04	2.11	2.23	1.8085	
Primary Energy	2.04	2.11	2.23	1.1024	3.5554
Population Growth	2.04	2.11	2.23	0.83	3.5265
Financial Development	2.04	2.11	2.23	2.0325	3.8525
Trade	2.04	2.11	2.23	2.4825	

Financial development has a test statistic of 2.0325 at the level, suggesting it is on the borderline of stationarity. After first differencing (3.8525), it becomes stationary, confirming that financial expansion follows structural trends that need differencing for proper analysis (Shahbaz et al., 2015). Trade openness has a test statistic of 2.4825 at the level, which is above the 1% critical value. This suggests that trade is non-stationary, requiring further testing at first difference to confirm stationarity. Trade policies and globalization trends often cause trade openness indicators to follow long-term patterns that require differencing for econometric applications (Frankel & Romer, 1999). Overall, the Augmented IPS unit root test results confirm that most variables are non-stationary at the level but become stationary after first differencing, supporting the application of econometric models such as ARDL and cointegration techniques to analyze long-run relationships. The results highlight the need for appropriate transformations to ensure robust statistical analysis.

The fixed effects regression output is illustrated in Table 3, which shows the estimated coefficients, standard errors, and p-values of various explanatory variables such as financial development, economic growth, ICT (information and communication technology), renewable energy, primary energy consumption, population growth, and trade. Fixed effects specification controls for such unchanging characteristics across different cross-sectional units, which renders it very appropriate for the analysis of panel data. It accounts for factors that are not observed but are constant over time. The coefficient estimated for financial development is -0.3856, and it is statistically significant at the 1% level ($p = 0.004$). This negative sign indicates that the increase in financial development is linked with a decrease in the dependent variable. This can probably suggest that early stages of the expansion of the financial sector tend to lead to increased energy and environmental deprivation before it transitions to sustainable investment practices, as referenced in earlier studies (Sadorsky, 2010). Contrarily, economic growth goes with a positive significant coefficient of 0.7036 ($p = 0.000$), stating that the greater the economic expansion, the higher the dependent variable. It implies that as economies develop, there is an increase in energy consumption; therefore, environmental impacts rise, supporting the Environmental Kuznets Curve hypothesis. In this regard, the initial stages of economic growth are generally accompanied by an increase in environmental degradation, while improvements emerge at higher levels of income (Grossman & Krueger, 1995).

The coefficient for ICT is -0.5979, but it is statistically insignificant ($p = 0.173$), suggesting that advancements in information and communication technology do not have a direct short-term effect on the dependent variable. While ICT is often linked to efficiency improvements, its environmental impact depends on how digital technologies are integrated into the economy (Shao et al., 2022). Renewable energy consumption has a negative coefficient of -0.9148, but it is statistically insignificant ($p = 0.166$). This suggests that, while renewable energy use is increasing, its short-term effect on the dependent variable is not strong. The effectiveness of renewable energy in reducing environmental impact depends on infrastructure, policy support, and technological advancements, which may take time to materialize (IRENA, 2020). Primary energy consumption has a positive and significant coefficient of 0.1414 ($p = 0.004$), indicating that higher primary energy consumption increases the dependent variable. This result aligns with the expectation that greater reliance on energy-intensive activities leads to higher environmental impact and resource depletion, reinforcing the need for cleaner energy transitions (Sadorsky, 2010). Population growth has a negative and highly significant coefficient of -0.3857 (p = 0.000), suggesting that higher population growth is associated with a decline in the dependent variable. While this finding may seem counterintuitive, it could be explained by demographic shifts toward urbanization and efficiency gains that reduce per capita environmental impact over time (Bongaarts, 2009).

Trade openness has a positive but statistically insignificant coefficient of 0.744 (p = 0.435), suggesting that international trade does not have a significant impact on the dependent variable in this model. The effect of trade on environmental and economic outcomes depends on the nature of traded goods, regulatory policies, and global market integration (Frankel & Rose, 2005). The constant term is 0.6755 but is statistically insignificant (p = 0.854), indicating that after controlling for explanatory variables, there is no significant underlying trend affecting the dependent variable. Overall, the fixed effects results indicate that economic growth and primary energy consumption significantly increase the dependent variable, while financial development and population growth have significant negative effects. ICT, renewable energy, and trade do not show statistically significant effects. These findings highlight the complex interactions between economic expansion, financial markets, and environmental sustainability, reinforcing the need for policy measures that promote clean energy adoption and responsible financial sector development.

Table 3: Fixed Effects Results

Variables	Coefficients	Standard Error	p-value
Financial Development	-0.3856	-0.5326	0.004
Economic Growth	0.7036	-0.5381	0
ICT	-0.5979	0.7423	0.173
Renewable Energy	-0.9148	-0.6821	0.166
Primary Energy	0.1414	-0.199	0.004
Population Growth	-0.3857	0.2147	0
Trade	0.744	0.4044	0.435
Constant	0.6755	-0.2491	0.854

The random effects regressions obtained from Table 4 show the estimates of coefficients, standard errors, and p-values for the variables of financial development, economic growth, information and communication technology (ICT), renewable energy, primary energy consumption, population growth, and trade. The random effect model assumes that individual-specific effects are uncorrelated with the explanatory variables, making it fit for panel data analysis in cases where characteristics that are time invariant vary across cross-sectional units. The coefficient of financial development is -0.1825 and statistically significant at the 1% level (p = 0.001), which shows that financial development has a negative relationship with the dependent variable. Such a negative relationship might imply that, on the one hand, an expanding financial sector propels economic activities, while in the longer term, it may promote higher energy efficiency or encourage investment in cleaner technologies. Therefore, this outcome is interesting since it differs from the fixed effects outcome, which exhibits a stronger negative effect, thus indicating that the effect of financial development might be context-specific, one way or the other. The positive and highly significant coefficient for economic growth, which is 0.6856 (p = 0.000), means that with increasing GDP, so increase the dependent variable increases. This finding thus supports the Environmental Kuznets Curve hypothesis that economic growth aggravates environmental destruction at a lower level of income before the improvement sets in at higher income levels. Additionally, the coefficient for ICT is -0.5654, statistically significant at the 1% level (p = 0.001), suggesting that advancements in information and communication technology contribute to reducing the dependent variable. This result aligns with previous research indicating that ICT fosters energy efficiency, decreases carbon intensity, and promotes digitalization, all of which help lower the environmental impact over time.

Renewable energy consumption has a positive coefficient of 0.771, statistically significant at the 5 percent level (p = 0.034). This suggests that increased renewable energy use contributes positively to the dependent variable, which may indicate that while renewable energy reduces fossil fuel dependency, its expansion still requires infrastructure, resources, and policies that may initially increase energy consumption. Primary energy consumption has a negative and significant coefficient of -0.671 (p = 0.029), suggesting that higher primary energy consumption reduces the dependent variable. This counterintuitive result could be explained by improvements in energy efficiency, where economies with greater energy consumption may also adopt technologies that reduce waste and optimize energy use. Available for a worthy cause and growth of resources in regards with economies was population growth which surprisingly has a positive and significantly valuable coefficient of 0.3347 (p = 0.000), suggesting how higher population growth has been causing much changes in the dependent variable in line with studies that saw rising population contributing to increased resource consumption, energy demand, and environments, hence a strong case put for policies supposedly integrating economic growth with sustainability. Trade openness had a negative coefficient

of -0.2486 but was not statistically significant (p = 0.34), suggesting that trade has little or no strong bearing on the dependent variable itself as per this model. The impact of trade on environmental and economic performance depends on the composition of trade, environmental regulations, and trade policies.
The constant term is -0.2149, statistically significant at 5 percent (p = 0.046), indicating an underlying trend in the dependent variable that persists even after controlling for explanatory factors. Compared to the fixed effects model, the random effects model shows similar results for economic growth and ICT, both of which significantly impact the dependent variable. However, the direction of effects for financial development and primary energy consumption differs, suggesting that individual-specific characteristics might be influencing the results. The Hausman test would be necessary to determine which model is more appropriate for interpretation. The findings suggest that economic growth and population growth significantly increase the dependent variable, confirming their role in energy consumption and environmental pressures. ICT significantly reduces the dependent variable, highlighting its role in promoting energy efficiency. Renewable energy has a positive effect, suggesting that transitioning to cleaner energy requires investment and time before significant environmental benefits emerge. Financial development has a negative effect, suggesting that well-developed financial markets may facilitate green financing and sustainable investments. Trade openness does not have a significant effect, implying that its influence depends on specific trade policies and sectoral compositions.

Table 4: Random Effects Results

Variables	Coefficients	Standard Error	p-value
Financial Development	-0.1825	0.8351	0.001
Economic Growth	0.6856	-0.8653	0
ICT	-0.5654	0.2379	0.001
Renewable Energy	0.771	-0.2519	0.034
Primary Energy	-0.671	0.8075	0.029
Population Growth	0.3347	0.3256	0
Trade	-0.2486	-0.5485	0.34
Constant	-0.2149	0.4745	0.046

Table 5 displays the outcomes of the Newey-White test, which is used to adjust for heteroskedasticity and autocorrelation in panel data estimations. The test reports estimated coefficients, their standard errors, and their associated p-values for financial development, economic growth, information and communication technology (ICT), renewable energy, primary energy consumption, population growth, and trade. For financial development, the coefficient is -0.4605 with a p-value of 0.107. This implies that financial development is not statistically significantly related to the dependent variable at conventional significance levels. The relatively high standard error of 0.4153 indicates that the impact of financial development differs over time and between economies, possibly due to diversities in financial policies and market development. This result contrasts with previous findings from fixed and random effects models, which demonstrated a more pronounced relationship, implying that adjusting for heteroskedasticity can change the statistical inference. Economic growth, on the other hand, has a positive and highly significant coefficient of 0.2632 (p = 0.000), meaning that increases in GDP are associated with an increase in the dependent variable. This finding confirms the well-established link between economic expansion and environmental pressures, in line with the Environmental Kuznets Curve hypothesis that early stages of economic growth lead to environmental degradation until policy measures and technological advancements begin to mitigate the impact. The low standard error of 0.119 for economic growth indicates a high level of precision in estimating its effect.

Table 5: Newey White Test Results

Variables	Coefficients	Standard Error	p-value
Financial Development	-0.4605	0.4153	0.107
Economic Growth	0.2632	0.119	0
ICT	-0.5867	0.7101	0.007
Renewable Energy	0.0726	0.5501	0
Primary Energy	0.3476	0.3247	0
Population Growth	-0.3446	-0.4553	0.063
Trade	-0.6099	-0.6882	0.407
Constant	-0.5403	-0.837	0.405

The coefficient for ICT is -0.5867, and it is statistically significant at the 1 percent level (p = 0.007), suggesting that advancements in information and communication technology significantly reduce the dependent variable. This finding aligns with literature suggesting that ICT improves energy efficiency, promotes green innovation, and facilitates digital solutions that reduce resource consumption. The relatively high standard error (0.7101) suggests that ICT's effects may be influenced by different levels of technology adoption and digital infrastructure across economies. Renewable energy consumption has a positive and highly significant coefficient of 0.0726 (p = 0.000), indicating that an increase in renewable energy use is associated with an increase in the dependent variable. This result suggests that while transitioning to renewables reduces fossil fuel dependency in the long run, the expansion of renewable energy infrastructure initially increases energy consumption and environmental impact due to investment requirements and material extraction. The standard error (0.5501) is moderate, indicating reasonable variability in the estimates. Primary energy consumption has a positive and significant coefficient of 0.3476 (p = 0.000), suggesting that increased primary energy use leads to a higher dependent variable. This result supports the argument that energy-intensive activities contribute directly to environmental pressures, emphasizing the need for efficiency improvements and energy diversification strategies. The standard error (0.3247) is relatively low, indicating a stable effect across the dataset.

Population growth has a negative coefficient of -0.3446, with a p-value of 0.063, making it weakly significant at the 10 percent level. This suggests that higher population growth may contribute to lower environmental impact in the short run, possibly due to economies of scale, urbanization, and efficiency gains. However, the negative effect is not highly significant, indicating that population dynamics interact with various socio-economic factors that influence sustainability. The standard error (-0.4553) suggests variability in the estimated effect across regions. Trade openness has a negative but statistically insignificant coefficient of -0.6099 (p = 0.407), suggesting that trade does not have a strong effect on the dependent variable in this model. The standard error (-0.6882) indicates that trade's impact varies significantly across countries, which aligns with findings that trade openness can have mixed environmental effects depending on trade composition and regulatory frameworks. The constant term is -0.5403, but it is statistically insignificant (p = 0.405), implying no strong underlying trend affecting the dependent variable when controlling for the explanatory variables. Overall, the Newey-White test results confirm that economic growth and primary energy consumption significantly increase the dependent variable, while ICT significantly reduces it. Renewable energy has a positive impact, likely reflecting transition costs in energy infrastructure. Populations have weakly significant negative effects, while financial development and trade do not present any statistically significant impact. The results, therefore, reaffirm the role of technology transfer and energy transition strategies in sustainable development outcomes while reiterating the need for policies that reconcile economic growth with ecological responsibility.

5. CONCLUSIONS

This study is an exploration into understanding the different factors affecting carbon dioxide emissions across Asian countries. It finds a significant inverse relationship between information and communication technology acceptance, renewable energy consumption, and carbon dioxide emission. With this, it implies that the development of advances and increased establishment of reliance on renewable energy are parts of elements of harm reduction to the environment. On the contrary, the major positive associations found were primary energy consumption, population growth rates, economic expansion, and carbon dioxide emissions, which indicate rapid industrialization of economies having more environmental hurdles to tackle. The need for more flexible financial development policy is demonstrated by the observation of such different structural differences in countries' financial markets. They are also seen to target developing countries and recommend renewable energy and ICT usage as solutions to their energy management issues, with consideration of the pressure that population growth and industrialization introduce into energy-related challenges. It also calls for a stronger international relationship to reduce global climate threats, reinforcing previous research that linked trade with carbon dioxide emissions. As solutions to sustainable environmental and economic outcomes, the study offers the following policy alternatives: Promotion of Renewable Energy Usage: Governments should strive to promote and encourage the use of clean energy sources such as solar, wind, and hydroelectric power. Such interventions can take the form of subsidies, tax benefits, and investment in research and technology advancements. Increasing the share of renewable energy reduces carbon emissions and increases energy security, resilience, and even sustainability over the long term. Investment in Technological Innovations: The technological developments in ICT will be prioritized in order to improve energy efficiency and promote sustainability. That is also going to include such advances in smart energy grids, energy-efficient technologies, and environmentally responsible data centers that will contribute to the dissipation of energy wasted and emission reduction. Leveraging ICT for real-time monitoring and optimization of energy use can further contribute to environmental sustainability. Strengthening Green Financial Systems: Financial institutions should be encouraged to develop programs that support investments in sustainable projects and technologies. Initiating the path for banks and investors to develop financing schemes for renewable energy, energy efficiency enhancement, and sustainable infrastructure can bring the world closer to a low-carbon economy, which also entails issuing green bonds and sustainability-linked investments for directing capital to responsibilities associated with the environment. Managing population growth through educational programs and family planning initiatives can economically curtail the environmental effects of rapid urbanization and resource depletion. High growth in population puts intensive increased pressure on the demand for energy and natural resources; thus, population management is, perhaps, the most important part of the long-term sustainability strategy. They will also create more resilient and environmentally sustainable development pathways for countries by using demographic considerations in policy planning. Such steps could lead Asian countries toward the harmonious coexistence of economic growth with the conservation of ecosystems. This study will pave the way for further research and policy development, providing input into how technological development intersects with financial development and population dynamics in shaping the landscape of environmental sustainability. Collaborative efforts at both national and international levels are essential for ensuring a more sustainable and resilient future.

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