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Article

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The Triple Impact of Innovation, Financial Inclusion, and Renewable Energy Consumption on Environmental Quality in some Emerging Economies

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ABSTRACT

This paper investigates the triple impact of innovation, financial inclusion, and renewable energy consumption on the quality of environment. The study employed data between 2007 and 2019 from selected emerging economies. Using the fixed effect two-step GMM econometric method. The result found that financial inclusion and innovation have a positive relationship with carbon emissions, hence, contributing to the reduction in the quality of the environment. Renewable energy consumption was found to reduce carbon emissions. Similarly, the interactive terms TPT*FIN, FIN*REN, and TPT*REN were all negatively related to carbon emissions. The study recommends that governments should increase financial instruments to support innovation that will enhance environmental quality. Additionally, governments should strengthen their environmental policies. Financial institutions should encourage firms to access green finance solutions. The value and originality of this study is the introduction of the interactive term which throws more light on variables that affect the environment and through which channel. Moreso, there are few works with these interactive terms relative to emerging economies. Third, there are no previous studies that employed the fixed effect two-step GMM to analyze the impact of financial inclusion, technological innovation, and renewable energy consumption on environmental quality.

Keywords: Financial Inclusion, Innovation, Renewable Energy, Emerging Economies, Fixed Effect GMM
JEL Classifications: C33, Q29, Q52, Q55

1. INTRODUCTION

The world is now being plagued by several environmental problems, including pollution, climate change, and resource depletion. These problems are serious and require prompt attention. Innovation, one of the primary forces driving change, has the power to help us get over these obstacles (Eberle et al., 2023). But innovation on its own is insufficient. It is also essential to make sure innovation is inclusive (Davenport, 2018). This suggests that it should be available to everyone, regardless of their financial situation or social status. Financial inclusion is required for inclusive innovation to take place. It makes it possible for consumers to get the financial services they need to start environmentally friendly businesses, make investments in clean technologies, and adopt sustainable habits (Danladi et al., 2023).

Financial inclusion contributes to sustainable development by ensuring access to finance is guaranteed sustainably and by providing basic financial services based on sustainability principles (Ozili et al., 2023). Financial inclusion is the provision of access to financial services, such as savings, credit, insurance, and payments, to people who previously did not have it. It also has a significant impact on job creation and reducing unemployment, particularly in countries with higher levels of education (Sun and Scola, 2023). Moreover, financial inclusion has been found to positively affect economic development in the Middle East and North Africa (MENA) region (Mostafa et al., 2023). To achieve financial inclusion and support inclusive innovation, there is a need for intelligent digital financial inclusion systems that leverage emerging technologies such as artificial intelligence, blockchain, and the Internet of Things (Rawat et al., 2023). Financial inclusion is a pivotal catalyst in reducing industrial pollution and carbon footprint levels (Hussain et al., 2023, Latif et al., 2023, Saqib et al., 2023 and Xiong et al., 2023). The integration of innovation, renewable energy, and financial inclusion has been realized to curb the adverse effect of financial inclusion on the environment, allowing for the long-term elimination of ecological damages and sustainable growth (Damrah et al., 2022). Therefore, the more inclusive the financial system is, the more likely it can support the achievement of a quality environment (Li et al., 2020). Further, Wang et al. (2012) contended that the more inclusive the financial system becomes, industrialization, economic, and anthropogenic activities also increase which has the potency of worsening the conditions of the environment. Moreso, once households and individual disposable income increase due to greater financial inclusivity, households and individuals are more likely to purchase items that may or may not increase pollution. Thus, it is a matter of choice and individual behaviours (Ahmad et al., 2022). Liu et al. (2022) investigated the impact of financial inclusion on growth and CO_2 emissions, and they found a positive relationship between financial inclusion and environmental quality. Similarly, Kwakwa (2021) Musah et al. (2023), Liu et al. (2022), Chaudhry et al. (2022), Tufail et al. (2022), and Xiong et al. (2023) all found similar results in their respective examinations. However, Yang et al. (2022), Saidi and Mubarek (2017), and Li et al. (2020) all found a negative relationship between financial inclusion and environmental pollution.

Innovation can be viewed as a process of introducing new products, services, or processes that are novel and improve the way we live and work. The idea of sustainable innovation is a fundamental approach to promoting economic resilience and inclusion in emerging markets, thus reducing poverty and inequality. Responsible research and innovation (RRI) are a concept that has gained substantial attention in academic and policy domains, emphasizing the importance of inclusion and public participation in research and innovation. Innovation is crucial in the pursuit of a sustainable environment and the achievement of a good ecology that can support progress in the well-being of humankind (Alfuraty, 2010). Additionally, innovation comes in different forms and shapes. Innovation could be a change in production process, new machinery to facilitate efficiency, a new product or idea, or a renewable energy source. Apparently, an innovation that fosters the production and consumption of renewable energy, technological advancement, and tourism can significantly reduce carbon emission and improve ecological quality (Peng and Zhu, 2023). Sustainable Business Model (SMB) innovation is most important are crucial in ensuring sustainability of the environment. The innovative SMBs should be crafted to incorporate principles that are ecology-centric that effectively curb the nuances and complexities of business externalities as well as contribute to the reduction of carbon emissions (Cillo et al., 2019).

Environmental sustainability connotes how anthropogenic activities do not derail the quality of the environment. The imperativeness of environmental sustainability among global leaders birthed the Kyoto Protocol and more recently the Paris Agreement (2050 Agenda) which places some commitment on countries who have ratified the Agreement to commit to ensuring that global temperature is kept below 1.5°C. Greenhouse gases (GHG), carbon dioxide (CO_2), and sulfur hexafluoride (SF6) are among the toxic emissions that destroy the air quality which affects health and the economy subsequently (Musah et al., 2023; Yousefi et al., 2021). This toxic emissions cause radiation effectively and possess longer life spans which form the fundamental basis for global warming. Thus, methane for instance can last up to 30 years within the atmosphere, hence, trapping heat for a long period of time (Environmental Protection Agency, 2021). Moreso, other activities in the fisheries and mining sector, industrial space, as well as agriculture also exacerbate the current conditions which pose a threat to future well-being. Providing access to green and renewable energy sources ensures hope for the pursuit of a net zero GHG as well as ensuring environmental sustainability. Additionally, increasing awareness of the dangers of GHGs and nations committing to providing access to cheap clean energy are practical and needed actions that make the achievement of SDG 7 a reality (Musah et al., 2023; Environmental Protection Agency, 2021). However, the 6% rise in GHG emissions raises more questions about the previous commitments made.

There has been a mix of conclusions in the literature regarding the impact of technological innovation on the environment. One strand of the literature assumes that innovation helps to reduce the toxic gases within the atmosphere especially when green standards are adhered to. Firms, businesses, and state institutions are making key investments in promoting a green environment (Musah et al., 2023). Another strand is that technological innovation can increase pollution (Munir and Ameer, 2018). However, innovation can be harnessed and controlled to be more beneficial. Wu (2020) further emphasized that innovation has a much greater potential to reduce pollution, particularly with the emergence of Industry 2.0. The relationship between innovation and reduction in pollution is not straightforward there are some complexities that highlight the varying impact innovation has on the environment (Xin et al, 2022). Regarding the complexity, Wang and Luo (2020) posited that the relationship between innovation and environmental quality is contingent on and influenced by the quantity and quality of investment and foreign direct investment. Agyeman et al., (2023) explored the connection linking environmental technology innovation, economic growth, financial development, trade openness urbanization, and energy consumption on environmental pollution by using 27 African Countries. They found that technological innovation and urbanization reduce pollution. Onifade et al. (2022) examined the impact of technological innovation and renewable energy on environmental sustainability. They found a negative relationship between innovation and environmental sustainability, though, the magnitude of the impact is very small. Similarly, Li et al (2021) found that technological innovation has a positive impact on the environment.

Although several works have been done within this space of research, it has become more crucial to continue the investigation, particularly having seen a 6% rise in GHG emissions. Chen et al., (2022) noted that developing countries have limited innovation levels, and far-reaching financial systems which when harnessed properly would inure to a technological boom. This study focuses on some selected emerging economies whose innovation levels are going up and financial systems are becoming more inclusive. The contribution of this study is the introduction of the interactive term which throws more light on variables that affect the environment and through which channel. Moreso, there are few works with these interactive terms relative to emerging economies. Third, there are no previous studies that employed the fixed effect two-step GMM to analyze the impact of financial inclusion, technological innovation, and renewable energy consumption on environmental quality.

The remainder of the paper is organized as follows: section two present data and methodology employed, section three details the discussion of the results, and section four presents conclusion and recommendation.

2. DATA AND METHODOLOGY

The study employed panel data on 20 emerging economies from 2007 to 2019. Data on financial inclusion was collected from the IMF financial development index datasets and following the works of Musah et al. (2023), Li et al. (2020), and Ozturk and Ullah (2022), the Principal Component Analysis (PAC) was used to create a financial inclusion index. Carbon emission per capita was used as a proxy for environmental quality. This is in conformity with Obobisa et al (2022) who used carbon emission (CO_2) as a proxy for environmental pollution. Total patent application was used to represent innovation and GDP per capita was employed as a control variable. These data were sourced from the World Bank's World Development Indicators (WDI). Renewable energy consumption is key to ensuring the existence of a quality environment (Gyimah et al., 2022). Renewable energy data is a composite data that includes hydropower, solar, wind, geothermal, wave and tidal, and bioenergy sourced from the Energy Institute - Statistical Review of World Energy (2023). The variables used and their definitions are presented in Table 1. The PCA results is in Appendix Table 1.

Innovation is considered as a product of research and development. Evidently, new growth theories place greater emphasis on technology or innovation as the exogenous factor that makes the production function more efficient and effective. Kihombo et al. (2021) align with the school of thought that professes that research and development are central to pushing the agenda of energy efficiency and green technological innovation as means of maintaining a quality environment. Financing green technology is one of the drawbacks that thwart efforts to ensure a quality environment. Emerging economies are engaged in upscaling production following an industrialization drive in which often the externality of production is neglected. Similarly, access to finance to bolster industrialization and innovation that are environmentally friendly is still a huge debate within the emerging economies. Evidently from the Table 1, the eigenvalues of the first two components of the PCA for financial inclusion is 70.9%. This suggests that the index created is good.

The general panel model used follows the techniques used by Musah et al., (2023), Li et al. (2020), and Ozturk and Ullah (2022).

$$lnCPC_{it} = \alpha_0 + \beta_1 lnCPC_{it-1} + \beta_2 lnTPT_{it-1} + \beta_3 lnFIN_{it} + \beta_4 lnREN_{it} + \beta_5 lnGDPC_{it} + \varepsilon_{it} \quad (1)$$

Where *CPC* is the dependent variable that measures environmental quality. Thus, the lower it gets the better the environment becomes and the higher it gets the worse the environment becomes. The independent variables are *TPT, FIN, REN,* and *GDPC*. $\beta_1, \beta_2, \beta_3, \beta_4$, and β_5 are the coefficients of the independent variables respectively. α_0 is the intercept of the model.

The error term is $\varepsilon_{it} = v_i + u_{it}$ where v_i is the unobserved time-invariant country-specific fixed effect and u_{it} is an i.i.d random term with $E(u_{it}) = 0$ and $Var(u_{it}) = \sigma^2$. i represents the countries used for the study and t is time for which data was collected (2007-2019). We considered a panel dynamic model and assumed that past carbon emissions determine the present amount of carbon emission hence having the lag dependent variable among the regressors.

The lag of total patent application was used in the model because, invariable when patent applications are made this year, the approval of the application may come next year. Thus, this year's patent application will determine the amount of total patent next year. Therefore, we took this into consideration to use the lag of total patent instead of total patent.

The link between financial inclusion and environmental quality is inconclusive (Musah et al., 2023). Financial inclusion provides individuals, households, and firms access to financial services and solutions that may foster capital creation, expansion in production, increased consumption of consumer goods and trigger a lot of anthropogenic activities that impact the environment either positively or negatively (Renzhi and Baek, 2020). If the impact is positive then it suggests that financial services acquired are used in an environmentally responsive way, whereas if negative it suggests that the anthropogenic activities that come about through financial inclusion are not environmentally friendly. Hence, equation 1 seeks to find answers to the first hypothesis of this study.

Further, to interrogate the second hypothesis the cross product of renewable energy consumption and financial inclusion ($lnFIN_{it}$ * $lnREN_{it}$) was included into the model to understand how they jointly affect the relationship between innovation and environmental quality.

$$lnCPC_{it} = \alpha_0 + \beta_1 lnCPC_{it-1} + \beta_2 lnTPT_{it} + \beta_3 lnFIN_{it} + \beta_4 lnREN_{it} + \beta_5 lnGDPC_{it} + \mu_{it} + \gamma_1 (lnFIN_{it} * lnREN_{it}) + \mu_{it} \quad (2)$$

From equation 2 the derivative of the model with respect to FIN gives the following result.

$$\frac{dlnCPC_{it}}{dlnFIN_{it}} = \beta_3 + \gamma_1 lnREN_{it} \quad (2a)$$

Table 1: Description of data and measurement unit

Variables	Id	Explanation	Source
Total patent application	TPT	Total patent application (sum of both resident and nonresident applications)	WDI
Financial Inclusion Index	FIN	The financial inclusion index was calculated using the	Authors calculation
Automated Teller Machine	ATM	PCA technique.	IMF, FDI
Bank capital to assets ratio	BCAR	Number of automated teller machines per 100,000 adults	IMF, FDI
Commercial bank branches	CBB	The ratio of bank capital to asset in percentage terms	IMF, FDI
Domestic credit to the private sector by banks	DCPSB	Number of commercial bank branches per 100,000 adults Domestic credit to the private sector by the bank as a share of GDP	IMF, FDI
CO_2 emission	CPC	Carbon emission per capita	WDI
Renewable energy consumption	REN	Renewable energy consumption (percentage of total energy consumption)	EISR, World Energy data
GDP per capita	GDPC	Gross domestic product per capita (constant 2015 US $)	WDI

The sign of β_3 and γ_1 are much of an interest in discussion. If both β_3, and γ_1 are >0, then financial inclusion reduces environmental quality through the consumption of renewable energy. This was the argument put forward by Durá-Alemañ et al. (2022) as they posit that renewable energy consumption has an adverse biodiversity impact mostly through the renewable energy production process. Additionally, Breeze (2017) power generation technologies have negative impacts on the environment. Most of the concern are related to the disposal of the waste generated by renewable energy or green technology. One of the key issues for instance, is how to dispose lithium batteries of electronic cars which has heavy metals that damages the environment. When both coefficients β_3 and γ_1 are negative signaling financial Inclusion reduces pollution through renewable energy consumption, hence ensuring much better environmental quality (Fareed et al., 2022).

Additionally, the impact of the interactive terms between innovation and renewable energy consumption ($lnTPT_{it}*lnREN_{it}$) and innovation and financial inclusion ($lnTPT_{it}*lnFIN_{it}$) were introduced to the model separately to explore the third and fourth hypotheses. This provides some level of understanding of the key role financial inclusion and renewable energy consumption play in the relationship between innovation and environmental quality. To avoid the problem of serious collinearity, the interaction terms are added in separate models below:

$$lnCPC_{it} = \alpha_0 + \beta_1 lnCPC_{it-1} + \beta_2 lnTPT_{it-1} + \beta_3 lnFIN_{it} + \beta_4 lnREN_{it} + \beta_5 lnGDPC_{it} + \mu_{it} + \gamma_2 (lnTPT_{it}*lnREN_{it}) + \mu_{it} \quad (3)$$

$$lnCPC_{it} = \alpha_0 + \beta_1 lnCPC_{it-1} + \beta_2 lnTPT_{it-1} + \beta_3 lnFIN_{it} + \beta_4 lnREN_{it} + \beta_5 lnGDPC_{it} + \mu_{it} + \gamma_3 (lnTPT_{it}*lnFIN_{it}) + \mu_{it} \quad (4)$$

The derivatives of these models with respect to innovation provide these results.

$$\frac{dlnCPC_{it}}{d\ln TPT_{it}} = \beta_2 + \gamma_2 lnREN_{it} \quad (3a)$$

$$\frac{dlnCPC_{it}}{d\ln TPT_{it}} = \beta_2 + \gamma_3 \ln FI_{it} \quad (4a)$$

The signs of if β_2, γ_2, and γ_3 are much crucial for analysis. If β_2, γ_2, and γ_3 are all greater than zero, then *innovation* reduces environmental quality through the consumption of renewable energy and financial inclusion (Ahmad et al, 2022; Dai et al., 2022) respectively by increasing pollution. Similarly, if β_2, γ_2, and γ_3 are all negative, they signal that *innovation* improves environmental quality through renewable energy consumption and financial inclusion (Zhang et al., 2022 and Damrah et al., 2022) by reducing ecological degradation. However, if β_2 is >0, and γ_2, γ_2, are <0, then innovation increases pollution and harms environmental quality while energy consumption and financial inclusion**,** respectively improve environmental quality. In a situation of reverse, β_2 is <0, and γ_2, γ_2 > 0, then it suggests that while the consumption of renewable energy and financial inclusion respectively are reducing environmental quality, innovation improves the quality helps to improve the environment ensuring sustainability.

To solve this problem with the within estimators proposed by Baltagi (2008) and Arellano and Bond's (1991), we employed the fixed effect GMM estimator developed by Schaffer (2020) and used by Aydemir and Guloglu (2017), and Turgutlu (2010) in their works. There is a distinction between this model and two-step difference GMM of Arellano and Bond (1991) and two-step system GMM of Blundell and Bond (1998). The fixed effect GMM estimator of Schaffer (2020) holds two key advantages over difference GMM and system GMM. First, the assumption that inconsistencies in the original model with fixed effect are not autocorrelated and homoscedasticity does not hold (Drukker, 2003). Hence, incorporating heteroscedasticity and autocorrelation generates more efficient estimates. Additionally, it does not use dynamic instruments because it assumes that instruments neither vary over time nor increase with the increase in time (T), hence, solving the issues of weak instrument.

To test the validity of instruments used in the estimations we employ three tests: Kleibergen and Paap rank LM test (2006), Cragg and Donald F test (1993) and Hansen J statistic (1982). The first two test check if the endogenous variables are correlated with instrumental variables, while the last one tests if instruments are correlated with errors. Additionally, Kleibergen and Paap rank LM test and Hansen J test statistics are robust to non-spherical disturbances. That is, we allow for the non-spherical characteristics of errors when testing the validity of instruments. As it is seen from Table 2, the results of Kleibergen and Paap rank LM test and Cragg-Donald F test indicate that the instruments are weakly correlated with endogenous variables. On the other hand, Hansen J test fails to reject overidentification restrictions. Thus, the instrumental variables used throughout the models seem to be valid except for the third model where it is significant at 10%.

3. RESULTS AND DISCUSSION

From Table 1 below the standard deviations of the variables are between 0.297 and 5.458 indicating that the data is spread around the mean. The maximum values are between 1.087 and 15.591 while the minimum values are between −15.382 and 3.029. The correlation matrix in Appendix Table 2 shows how the variables are correlated with each other.

The results indicate that financial inclusion, GDP per capita and the interactive terms of total patent and financial inclusion (TPT*FIN) and financial inclusion and renewable energy consumption (FIN*REN) are highly correlated with carbon emissions with values of 69%, 73%, 69% and 64% respectively. The results of the unit root test in Appendix Table 3 indicates that FIN, RE, FIN*REN and TPT*FIN are station at level in both CIPS and Pesaran CADF test. Further CPC, TPT, GDPC, and TPT*REN are stationary at first difference. Additionally, the null hypothesis of no cross-sectional dependency was rejected in 3 tests, thus, Breusch-Pagan LM test, Pesaran Scaled LM test, and Biased-Correlated Scaled LM test (Appendix Table 4).

The results of the fixed effect two-step GMM estimation is in Table 3. The regressors TPT, FIN, GDPC, and REN are all statistically significant in all the models except for FIN which was insignificant in model 4. The interactive terms are statistically significant in model 2 and 4. In model 3, the interactive term was not significant. The lag dependent variable results suggest that the previous year's carbon emission increases the current carbon emission. Emerging economies are on an industrialization drive which necessitate the establish of industries which have high potential of emitting large amounts of carbons (Lin et al., 2022). Additionally, this could be attributed to some of the countries under study's pollution levels. For examples India, South Africa, South Korea, Indonesia, and Russia are among the top ten polluters[1].

The lag of total patent application has a positive relationship with carbon emission. Thus, when previous patents applications go up by 1%, then the current carbon emission goes up by 6.7%, 7.4%, 8.3% and 7.3% respectively in models 1, 2, 3, and 4 ceteris paribus. The means that the quality of the environment is declining as mores more innovation springs up in the study countries. The rationale behind using the lag is because when patents are applied this year it will take some time for the patent to be approved. Additionally, given the facts of economies of scale and protectionism, with relatively smaller markets of green patenting, are likely to thwart incentives for green innovation and leads to duplication of efforts among countries.

Further, the results suggests that the green friendly patent approved by these economies are few as compared to high carbon emission technologies. For instance, the general profile of innovation in patent in emerging economies between 2010 and 2019 are in human necessities, performing operations, transport, chemical, metallurgy, textiles, papers, fixed constructions, mechanical engineering, lightening heating, weapons, explosions, physics, and electricity (Tatum and Russo, 2020). Our results are consistent with the work of Wang et al. (2012), that is, the increase in technology or patent application does not reduce carbon emission. Conclusively, in selected emerging countries[2] under study, the higher technology goes up the more carbon emission are emitted.

Table 2: Descriptive statistics

Variable	Obs	Mean	SD	Min	Max
cpc	247	0.655	0.297	0.051	1.087
tpt	247	3.791	0.635	2.477	5.34
fin	247	0.079	1.367	−4.092	2.98
gdpc	247	3.97	0.318	3.029	4.598
ren	247	1.815	0.682	−0.804	3.218
tpt fin	247	0.541	5.458	−15.382	15.591
tpt ren	247	6.988	3.17	−2.728	14.177
fin ren	247	−0.105	2.553	−8.033	5.529

1 Trade, C. (2021). Which countries are the world's biggest carbon polluters? *climatetrade.com. Retrieved July 5,* 2022.

2 Argentina, Brazil, Chile, Columbia, Czech Republic, Greece, Hungary, India, Indonesia, Israel, Malaysia, Mexico, Peru, Poland, Russia, South Africa, South Korea, Thailand, and Türkiye.

Table 3: Fixed effect two step GMM results

Dependent Var CPC	Model 1	Model 2	Model 3	Model 4
CPC (−1)	0.142**	0.205**	0.021**	0.043**
TPT (−1)	0.067*	0.074*	0.083**	0.073**
FIN	0.026***	0.055**	0.024**	0.035
GDPC	0.808***	0.772***	0.798***	0.789***
REN	−0.132***	−0.112***	−0.130***	−0.131**
FIN*REN	---------	−0.016*	-----------	---------
TPT*REN	---------	---------	-0.010	---------
TPT*FIN	---------	---------	-----------	−0.002**
Kleibergen-Paap LM	34.646***	35.704***	32.251***	31.943***
Cragg-Donald's Wald F-stats	38.317	39.790	39.704	38.086
Kleibergen-Paap Wald F-stats	34.493	36.650	44.208	41.409
Hansen J test	1.739	3.233	2.898*	2.640
Wooldridge AR test	30.303***	27.635***	32.890***	30.197***
F-stats	30.99***	28.82***	20.54***	18.24***
Root MSE	0.0319	0.0309	0.0314	0.0321
Obs	228	228	228	228

***, **, * signifies 1%, 5% and 10% levels of significance respectively

Financial inclusion is understood as providing access financial services to firm, household, and business to expand economic activities, increase consumption or improve efficiency in production. From our results an increase in access to financial service leads to a 2.6%, 5.5%, 2.4% and 3.5% respectively in models 1, 2, 3, and 4 ceteris paribus. However, in model 4, financial inclusion is not statistically significant. This indicates that financial inclusion decreases the quality of the environment. This suggests that financial inclusion grants households, individuals, and firm easy access to credit which are expended on goods, services and equipment that are emit high levels of carbons. Further, easy access to credit means the disposable income of firms get enough capital to expand production thereby generation more carbon emission as the drive for industrialization is in full gear. Similarly, Household access to credit means that there will an increase and a shift in consumption. Household will tend spend more on consumables that emit more carbons. The result of this study confirms the outcomes obtained by Liu et al. (2022), Chaudhry et al. (2022), Musah et al. (2023) and Tufail et al. (2022).

GDP per capita increases carbon emission in all four models by 80.8%, 77.2%, 79.8%, and 78.9% respectively ceteris paribus. This is because most of the countries used for the analysis have expanded their economies and growth per capita over the years. This translates to a rigorous economic transformation drive underpinned by industrialization, innovation, and high energy consumption. The industrial and production sectors of Turkey, Brazil, South Africa, India, Argentina, Indonesia, and Malaysia have seen some considerable expansion which means that more carbon dioxide is emitted during the expansion, and ultimately, affect the quality of the environment. Evidently, India has one of the most polluted atmospheres despite the gain it chalked in growth and technological development in recent years. Moreso, our results point to the fact that as the per capita contribution of households to GDP goes up more carbon emission are produces. This means that the productivity of the average household is increasing through economic and anthropogenic activities that not only increases GDP but also carbon emission. Our results are similar to results found by Grossman and Kruger (1995), Chong et al. (2022), Ridzuan et al. (2017) and Rofiuddin et al. (2017).

Renewable energy consumption is well known to reduce carbon emissions in scientific analysis. Our results correspond to this popular opinion as a percentage increase in renewable energy consumption decreases carbon emission by 13.2%, 11.2%, 13%, and 13.1% in model 1, 2, 3, and 4 respectively ceteris paribus. As the concept of renewable energy consumption gets massive acceptability from household and firms, it helps to reduce the emission of carbon dioxide thereby improving the quality of the environment. Ali et al. (2023) also found similar negative relationship between renewable energy and carbon dioxide emission. Zhang et al. (2023) confirmed same results in their analysis of the dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth, and carbon emissions among Asian emerging economies. Similarly, our result is in congress with the results of Nahrin et al. (2023).

The points of interest for this study are responds of the interactive terms as we introduce them each into the first model. The interactive term of financial inclusion and renewable energy was statistically significant at 10% and reduces carbon emission by 1.6% ceteris paribus. In effect, this could be based on two factors. Firstly, the type of financial access household and firms get because of development within the financial system. Per the government energy spending tracker report 2023 of the IEA, emerging and developing economies have increased financial support for renewable energy affordability by USD 23 billion in last six months. This support was in the form of transfers to energy companies to invest in renewable energy sources and to keep prices at affordable levels through the early part of the energy crises (IEA, 2023). The latter reason is based on our assumption that, household and firms in the country understudy will use the credit gain to purchase energy efficient equipment to reduce energy cost there by reducing carbon emission. Although, we agree that from behavioral economics point of view, this is not necessary the case as household and firms may want to satisfy their needs which may not necessarily be green friendly.

Second, the interactive term between total patent and renewable energy consumption, although statistically insignificant, have a negative relationship with carbon emission. Total patent application (innovation) reduces carbon dioxide emission through consumption of renewable energy hence improving the quality of the environment. This signals that innovation improves environmental quality through renewable energy consumption (Zhang et al., 2022 and Damrah et al., 2022). This could be explained that more of the approved patent are geared to reinforcing the efficiency in energy consumption through renewable energy sources. For example, the consumption of renewable energy in India has grown significantly, supporting the government's newly announced goal of reaching 500 GW of renewable power capacity by 2030. The renewable energy consumption was also due to the increase in renewable energy innovation in India (IEA, 2021 and Renné, 2022).

The final interactive term of innovation and financial inclusion also had a negative relationship with carbon emissions. It reduces environmental degradation by 0.2%. It can be argued that to achieve net zero carbon, the selected emerging economies have placed premium of financing innovation that will foster the achievement of net zero carbon agenda. Our result is similar to Musah et al. (2023). Innovation is needed to help reduce carbon emission to its barest minimum and this could be attained if there is financial commitment for agenda 2030 which is Central to COP 28 protocol to make fund available to support the agenda. In this regard, the concepts of green bonds are available for innovations that are centered on reducing carbon missions.

4. CONCLUSION AND POLICY RECOMMENDATION

In the quest to achieve net zero carbon emission and achieving the 2030 agenda of the Paris Accord, we set to explore the role of innovation, financial inclusion and renewable energy consumption play in improving the environment through carbon dioxide reduction in 20 selected emerging economies over the period of (2007-2019). From the regression results innovation and financial inclusion where all increasing carbon emission and thereby reducing the quality of the environment. Renewable energy consumption as expected improves the environment by reducing carbon emission. Similarly, the interactive terms provide an insight of how financial inclusion reduces carbon emission through the consumption of renewable energy. Further, innovation also reduces carbon emission the renewable energy consumption and financial inclusion. Thus, as more financial solutions are made available for innovation purposes, the financial solution are conditioned to support innovation within the renewable energy sectors.

There are few recommendations that can be derived from the results of our analysis. From a practical perspective, financial inclusion should be modeled around providing financial services that will support clean fuel and renewable energy consumption. Moreso, green financing schemes or green venture capital should be made available to support innovation that are energy efficient, reduce carbon, and be ecologically friendly. Further, patenting regimes and green financing schemes should foster some collaboration to support innovation that is geared towards improving the quality of the environment. In theory our study suggests that emerging economies should prioritize renewable energy, green innovation, and financial inclusion as a fundamental policy pathway towards achieving net zero carbon emission and the agenda 2050 of the Paris Accord.

From the policy perspective, governments of the countries understudy should increase financial instrument to support innovation that will enhance environmental quality. Additionally, state authorities should strengthen their environmental policies as some of them still do have serious carbon levels. As we pointed out previously, India, South Africa, South Korea, Indonesia, and Russia are among the top ten carbon emitters. Financial institution, in their quest to increase access to financial services, should encourage firms to access green finance solution. This would encourage firms to engage in environmentally friendly activities that will eventually improve environmental quality. Additionally, the renewable energy resource infrastructure should be improved significantly by states to ensure the realization of the agenda 2050 of the Paris Accord.

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APPENDIX

Table 1: Financial inclusion index (fi), PCA result

Eigenvalues: (Sum=4, Average=1)					
Number	**Value**	**Difference**	**Proportion**	**Cum. value**	**Cum. prop.**
1	1.802296	0.765007	0.4506	1.802296	0.4506
2	1.037289	0.261316	0.2593	2.839585	0.7099
3	0.775973	0.391531	0.1940	3.615558	0.9039
4	0.384442	…….	0.0961	4.000000	1.0000
Eigen Vector (loadings)					
Variable	**PC1**	**PC2**	**PC3**	**PC4**	
lnatm	0.627096	0.248683	0.212101	−0.707051	
lnbcar	−0.280282	0.774505	0.536175	0.184663	
lncbb	0.467862	0.494555	-0.609647	0.406018	
lndcpb	0.556145	-0.306128	0.543929	0.548752	

Table 2: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) cpc	1.000								
(2) tpt	0.097	1.000							
(3) fin	0.691*	0.277*	1.000						
(4) gdpc	0.728*	−0.121	0.583*	0.042	1.000				
(5) ren	−0.470*	0.251*	−0.268*	−0.094	−0.492*	1.000			
(6) tpt_fin	0.694*	0.363*	0.982*	−0.021	0.607*	−0.253*	1.000		
(7) tpt_ren	−0.377*	0.556*	−0.118	−0.118	−0.472*	0.937*	−0.085	1.000	
(8) fin_ren	0.645*	0.274*	0.956*	−0.006	0.501*	−0.081	0.942*	0.041	1.000

***P<0.01, **P<0.05, *p<0.1

Table 3: CIPS and CADF

Variables	CIPS				Pesaran CADF			
	Level		1st difference		Level		1st difference	
	Constant	Const. and trend	Constant	Const. and trend	Constant	Const. and trend	Constant	Const. and trend
Cpc	−1.399	−1.399	−2.689***	−2.714**	−1.399	−1.847	−2.689***	2.714**
Tpt	−1.640	−2.098	−3.303***	−3.819***	−1.640	−2.098	−3.303***	−3.819***
Fin	−2.583***	−2.280	−2.981***	−3.182***	−2.583***	−2.280	−2.981***	−3.182***
ren	−2.478***	−2.384	−2.928***	−3.180***	−2.478 ***	−2.384	−2.928***	−3.180***
fdi	−2.468***	−2.884**	−3.961***	−3.837***	−2.468***	−2.884 **	−3.961***	−3.837***
gdpc	−1.183	−1.565	−2.244**	−2.924**	−1.183	−1.565	−2.244**	−2.924**
fin*ren	−2.301**	−2.605	−3.156***	3.444***	−−2.301**	−2.605*	−3.156***	−3.444***
tpt*ren	−1.806	−1.956	−2.785***	−3.144***	−1.806	−1.956	−2.785***	−3.144***
tpt*fin	−2.730***	−2.286	−2.961***	−3.311***	−2.730***	−2.286	−2.961***	−3.311***

Table 4: Cross-sectional dependency test

Test	Model 1	Model 2	Model 3	Model 4
Breusch-Pagan LM	687.6036***	671.4115***	500.3142***	638.7567***
Pesaran Scale LM	27.9347***	27.0592***	17.8073***	25.2934***
Biased-Corrected Scaled LM	27.1431***	26.2675***	17.0156***	24.5017***