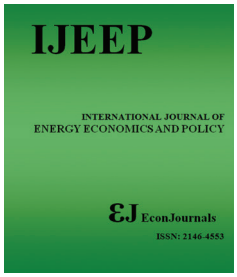

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Analyzing the Impact of Natural Resource Rents, Green Finance and Digital Finance on Environmental Quality: Evidence from Developing Countries

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ABSTRACT

Most of the developing economies face the issue of environmental degradation despite having tremendous growth in previous decades. Therefore, these countries are not able to preserve their development level if they do not achieve their targets of environmental sustainability. In this view, this study aims to analyze the effect of green finance, digital finance and natural resources on carbon dioxide (CO_2) emissions for a panel of 23 developing countries over 2010-2020 period. The study has applied Driscoll-Kraay Standard Error estimation technique to conduct the empirical estimation. The outcomes of the study identify that natural resources and digital finance reduce, whereas green finance increase the level of CO_2 emissions. The findings of causality test indicate that green finance, digital finance and natural resources do not granger cause the CO_2 emissions. Thus, natural resources and digital finance have significant contribution to improve the environmental quality. Based on the findings, the study recommends relevant policies for the effective utilization of natural resources and promoting digital finance to achieve the targets of environmental sustainability in developing countries.

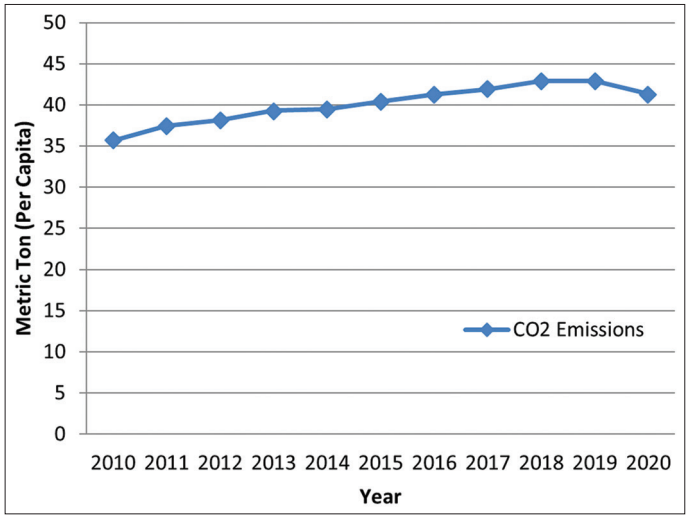
Keywords: Natural Resource Rents, Green Finance, Digital Finance, Environmental quality, Developing Countries
JEL Classifications: O13, P28, O17, F64, O44, P48

1. INTRODUCTION

The increased pace of global climate change in recent decades has caused various serious repercussions to the social and economic development of all countries. The International Panel on Climate Change pointed out that greenhouse gases emissions (GHGs), specifically CO_2 emissions caused by human activities, have caused several environmental issues including increased atmospheric temperature and global warming (Cong et al., 2020), which are among the most challenging issues for the human well-being (Le Quéré et al., 2019). Many international conferences such as Conference of Parties (COP26) and Paris Agreement had struggled for raising voice about the disastrous climate change and to achieve the net zero economy. In this regard, many developing and developed countries are making significant efforts to cope up with the environmental challenges and meet the targets of carbon neutrality (Qin et al., 2021).

Developing countries, in particular, face several challenges resulting from environmental degradation and pollution such as health issues, unemployment, poverty and low income, all resulting from their continuous efforts to enhance the level of economic growth. The increased industrial production and manufacturing of the goods need high energy usage which has resulted in increased CO_2 emissions as evident in Figure 1 (Sadiq et al., 2022). Developing economies prioritise economic growth that raises average wealth at the expense of the environment and depletion of the natural resources (NTR) (Usman and Radulescu,

Figure 1: CO_2 emission in developing countries (2010-2020)



2022). Among several factors that play a vital role in environmental problem, the NTR is the most prominent one. The NTR are without any doubt is a major source of economic growth as the availability of NTR stabilizes living standards and financial structure of an economy (Nawaz et al., 2019). But on the other hand, NTR, such as biotic and abiotic materials, soil, land, minerals, fossil fuels, and water, accounts for the increase in energy consumption and waste material disposal into air, soil and water which not only leads to the depletion of the NTR, but also the contamination of soil, water and air (Hanif et al., 2022). The NTR depletion has been increased rapidly over the past decades, including fossil fuel extraction from 6 to 15 and biomass consumption increased from 8 to 24 billion tons. Rapid economic expansion was the cause of this depletion of NTR which has created severe environmental issues (Jahanger et al., 2023). Moreover, the NTR extraction is highly energy-intensive process which causes high GHG emissions. The industries involved in the NTR extraction generate approximately half of the global CO_2 emissions and cause a 90% loss to biodiversity (Hussain et al., 2020).

Thus it is mandatory to expedite and upgrade the economic transformation and restructuring to promote low carbon economy to achieve the carbon neutrality goal by 2060. A key component of this endeavor is green finance (GF). Adopting GF to reduce environmental externalities is crucial and urgent given the severe environmental degradation problem. GF is the term for economic activities that support the conservation of the environment, combat climate change, and encourage resource efficiency. GF has been introduced to achieve the environmental sustainability and efficient resource allocation by promoting the investments to reduce investment as well as climate risk (Nawaz et al., 2021). In contrast to traditional financing methods, GF prioritizes resource efficiency to achieve environmental sustainability (Tariq and Hassan, 2023). It involves different financial services aimed at project financing, investment, operation, as well as the risk management in different sectors such as energy conservation, environmental sustainability, green transportation, clean energy, green buildings etc. (Zhang 2023). GF leverages different financial policies and instruments, including green bonds, green credits, carbon finance and green insurance to steer the capital flow towards low carbon projects and industries. It serves as a powerful incentive to enhance energy efficiency and reduce pollution emissions. Additionally, GF is essential in helping society deal with the dangers and difficulties associated with climate change and in easing the shift to a more environmentally conscious and sustainable economic model (Wang and Zhang, 2022; G. Wu et al., 2024). In short, an appropriate GF policy can improve the environmental quality as its main purpose is to bring trade-off between greening and growing economy (Khan et al., 2022).

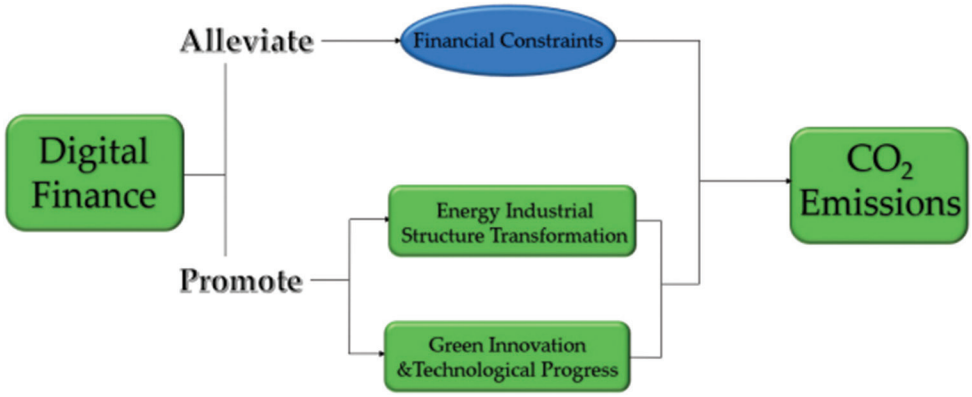
Meanwhile, the emergence of industry 4.0 has led to a growing application of big data, blockchain, and artificial intelligence in the current industrial structure, which not only significantly raises economic growth but also the quality of life. In this regard, the financial support provided by digital finance (DF) plays a crucial role to form a modern economic system (Aziz and Naima, 2021; Mpofu, 2024). DF has extended the scope of financial coverage significantly, lowered the cost and increased the efficiency of financial services. DF increases the efficacy of green investment, raises R&D investment and decreases financial constraints while improving the structure of industry. It also enhances regional productivity in agriculture and the degree of openness to the global marketplace, improves the integration of regional growth, and fosters high-quality growth (Xie and Liu, 2022). Moreover, DF contributes to a eco-friendly and stable future by making transactions smooth, increasing the transparency, and the optimal resource allocations (Schulz and Feist, 2021).

Recently, interest has been increased among the researchers to study the relationship between DF and CO_2 emissions (Wu et al., 2022). However, the mixed conclusions are provided by the studies regarding the relationship between DF and CO_2 emissions. But the majority of them assert that the advancement of DF can successfully lower CO_2 emissions (Razzaq and Yang, 2023). For example, Razzaq and Yang (2023) and found that DF promote green growth in China. According to Tian et al., (2022), the innovations in financial technologies transform the conventional financial services through producing several chain reactions about environmental sustainability. The mechanism of the impact of DF on EQ is demonstrated in the Figure 2 below.

In contrast, Zhang et al., (2024) mentioned that some heterogeneity exists regarding the role of DF on green innovations which affect CO_2 emissions significantly. Thus mixed conclusion is found in previous studies about the role of DF in CO2 emissions as some authors found the inhibitory impact of DF on CO2 emissions, whereas others conclude that DF causes carbon emissions to increase (Song et al., 2023).

In light of the above discussion, the present study aims to analyse the role of GF, NTR and DF in environmental quality (EQ) in developing countries for the period 2010 to 2020. By analysing this objective empirically using a panel data of developing countries the present study contributes significantly in the literature. To the best of the author's knowledge, none of the previous studies have empirical estimated the role of DF in EQ in the context of developing countries. Moreover, only a few previous studies have studied the role of GF and NTR in developing countries. Therefore,

Figure 2: Graphical illustration of mechanisms of digital finance impacting CO_2 emissions



Source: Wu et al. (2022)

in the current study we extend the limited literature regarding the developing countries by including the key factors such as GF, DF and NTR in EQ to fill this gap in literature. Secondly, the study quantitatively estimates the role of the afore-mentioned nexus using Driscoll and Kraay (1998) Standard Error approach which is a robust panel estimation technique as compare to conventional Fixed Effects or OLS estimation approaches by providing unbiased findings in the presence of cross sectional dependence, serial correlation and heteroskedasticity issues in panel data (Shah et al., 2021).

The remaining sections of the study include literature review given in Section 2, model specification and methodology described in section 3, empirical results and their brief discussion given in section 4 and conclusion of the study and policy recommendations given in section 5.

2. LITERATURE REVIEW

To review the existing literature regarding GF, DF, NTR and EQ, the literature is divided into three strands: the first strand discusses the literature regarding NTR and EQ nexus. The second strand covers the studies exploring GF and EQ relationship and the third strand of literature includes the studies related to DF and EQ nexus.

2.1. Natural Resources and Environmental Quality

Now a days, there is much of pollution being caused due to waste material and harmful emissions and if environmental quality is harmed it can have impact on economic growth (Arslan et al., 2022). There is a staunch connection between NTR and its impact on EQ. A number of studies have tried to investigate the impact of NTR on EQ. Some of them consider NTR as a blessing for improving EQ such as Baloch et al., (2019) tried to estimate the effect of NTR on EQ in BRICS. Applying Augmented Mean Group (AMG) estimation approach, the authors concluded that the effect of NTR on EQ was positive in some countries and negative in other BRICS countries. Likewise, the estimation findings of Balsalobre-Lorente et al., (2018) in case of EU-5 countries support the results of their study. The authors tried to investigate the impact of NTR on CO_2 emissions in selected economies. According to the findings of Panel Ordinary Least Square approach, the impact of NTR was negative on CO_2 emission.

Similarly, in case of ASEAN countries, Shah et al., (2023) studied the impact of NTR on CO_2 emissions using AMG and CCEMG approaches. The results indicated that NTR reduced CO_2 emissions in ASEAN countries. Tufail et al., (2021) studied the impact of NTR on CO_2 emissions. Applying CS-ARDL approach, NTR were found to have a negative impact on CO_2 emissions. Khan and Hassan (2024) studied the impact of NTR on CO_2 emissions in 141 developing countries. The authors applied MMQR estimation approach, NTR were found to reduce CO_2 emissions across different quantiles.

On the other hand, some of the authors consider NTR as blameworthy for degradation of the environment. Out of them, the study by Ulucak et al. (2020) concluded that NTR increased environmental degradation. The authors explored the role of NTR in CO_2 emissions, carbon footprints and ecological footprints in OECD countries and the findings of AMG estimation approach revealed that NTR had positive role in promoting CO_2 emissions whereas its impact on ecological footprints and carbon footprints was found to be insignificant. Likewise, Khan et al., (2020) studied the role of NTR on CO_2 emissions in BRI countries. Difference and System GMM approaches were applied in the study and according to the results, NTR promoted CO_2 emissions. In case of Saudi Arabia, Agboola et al., (2021) studied the relationship between NTR and CO_2 emissions. Applying Toda and Yamamoto estimation approach, NTR was found to increase CO_2 emissions.

Based on the literature, the first hypothesis of the study is formulated as:

H1: Natural Resource Rents have a significant impact on environment quality and climate change.

2.2. Green finance and Environmental Quality

According to recent studies, GF can improve EQ by reducing CO_2 emissions and financing laws pertaining to the environment. Although GF is gaining prominence now a days, only a few researchers have empirically estimated its impacts on EQ (Khan et al., 2022). For instance Bakry et al., (2023) selected the panel of 76 developing countries and analysed the impact of GF on CO_2 emissions. According to the findings of Panel VECM approach, GF was found to mitigate CO_2 emissions in the selected countries. Meo and Abd Karim (2022) analysed the effect of GF on CO_2 emissions

in top GF supporting countries. According to Quantile on Quantile regression approach, GF was observed to mitigate CO_2 emissions across different quantiles. In case of Asian countries, Khan et al. (2022) analysed the effect of GF on ecological footprints. Using Fixed Effects model, the findings revealed that GF reduced ecological footprints in Asian countries.

Similarly, taking a panel of 70 countries, Tariq and Hassan (2023) studied the role of GF on CO_2 emissions under the moderating effect of environmental regulations. The results of GMM estimation approach indicated that GF promoted EQ by reducing CO_2 emissions under the positive moderation effect of environmental regulations. Sharif et al., (2022) studied the effect of GF on CO_2 emission by taking a panel of G-7 countries. Using CS-ARDL approach GF was found to have a negative effect on CO_2 emission. Likewise, Wang and Ma (2022a) studied the effect of GF on carbon emissions by considering the data of Chinese provinces and GF was found to reduce CO_2 emissions in China. In case of ASEAN countries, Dinh et al., (2022) analysed the role of GF on CO_2 emissions and according to the CSARDL estimation, GF was found to reduce CO_2 emissions in selected countries. Likewise, Fu and Irfan (2022) also analysed the role of GF in CO_2 emission and environmental sustainability in ASEAN countries. The findings of the FMOLS estimation technique indicated that GF was positively related with environmental sustainability and negatively with CO_2 emission.

Thus we formulate the second hypothesis as follows:

H2: GF has a significant impact on environment quality and climate change.

2.3. Digital Finance and Environmental Quality

Due to continuous development in digital technology, a clear change has been observed in the financial market in way how people engage in financial transactions. DF has resulted in prominent financial and economic development (Su et al., 2021). DF helps in boosting economy in a way that all the data is moved to the internet and the country uses Internet for their financial services like payments, mobile banking, credit lines, e-commerce etc. (Jiang et al., 2021). Arjunwadkar (2018) discussed that DF has helped in cutting financial cost due to use of innovative technologies like cloud computing and helped in accessibility of financial services. Similarly, banks are also getting benefits through this technology in a way that they are cutting cost of paperwork, managing long queues digitally and helping users in mobile banking for day to day usage. Jiang et al. (2021) research study showed that DF has directly contributed towards the growth of the economy in China from the perspective of entrepreneurship.

Likewise, Zhou (2022) estimated the impact of DF on CO_2 emissions in Chinese cities using Fixed Effects Model estimation technique. The findings indicated that DF reduced CO_2 emissions in China. In case of emerging countries, Khan et al., (2023) analysed the role of DF on CO_2 emissions. Using GMM estimation approach, DF was found to promote CO_2 emissions. Tariq et al. (2022) studied the impact of DF on environmental sustainability on emerging Asian countries. According to the findings of Fixed Effects and the Random Effects model techniques, DF was found to mitigate CO_2 emissions and promote environmental sustainability. In case of China, Mo and Ke (2023) studied the role of DF in CO_2 emissions using non linear ARDL approach and found that DF mitigated CO_2 emissions in China. In a most recent study, Wang et al., (2024) explored the effect of DF inclusion on CO2 emissions in 284 Chinese cities. Using conditional heterosckedastic error approach, DF inclusion was found to reduce CO_2 emissions.

Thus, we formulate the third hypothesis of the study as:

H3: DF Adoption has a significant impact on environmental quality and climate change.

2.4. Literature Gaps

It is central to highlight that the previous studies regarding the relationship between GF, DF, NTR and EQ have provided mixed conclusions which require further estimation. Secondly, only a few studies have analysed the effect of DF on EQ previously. Thirdly, the previous studies have neglected developing countries to explore the effect of NTR, GF and DF on EQ. Therefore, in accordance with the insufficient literature and the mixed conclusions, this study aims to explore the role of the selected regressors on EQ in developing countries and therefore can be regarded as a novel addition to the literature.

3. RESEARCH METHODOLOGY

The present study aims to empirically assess the EQ in developing countries (Afghanistan, Armenia, Bangladesh, Bolivia, Chile, China, Costa Rica, Cuba, Morocco, Malaysia, Nepal, Turkey, Ecuador, Ethiopia, Egypt, Indonesia, Ghana, Kenya, Malawi, Mali, Laos, Pakistan, and Mozambique). For this purpose, the researcher has analysed the effect of NTR, GF, and DF on the environmental quality. For this purpose, the model is formulated under the STIRPAT framework proposed by (Dietz and Rosa, 1997). The STIRPAT is a theoretical framework which provides us the deep understanding of the factors of environmental quality. This framework assumes that environmental impacts arise from the interplay between three factors namely Affluence, Technology and Population. The basic STIRPAT model can be written as:

$$I=P\times A\times T \quad (1)$$

Where, in eq (1) I denotes environmental impacts and P, A and T denote population, affluence and technology respectively. The STIRPAT framework applied multiple regression analysis to analyze the relative contributions of all explanatory variables to EQ as well as to find the key factors of climate change. Through the simultaneous analysis of several variables, the STIRPAT model offers a deeper comprehension of the intricate and dynamic interactions that exist between human behaviour and EQ (Fei Wang and Taghvaee, 2023). Following this framework, our study specifies the following model.

$$CO_{2it} = \beta_0 + \beta_1 NTR_{it} + \beta_2 DF_{it} + \beta_3 GF_{it} + \beta_4 POP_{it} + \beta_5 GDP_{it} + \beta_6 GDP_{it}^2 + \mu_{it} \quad (2)$$

Where in above equation, CO_2 shows CO_2 emissions, NTR denotes natural resources, DF denotes digital finance, GF shows

green finance, POP denotes population and GDP and GDP^2 shows gross domestic product and the square of gross domestic product respectively. Hence we measure I component of STIRPAT model with CO_2 emissions, T with DF and A with GDP. Moreover, by taking the support from earlier studies, GF and NTR are added into the model to estimate their role in EQ in developing countries (Baloch et al., 2019; Balsalobre-Lorente et al., 2018; Meo and Abd Karim, 2022; Wang et al., 2021). Table 1 present the variable description, their abbreviation, source, type and details.

4. METHODS OF ANALYSIS

The researcher has implemented different statistical tests and technique to study the associations among variables. The detail of the procedure of empirical analysis is given as follows:

4.1. Cross-sectional Dependence Test

First of all, it is necessary to ascertain the presence of cross sectional dependence (CSD) in panel series to select an appropriate estimation technique to find the relationship among variables of study. Therefore, the CSD test proposed by Pesaran (2004) is used in the present study. The null hypothesis of the test states that CSD does not exist in panel data and the alternative hypothesis states that CSD exists in data. The basic test statistics is expressed as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \sim N(0,1) i, j \quad (3)$$

Where, $\hat{\rho}_{ij}$ reveals the coefficients of pairwise correlation.

4.2. Slope Heterogeneity Test

The next crucial step in empirical estimation includes testing slope homogeneity in panel data. For this purpose, the slope heterogeneity test proposed by Pesaran and Yamagata (2008) is commonly used in the literature. The slope homogeneity test proposed by Swamy's (1970) supposes the strict exogeneity of the regressors. In contrast, the test proposed by Pesaran and Yamagata (2008) is valid for analyzing the long and dynamic panels. The basic test statistic of is given as follows:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right) \quad (4)$$

$$\tilde{\Delta}_{adj} = \frac{\sqrt{N}\left[N^{-1}\tilde{S} - E(\tilde{Z}_{it})\right]}{\sqrt{Var(\tilde{Z}_{it})}} \quad (5)$$

Where, $\tilde{\varnothing}$ and $\tilde{\varnothing}_{adj}$ denote delta tilde and adjusted delta tilde respectively. The null hypothesis of the test assumes that slope parameters are homogeneous whereas the alternative hypothesis assumes that slope parameters are heterogeneous.

4.3. Unit Root Tests

The tests for unit root involve two generations. The first generation tests of unit root assume the absence of CSD among cross sectional units and therefore provide misleading results in the presence of CSD. In contrast, the second generation unit root tests are capable of dealing with the issue of CSD. Therefore, to address this issue, the second generation unit root tests namely CIPS and CADF tests are applied in the present study. The equation of CADF test is given as:

$$\Delta y_{it} = \alpha_i + \rho_i^* y_{it-1} + d_0 \bar{y}_{t-1} + \sum_{j=0}^{p} d_{j+1} \bar{\Delta}_{t-j} + \sum_{k=1}^{p} c_k \Delta y_{it-k} + \varepsilon_{it} \quad (6)$$

where, Δy_{it} represents the cross-sectional averages. The CIPS test statistics can be obtained by using this basic CADF statistics as follows:

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (7)$$

4.4. Driscoll-Kraay Standard Error Approach

As the main focus of this study is to assess the relationship between dependent and independent variables by taking control variables into consideration, therefore for the estimation of the long-run relationship among the variables of concern, Driscoll and Kraay standard error (DK-SE) approach proposed by Driscoll and Kraay (1998) is applied in the present study. The DK-SE approach is a non-parametric estimation method with great versatility and broad time dimension. It is also capable of dealing with both unbalanced and balanced panel data and effectively handles the missing values. The DK-SE approach takes the average of all independent variables with residuals and these averaged values are used to produce standard errors resilient to CSD. Moreover, the DK-SE approach deals with the problems of serial correlation, CSD and heteroskedasticity (Yang et al., 2022).

5. FINDINGS AND DISCUSSIONS

5.1. Summary Statistics

The outcomes of the summary statistics are given in Table 1. The mean or average value of all variables is found to be positive. Industrialization is observed to have the highest mean value whereas population has the lowest mean value. Similarly, the highest value of standard deviation is also observed to be for industrialization and lowest for population. Moreover, the data range i.e., maximum and minimum values of the data series is also given in Table 2.

Table 3 gives the test statistics of the CSD test. The results demonstrate that variables are cross-sectionally dependent because the test statistics are significant for all variables, except GF which reject the null hypothesis of the absence of CSD. Table 4 gives us the results of the slope heterogeneity test. According to the results, the null hypothesis of slope homogeneity is rejected and therefore all of the concerned variables are found to have heterogeneous slopes.

The presence of CSD and slope heterogeneity issues lead us to apply the second generation unit root tests as the findings of the

Table 1: Variables of the study

Variable name	Type	Measurement	Abbreviation	Source
Environmental Quality (CO_2 emissions)	Outcome Variable	CO_2 emissions (metric ton per capita)	EQ	WDI
Green finance	Predictor Variable	International financial flows to developing economies to support clean energy R&D and production of renewable energy, including in hybrid systems (constant US dollars millions)	GF	Our World in Data
Digital Finance Adoption	Predictor Variable	ATMs (per 100,000 adults)	DF	WDI
Natural Resources	Predictor variable	Total Natural Resource Rents (% of GDP)	TNR	WDI
Economic growth	Control Variables	Gross Domestic Product (Constant US$)	GDP	WDI
Population	Control variable	Total population	POP	WDI

Table 2: Descriptive or summary statistics

Variables	Mean	SD	Minimum value	Maximum value
CO_2	1.9338	2.0804	0.0634	7.7561
GDP	6.4811	2.3112	7.530	1.4613
GF	2.580	4.550	−9.770	3.3909
IND	126.00	73.172	1.000	252
NR	5.1911	4.555	0.221	18.051
DF	106.296	71.137	1.00	230
POP	1.1408	2.7808	28056	1410000

Source: Author's Estimation

Table 3: Findings of CSD test

Variables	CD-test	P-value
CO_2	15.55***	0.000
GDP	49.486***	0.000
GF	1.188	0.235
IND	4.498***	0.000
NR	27.72***	0.000
POP	40.54***	0.000
DF	2.449**	0.014

Where, *** and ** show significance at 1 and 5% respectively, Source: Author's Estimation

Table 4: Findings of slope heterogeneity test

	Test statistics	P-value
Delta	−1.487**	0.013
Adj. Delta	−3.486***	0.000

Where, *** and ** show significance at 1 and 5% respectively, Source: Author's Estimation

Table 5: Findings of unit root tests

Variables	CIPS		CADF	
	Level	First Difference	Level	First Difference
CO_2	−2.138*	---------	−4.616***	---------
GDP	−1.305	−2.217*	−0.896	−1.710**
GF	−3.260***	---------	0.932	−2.251**
IND	−1.819	−3.120 ***	−2.528***	---------
NR	−1.775	−2.567***	−2.943***	---------
POP	−0.309	−2.624***	−1.611	−1.632**
DF	−2.019	−2.613***	0.286	−3.303***

Source: Author's Estimation

first-generation tests are biased in this situation. Therefore, the CIPS and CADF tests are applied in the present study and both of the tests produce identical outcomes. According to the outcomes, the mixed order of integration is found to be present among data series.

The findings in the Table 6 determine the long run effects through DK-SE regression. According to the results, NTR has negative impact on CO_2 emissions in developing countries. According to

Table 6: Findings of DK-SE estimation

Variables	Coefficients	Driscoll-Kraay SE	t-stat	P-value
NTR	−0.040**	0.006	−6.65	0.000
DF	−0.0003***	0.0001	−2.53	0.030
GF	7.711**	2.951	2.61	0.026
GDP	9.891**	2.631	3.76	0.004
GDP^2	−3.552**	1.142	−3.13	0.011
IND	0.0007**	0.0001	4.28	0.002
POP	−8.060**	2.010	−4.01	0.002

***, ** & * represent significance at a 1, 5 and 10 percent respectively. Source: Author's Estimation

the magnitude of the coefficient, a unit increase in NTR leads to 0.040 units decrease in CO_2 emissions. Thus, in relation to H1, the claim that environmental sustainability can be facilitated by responsible stewardship and consumption of NTR is supported through a positive relationship between resource rents and EQ. When these revenues are used sensibly for sustainable practices and environmental protection, the quality of environment increases in general. Another possible justification of the positive impact of NTR on EQ lies in the fact that abundance of NTR reduces the dependence of the countries on energy imports by promoting the use of sustainable energy resources available in country (Iqbal et al., 2022). These findings establish the availability of renewable energy sources reduce the emission level resulting from fossil fuel sources. From previous studies, the findings are in line with Leng et al. (2024) who argued that NTR promotes sustainable development in resource rich developing countries. According to Balsalobre-Lorente et al. (2018), NTR improve environmental quality by reducing CO_2 emissions and therefore support the results of the present study. The findings showcase the significance of strategic resource management plans which contribute to climate resilience.

The results presented in Table 5 postulate that 1 unit increase in DF will postulate −0.00003 units decrease in CO_2 emissions. The finding supports our third hypothesis proposing that the use of digital financing enhances EQ. The finding justifies the fact that the use of DF leads to use and control resources in a better way and therefore the level of environmental performance increases. This also highlights the fact that technology advances play a crucial role in building climate resilience. From earlier studies, the finding is in line with Zhou (2022) as the author found that DF has CO_2 reducing effect in China. Likewise, the findings of Wu et al. (2022) is also consistent with our estimation results as they also found the inhibitory effect of DF on CO_2 emissions in China. In contrast and contradictory to a number of empirical

Table 7: Findings of panel causality test

Null hypothesis	Statistics	P-value
DF doesn't homogenously cause CO_2	0.255	0.774
CO_2 doesn't homogenously cause DF	2.609*	0.076
GF doesn't homogenously cause CO_2	0.177	0.837
CO_2 doesn't homogenously cause GF	5.073**	0.007
NTR doesn't homogenously cause CO_2	0.283	0.753
CO_2 doesn't homogenously cause NTR	1.418	0.244
GDP doesn't homogenously cause CO_2	0.748	0.474
CO_2 doesn't homogenously cause GDP	1.246	0.289
GDP^2 doesn't homogenously cause CO_2	0.792	0.453
CO_2 doesn't homogenously cause GDP^2	3.118**	0.046
IND doesn't homogenously cause CO_2	0.592	0.554
CO_2 doesn't homogenously cause IND	0.017	0.982
POP doesn't homogenously cause CO_2	1.300	0.274
CO_2 doesn't homogenously cause POP	6.168**	0.002

***,** and * represent significance at a 1, 5 and 10 percent respectively, Source: Author's Estimation

studies, the effect of GF is found to be statistically significant and positive on CO_2 emissions. For a unit rise in GF, CO_2 emission is found to be increased by 7.71 units in developing countries. The finding is unexpected but in line with the study of Wang and Ma (2022b) as the authors found that GF promotes CO_2 emissions in China. A possible explanation of the positive impact of GF on CO_2 emission can be the backwardness of the economic systems of the developing countries that hinders the efficient working and distribution of the green financial products which does not alleviate the greenhouse effect (Wang and Ma, 2022b).

The output of the DK-SE reveals that GDP has a positive effect on the emission of CO_2. For a unit increase in GDP, CO_2 emissions decrease by 9.89 units in the long run. This implies that environmental quality deteriorates with the increase in affluence or GDP. Higher level of growth or affluence accelerate the production and consumption of the goods which result in increasing CO_2 emissions, waste generation, and overuse of NTR that degrade the environmental quality.

However, the square of GDP is found to cause improvement in EQ as the sign of the coefficient is negative. Also the magnitude of the coefficient shows that a unit rise in square of GDP results in 3.55 units decline in CO_2 emissions. The facts that GDP increases and GDP^2 decreases the CO_2 emissions is consistent with the theoretical underpinnings of the EKC hypothesis which hypothesizes that during early stages of economic development, level of environmental degradation increases, however, after passing a certain threshold level, the rise in economic growth improves the environmental quality (Lv et al., 2024). The positive effect of GDP and the negative effect of GDP^2 on CO_2 emissions is consistent with Hanif et al., (2022), Nawaz et al. (2021) and (Adedoyin et al., 2020).

Next, in accordance with the results of Van et al. (2018), Aslam et al. (2021) and Asumadu-Sarkodie and Owusu (2017) the long run results of DK-SE approach reveal that IND deteriorates the EQ as its effect on CO2 emission is found to be statistically significant and positive. A one unit rise in IND leads to 0.0007 unit increase in CO_2 emissions. Last, the finding shows that POP in developing countries improves the quality of environment by reducing the CO_2 emissions. A one unit increase in POP reduces CO_2 emissions by 8.060 units in the long run. The finding is in line with Mehmood et al., (2021) who argued that population in certain age bracket improves the environmental quality by reducing CO_2 emissions.

In the last step to finalize the empirical estimation, we have applied Panel Granger Causality Test to assess the direction of causality among the variables of the study. The findings of the test are given in Table 7. It can be seen from the outcomes that unidirectional causality from CO_2 emissions to DF, GF, POP and GDP^2, whereas no causality is found to exist between NTR and CO_2emissions.

6. CONCLUSION AND RECOMMENDATIONS

The study has been conducted to empirically estimate the effect of NTR, DF and GF on EQ. For this purpose, a comprehensive dataset comprising of 23 developing countries over 2010 to 2020 period is analysed using DK-SE approach. Specifying the model on the basis of STIRPAT framework, economic growth, population and industrialization are also added in the model. According to the findings, DF and NTR are helpful in promoting EQ, whereas GF is found to be detrimental for EQ. In terms of control variables, economic growth and industrialization are found to reduce whereas population and the square of the economic growth are found to enhance the EQ in the studied countries. The findings of this study have provided helpful information about the complex relationships between various elements that impact EQ in developing countries. The accepted hypotheses provide better insights into positive impacts in terms of EQ from NTR and DF while rejected GF hypothesis needs further research.

To conclude, the current study gave a profound understanding about conjunction between the selected regressors and EQ. It confirmed the hypothesis that NTR had a positive impact on EQ. It was also evident that the sustainable use of resource rents contributed toward helping a nation to preserve nature. Denying the idea that GF had a powerful effect on environmental quality was astonishing. This increased interest in how effective GF is and ways they could be used to achieve the desired ecological results. The findings underscored the need for a deeper understanding of how financial instruments impact environmental outcomes. The results of the study supported H3, which demonstrated that the developing countries improved their environmental quality after DF take up. Research has shown, however; that embedding DF into conservation strategies was an effective means of reconciling ecological sustainability with economic growth.

The theoretical contributions arising from the study present a powerful tool towards understanding the complex dynamics between different economic activities as well as EQ particularly on climate resilience of developing countries. Through underlining the potential sustainability of resource management that encourages ecological conservation, the confirmed effect of NTR strengthens environmental economics idea. This highlights why such environmental factors should be considered in resource extraction policies and processes. Moreover, the idea challenging financial

instruments' capacity for achieving goals related to sustainability is reinforced by rejecting the hypothesis about substantial impact of GF on EQ. This puts into doubt the premises that underlie current conceptions and suggests the development of a more nuanced approach to interpret links between ecological effects and financial flows. Furthermore, the study contributes to DF's area of development through verification process by confirming that it improves EQ. This enlarges theoretical perspectives on the ability of digitalization to facilitate sustainable development by emphasizing financial technology's potential for balancing environmental management and economic growth.

The study's practical implications offer valuable guidance to policymakers, corporate managers and environmental parties on coping with EQ challenges in developing countries. The embrace of sustainable resource management practices is highly important when dealing with the pros and cons brought about by natural assets rents. With this understanding, policymakers can formulate and enforce laws that promote the morally sustainable use of NTR balancing economic enhancement with conservation. The rejection of the GF hypothesis highlights that such financial tools need to be reassessed on their effectiveness in fulfilling environmental objectives. Practitioners in the environmental and finance fields should collaborate to enhance the implementation of GF so that they more closely align with desired ecological outcomes. This means increased accountability, transparency and effective channelling of funds to initiatives that have measurable environmental benefits.

Moreover, the fact that the adoption of DF's positive effect has a pragmatic implication that implies that improving environmental quality can be attained by integrating digital technology into financial institutions. Policymakers and financial institutions can conduct investigations on the DF products that foster sustainable activities including eco-friendly transactional activity as well as green investment so that these solutions are put in place.

5.1. Limitations of the Study and Directions for Future Studies

Some limitations should be considered when assessing the outcomes of this study:

- The main focus of the study on selected countries has restricted the generalization to other regions with different types of socioeconomic contexts and environmental issues. The future studies must broaden the scope of the study by adding additional countries to provide a comprehensive picture of the relationship between dependent and independent variables.
- The time coverage of this study was narrow and therefore it failed to conduct an in-depth analysis on how economic variables shape environmental behaviours. Broadening the time span will made it possible to provide a detailed description impossible.
- There might be a difference in the effect of these regressors on EQ across different regions of the developing countries which is not documented in the present study. Therefore, a deeper analysis on regional level can identify geographical differences in the impact of these factors by future studies would be very useful for crafting specific policy recommendations.
- Moreover, a broader perspective should be offered by exploring the other social and cultural aspects such as human capital, religion, inequality, that influence environmental behaviours. A more dynamic understanding of their sustained impact would be achieved through longitudinal studies tracing the development of policy landscapes and technology milestones.

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