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Original Research

Financial Development and Environmental Quality: Differences in Renewable Energy Use and Economic Growth

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Abstract

This paper uses feasible generalized least squares (FGLS) to empirically investigate the effect of financial development on environmental quality via carbon dioxide (CO_2) emissions for 148 countries from 1990 to 2019. The advantage of FGLS is overcoming the heteroskedasticity and serial and cross-sectional correlations and giving more efficient results than the Ordinary least squares estimate. Research innovations include the development of general regression models that establish the links among financial liberalization, renewable energy use, and economic development, which has been largely neglected in previous research. Initial findings indicate that the total effect of financial development on CO_2 emissions depends on economic growth and consumption of renewable energy. Notably, while the use of renewable energy may reduce the emissions-increasing effect of economic growth, economic growth may exacerbate the problem of environmental degradation caused by economic growth. The magnitude of the effect varies by income group. The role of renewable energy consumption holds true in countries with high and middle incomes but not in countries with low incomes. Regarding the effect of economic growth, research finds that economic growth may worsen (improve) the impact of financial development on environmental quality among high- and middle-income groups (low-income groups). The findings are robust across financial development dimensions (including the financial institution and the financial market). Thus, the implications are that governments in high- and middle-income countries should promote green credit policies and focus on technology related to environmentally friendly technological innovations to improve environmental quality.

Keywords: financial development, carbon dioxide (CO_2) emissions, renewable energy, economic growth

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Introduction

Due to its impact on the global environment and economic activities, carbon dioxide (CO_2) emissions and methods for reducing them have remained a topic of discussion in the relevant literature [1, 2]. Global warming has been recognized as the result of greenhouse gas emissions, primarily CO_2, over the past several decades; it also causes changes in the global climate [3-5, 6]. Thus, CO_2 emission has become one of the most significant global issues that can negatively impact human health [7-9] and the long-term economic performance of nations [10, 11]. Previous research has suggested that economic growth is associated with environmental deterioration because an increase in production results in a rise in energy consumption and carbon emissions [12]. Governments can reduce their environmental impact through various actions and commitments, laying the groundwork for technology-driven businesses to innovate with clean and environmentally friendly manufacturing processes [13]. As a result, it influences how policymakers respond to environmental concerns and how institutional platforms, such as the financial sector, provide resources to support environmental improvement and cleaner production.

In 1997, the United Nations brought this matter to get the agreements of the Kyoto protocol, which went into effect in 2005. However, the Kyoto Protocol implementation process is unfavorable. The United States and other world powers, including China, Japan, New Zealand, and Russia, have refused to implement the second phase of the Kyoto Protocol (from 2013 to 2020), and Canada announced its withdrawal from the Kyoto Protocol in 2011. Moreover, conflicts between rich countries and developed countries over emissions reduction targets are increasing. According to Friedlingstein et al. (2022) [14], global CO_2 emissions in 2021 (excluding cement carbonate) returned to 2019 levels after decreasing by 5.4% in 2020. China's emissions are expected to increase by 5.5% in 2020 compared to 2019, accounting for 31% of total global emissions, while India accounts for approximately 7%, the United States and the European Union (E.U.) account for 14% and 7% of total global emissions, respectively, with decreases of 3.7% and 4.2%. Despite the efforts of developed nations to reduce emissions, the focus of developing nations on low-cost fossil fuels exacerbates emissions problems on the path to sustainable global economic growth [12].

In the literature review, the relationship between energy consumption and CO_2 emissions has received considerable attention in economic development research due to the connection between economic growth and environmental degradation and the tendency to use renewable energy effectively [5, 15]. Previous research has examined carbon emissions under varying socioeconomic conditions across nations (e.g., energy consumption, economic growth, population, and industrial structure); however, the results are still contested [16-23]. Although there are numerous studies on the effect of financial development on CO_2 emissions, few of them explain how enhancing the financial system can influence environmental quality. For instance, some studies suggest that previous literature frequently considers direct effects and does not delve into indirect effects; however, indirect effects can occur through multiple channels, including renewable energy and economic development levels [24, 13]. The literature on energy economics frequently focuses on the relationship between economic expansion and energy consumption and omits the role of financial development [25]. In addition, evidence of this association is frequently tied to a specific country (or country group) contexts, such as China [10], Organization for Economic Cooperation and Development - OECD [26], and other emerging countries [27]. Therefore, the connection between financial development and CO_2 emissions requires further investigation, particularly in a global context.

In an attempt to contribute to this field of study, this paper examines the relationship between financial development and CO_2 emissions in relation to the use of renewable energy and economic development levels. Based on the argument that the financial development of a country plays a significant role in efficiently allocating capital and minimizing information asymmetry, thus shifting capital flows into areas required to improve environmental quality through research and development (R&D) and the construction of new environmentally friendly facilities [21, 18]. This paper differs from previous research in that it develops a general regression model that establishes a link between financial liberalization, renewable energy use, and economic development, a topic that has been largely neglected in previous research. On the one hand, the expansion of the financial sector provides additional funding to the energy sector for the development of new technologies that reduce CO_2 emissions. On the other hand, financial development can stimulate productive activities, leading to an increase in pollution caused by financial development with inadequate institutional frameworks [28]. By connecting these factors, the study can provide a clearer picture of how financial development can facilitate CO_2 emission reductions. According to our knowledge, none of the previous studies have comprehensively examined financial development, renewable energy, economic growth, and CO_2 emissions. Second, previous research rarely emphasized a global perspective [18]. Most examine the relationship between CO2 emissions and economic development using time series of individual (or group) countries. Consequently, a global sample will permit us to see the big picture and obtain more generalized results.

The remainder of this study is organized as follows: In Section 2, the study provides an empirical literature review. In Section 3, the study presents the econometric model and data set used. Section 4 details experimental results and findings. Finally, Section 5 provides the implications and conclusions.

Literature Review

Both theoretical and empirical studies recognize the importance of financial development for environmental quality, and this relationship is still being debated among scholars. On the one hand, financial development may promote economic growth but reduce the environmental quality, leading to environmental degradation [29]. First, financial development decreases environmental quality through economic growth. Following this view, economic growth boosts energy use and increases CO_2 [30]. In addition, an increase in financial development reflects higher financing of new investments and a higher expanding existing corporate business [18]. As a result, when energy consumption is boosted, the greenhouse effect also increases, implying that the environment quality declines. Second, financial development affects environmental quality by providing better financial services and greater access to cheap resources. This leads to more products related to cheap techniques which requires a higher energy demand. Hence, the high level of CO_2 emissions is an indirect side-effect of financial development.

Indeed, previous studies showed that the development of financial markets increased the demand for energy caused by the expansion of consumption and production. Haseeb et al. (2018) [31] analyzed the effect of financial development on CO_2 emissions in the EKC model for BRICS countries from 1995 to 2014. They found an emissions-increasing effect is a result of financial development. The development of the financial sector might support listed firms with an increment of financial channels, minimizing risk, and decreasing financial cost, thus boosting investment in new projects, followed by boosted energy usage and CO_2 emissions. These findings were similar to Nigeria, where financial development boosted CO_2 emissions from 1971 to 2010 [32]. Recently, Dhrifi et al. (2020) [33] showed that financial development attracted foreign direct investments and promoted a rapid transition to energy-intensive growth, using a three-stage least square for 98 developing countries from 1995 to 2017. This implied that financial development degraded the environment by increasing the use of fossil energy to promote economic expansion. Le and Ozturk (2020) [34] analyzed the effect of financial development on CO_2 emissions for 47 emerging markets and developing economies from 1990 to 2014. They demonstrated that financial development stimulated CO_2 emissions. This result suggested that while the development of financial sectors could provide households and corporations with access to funds for new projects and investments, capital might not be allocated to environmentally friendly projects. Ling et al. (2022) [23] used a nonlinear autoregressive distributed lag (NARDL) to explore the asymmetric impact of financial development on carbon emissions in China from 1980 to 2017. Their findings provided the asymmetric relationship between financial development and carbon emissions in China, followed by the positive shock of financial development had a statistically significant impact, while the negative shock insignificantly affected carbon emissions. This finding exhibited that the level of CO_2 emissions was increased due to higher financial development in China. They argued that financial development might boost the wealth and capital of households and corporates. In turn, this increase raised the need for energy consumer products, and the level of CO_2 emissions increased as a result.

On the other hand, if corporates had access to cheap finance and used capital to invest in environmentally friendly technological innovations (referred to as the technical effect), energy efficiency would rise, which would lead to a reduction in the greenhouse effect [28, 35]. This argument focused on how financial development enhanced renewable energy consumption [36]. Tamazian et al. (2009) [28] found that the financial sector played a crucial role in determining the environmental quality of BRIC economies from 1992 to 2004. In particular, the development of the capital market and banking sector assisted nations in reducing their CO_2 emissions. They explained that a negative relationship resulted from increasing firms' access to long-term financing for technology development and implementing policies that created long-term value for greenhouse effect reductions and consistently supported the development of new technologies that lead to a less carbon-intensive economy. Jalil and Feridun (2011) [37] examined the impact of China's economic growth on environmental pollution from 1953 to 2006. Using the ARDL model, they demonstrated the CO_2 emissions-decreasing effect of financial development, indicating that financial development aided in the provision of capital for the construction of new facilities that reduced environmental pollution, such as waste disposal in the long-term. Also, Salahuddin et al. (2015) [38] examined the long-term relationship between financial development and CO_2 emissions in high-income countries from 1980 to 2012, such as Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Bahrain, and Oman. They discovered a negative correlation between economic growth and CO_2 emissions. A simultaneous-equation panel data V.A.R. model was applied to a panel of 17 MENA countries to examine the relationship between financial development, FDI, and CO_2 emissions, Abdouli and Hammami (2017) [39] found that a rise in financial development increased the stocks of foreign direct investment (FDI) and that an increase in FDI stocks resulted in a decline in CO_2 emissions. This finding suggested that policymakers were concerned with the environmental quality of FDI in order to avoid the "pollution haven" problem by promoting the transfer of clean technologies. Charfeddine and Kahia (2019) [21] employed the panel

VAR model developed by Love and Zicchino (2006) [40] to analyze the impact of financial development on CO_2 emissions in countries of the MENA region from 1980 to 2015. Their results indicated that although the impact was relatively weak, financial development still negatively affected CO_2 emissions. This relation showed that the financial system could be used to encourage households and firms to invest in energy-proficient technologies by providing lower interest rates and carbon-related requirements.

Emphasizing the use of clean energy, some other studies suggest that financial development without binding conditions on the use of clean energy and new technologies is the cause of the increase in CO_2 emissions. Ehigiamusoe and Lean (2019) [41] found that financial development only emitted CO_2 emissions in the low-income group, whereas the opposite effect was in the high-income group. They suggested that this difference might be attributed to the level of financial development and applied technologies. Similarly, Jiang and Ma (2019) [18] examined the relationship between financial development and CO_2 emissions in 155 countries from 1990 to 2014 and concluded that financial development influenced CO_2 emissions positively. These findings held true for emerging markets and developing countries, but this effect was negligible in developed nations. They explained this difference by noting that developed nations typically had more advanced industrial systems and stricter environmental regulations than emerging nations. Consequently, businesses were inclined to invest in technological innovation and received government support when developing green finance. Khan et al. (2019) [24] emphasized that financial development improved environmental quality in Asia, Europe, and America regions when higher financial development was related to higher renewable energy consumption and more environment-friendly technologies. Remarkably, they argued that financial development facilitated the credit for investment or projects related to environmentally friendly energy technologies. Shoaib et al. (2020) [20] provided empirical evidence that financial development contributed to CO_2 emissions in developing and developed countries from 1999 to 2013. Their findings were consistent with the argument that the development of the financial sector could increase access to external funds, which led to increased investment in production and a subsequent increase in CO_2 emissions. However, they found that the adoption of plans to reduce CO_2 emissions differed between developed and developing nations. They indicated that developed nations had already adopted or were in the process of adopting carbon emission reduction strategies while developing nations might not.

Overall, previous studies have provided conflicting evidence on the relationship between financial development and CO_2 emissions. Notably, intermediate factors such as renewable energy and economic development level appear to play a significant role in explaining this difference but are sadly ignored by most studies. In addition, a global sample was not considered in order to identify generalized relationships. Therefore, this study will supplement the preceding work as added contributions.

Research Data

Based on all countries worldwide from 1990 to 2019, this study eliminates countries with missing or discontinuous data and obtain unbalanced panel data, including 4086 observations from 148 countries. This study categorizes these data into three income groups, including 43 high-income countries, 87 middle-income countries, and 18 low-income countries. The World Bank's World Development Indicators (W.D.I.), International Monetary Fund (I.M.F.), and Energy Information Administration (E.I.A.) are the data sources. Remarkably, this study utilizes the FD index collected from I.M.F. According to I.M.F., the FD index captures the access, depth, and efficiency of financial institutions and financial markets. Financial institutions include banking and insurance sectors, whereas financial markets relate to equity, bond markets, and other nonbanking financial institutions. Therefore, the FD index is broader and captures wide-ranging aspects of financial sectors. The data on CO_2 emissions and other variables in our research models come from W.D.I., whereas the data on renewable energy consumption is collected from E.I.A.

Measuring CO_2 Emission

This research used a database of FD from the International Monetary Fund (IMF) developed by Svirydzenka (2016) [42]. The database of FD has nine indexes. Following Svirydzenka (2016) [42], the FD index is constructed using a standard three-step approach. Notably, the first step is the normalization of variables. The next step is the aggregation of normalized variables into the sub-indices illustrating a particular functional dimension. The final step is the aggregation of the sub-indices into the final index. Therefore, six lower-level sub-indices include a list of indicators to measure the depth, access, and efficiency of financial institutions and markets. These sub-indices are aggregated into higher-level sub-indices measuring the development of financial institutions (FII) and financial markets (FMI). Finally, FII. and FMI are aggregated into the financial development index.

Empirical Model Construction

According to the most recent empirical studies (e.g., [22, 23], financial development is a principal contributor to CO_2 emissions. The literature highlighted that the total effect of financial development on environmental quality depends on economic growth and renewable energy consumption [41, 36]. Consequently, following Aluko and Obalade (2020) [43], the study added the interaction variable between FD and economic growth (renewable energy consumption) into our model. Besides, population, urbanization, and economic growth are also found to contribute to determining CO_2 emissions. Therefore, the present study uses population, urbanization, and economic growth as explanatory variables. The relationship between the variables is described by using the empirical equation expressed below:

$$CO_{2it} = f(FD_{it}; RENEW_{it}; POP_{it}; URBAN\_POP_{it}; GDPGR_{it}) \quad (1)$$

Where CO_2 shows the CO_2 emissions (logarithm CO_2, kt); *FD* reflects the financial development index (including sub-indices); *RENEW* shows the renewable energy consumption over the total energy consumption; *POP* denotes logarithm population; *URBAN_POP* shows urbanization (Urban population/Total population); *GDPGR* represents economic growth (Growth of G.D.P. this year/G.D.P. at the beginning of the year). The error term is incorporated in our model [32]; hence Eq. (1) becomes

$$CO_{2it} = \alpha_0 + \alpha_1 * FD_{it} + \alpha_2 * FD_{it} * RENEW_{it} + \alpha_3 * RENEW_{it} + \alpha_4 * POP_{it} + \alpha_5 * URBAN\_POP_{it} + \alpha_6 * GDPGR_{it} + \varepsilon_{it} \quad (2)$$

$$CO_{2it} = \beta_0 + \beta_1 * FD_{it} + \beta_2 * FD_{it} * GDPGR_{it} + \beta_3 * RENEW_{it} + \beta_4 * POP_{it} + \beta_5 * URBAN\_POP_{it} + \beta_6 * GDPGR_{it} + \varepsilon_{it} \quad (3)$$

From Eq. (2) and Eq. (3), they measure the total effect of financial development on CO_2 by computing the partial derivatives of environment quality with respect to financial development:

$$\frac{\partial CO_{2it}}{\partial FD_{it}} = \alpha_1 + \alpha_3 * RENEW_{it} \quad (4)$$

and

$$\frac{\partial CO_{2it}}{\partial FD_{it}} = \beta_1 + \beta_3 * GDPGR_{it} \quad (5)$$

The total effect of financial development on environmental quality proxied by CO_2 emissions depends on renewable energy consumption and economic growth. Particularly, if the coefficients of renewable energy consumption and economic growth in Eq. (4) and Eq. (5) (α_3 and β_3) are positive (negative), renewable energy consumption and economic growth increase (decrease) the problem of environmental degradation of financial development through emitting CO_2 emissions when the financial system develops, respectively.

Research Method

The feasible generalized least square (FGLS) is applied to regress Eq. (2) and (3) to explore the effect of financial development on environmental quality through renewable energy consumption and economic growth. The advantage of FGLS over the O.L.S. method is overcoming the heteroskedasticity and serial and cross-sectional correlations [44]; as a result, the FGLS estimates give more efficient results than OLS estimates. The model has the following general form:

$$Y_{it} = \alpha X_{it} + \varepsilon_{it}$$

Where, Y_{it} is the environmental quality, X_{it} is vector of independent variables which affect environmental quality and ε_{it} is error term. Normally, the OLS method is applied to regress above equation; however, this method requires that assumptions of BLUE (Best Linear Unbiased Estimator) are satisfied, such as: $E[\varepsilon_{it}] = 0$, $Var[\varepsilon_{it}] = \sigma^2$, and $Cov[\varepsilon_{it}; \varepsilon_{js}] = 0$. Among these assumptions, panel data may suffer from problems of autocorrelation and heteroskedasticity. To overcome these problems, Greene (2012) suggested using the FGLS method. If there are autocorrelation and heteroskedasticity, the variance-covariance matrix may have the form: $Var\ Cov(\varepsilon_{it}) = \Sigma$. Where, Σ is a symmetric matrix with all positive eigenvalues. Thus, there exists a non-singular value matrix P such that: $\Sigma^{-1} = P^{1} * P$. In this scenario, the original regression has the form:

$$Y_{it} = \alpha X_{it} + \varepsilon_{it} \leftrightarrow PY_{it} = P\alpha X_{it} + P\varepsilon_{it} \leftrightarrow Y^*_{it} = \alpha X^*_{it} + \varepsilon^*_{it},$$

$$\text{where, } Y^*_{it} = PY_{it}; X^*_{it} = PX_{it}\varepsilon^*_{it} = P\varepsilon_{it}$$

The final model may satisfy BLUE's assumptions, including no autocorrelation and no heteroskedasticity. Consequently, using the OLS method to estimate this model, the study may obtain reliable, efficient, and unbiased estimates with the regression coefficient matrix calculated as follows:

$$\hat{\beta}_{FGLS} = \left(X'_{it}\Sigma^{-1}X_{it}\right)^{-1}\left(X'_{it}\Sigma^{-1}Y_{it}\right)$$

The FGLS method solves the autocorrelation and heteroskedasticity problems. The main difference between OLS and FGLS is heteroskedasticity and autocorrelation. Thus, this study applies Bruesch-Pagan/ Cook-Weisberg and Wooldridge tests to choose the appropriate method. The null hypothesis of the two tests is as H_0: no heteroskedasticity (no autocorrelation). In the case of rejecting H_0, the FGLS method is more appropriate than the OLS method and otherwise.

Results and Discussion

Table 1 shows the descriptive statistics (mean, standard deviation, minimum and maximum) of variables in our models. The mean value for the CO_2 emissions is 9.5372. The lowest value of CO_2 emissions is 2.3026 (Mali), and the highest is 16.2134 (China). For dimensions of financial development, the mean value of FI (0.3766) is higher than the mean value of FM (0.2047), indicating that financial institutions develop more than financial markets in our sample. As regards renewable energy consumption, Kuwait uses the least amount of renewable energy with a value of RENEW of 0.0000, whereas Bhutan achieved the highest ratio of renewable energy consumption of 90.6568.

According to Table 2, FD has a significant positive relationship with CO_2 at a 1% level, indicating that increased FD leads to higher CO_2 emissions. However,

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	4086	9.5372	2.3937	2.3026	16.2134
FD	4086	0.2952	0.2274	0.0000	1.0000
FI	4086	0.3766	0.2209	0.0000	1.0000
FM	4086	0.2047	0.2551	0.0000	1.0000
RENEW	4086	20.3086	19.4120	0.0000	90.6568
POP	4086	16.0051	1.8215	11.1512	21.0597
URBAN_POP	4086	53.8637	22.5721	5.4160	100.00
GDPGR	4086	3.5936	4.9202	-50.2481	88.9577

Source: I.M.F. and W.B.

Table 2. The effect of financial development on CO_2 through renewable energy consumption and economic growth.

Independent variable: CO_2	FD	FI	FM
The effect of financial development on CO2 through renewable energy consumption			
Financial Development Index	0.6028*** (11.17)	0.5806*** (10.42)	0.2569*** (7.13)
Financial Development Index *RENEW	-0.0059*** (-3.56)	-0.0043*** (-2.63)	-0.0047*** (-3.79)
RENEW	-0.0119*** (-16.69)	-0.0119*** (-14.41)	-0.0127*** (-22.54)
POP	0.9400*** (99.30)	0.9497*** (97.83)	0.9448*** (95.53)
URBAN_POP	0.0470*** (62.50)	0.0464*** (59.24)	0.0489*** (66.69)
GDPGR	0.0021*** (6.34)	0.0021*** (6.55)	0.0021*** (6.78)
Constant	-7.8567*** (-47.75)	-8.0058*** (-47.57)	-7.8971*** (-45.70)
Wald test	127.25***	110.89***	51.38***
N	4086	4086	4086
The effect of financial development on CO_2 through economic growth			
Financial Development Index	0.4745*** (11.07)	0.5215*** (11.89)	0.1368*** (5.08)
Financial Development Index *GDPGR	0.0054*** (3.38)	0.0057*** (3.55)	0.0049*** (3.89)
RENEW	-0.0136*** (-26.94)	-0.0135*** (-27.09)	-0.0136*** (-27.15)

Table 2. Continued.

POP	0.9422*** (100.25)	0.9523*** (101.17)	0.9466*** (93.95)
URBAN_POP	0.0468*** (62.29)	0.0463*** (60.27)	0.0486*** (64.66)
GDPGR	0.0005 (0.96)	0.0001 (0.13)	0.0011*** (2.60)
Constant	-7.8446*** (-48.01)	-8.0217*** (-49.25)	-7.8801*** (-44.80)
Wald test	177.78***	189.82***	36.22***
N	4086	4086	4086

T-value in the brackets, Wald test shows the Chi-squared statistics, and * p<10%, **p<5%, ***p<1%.

Table 3. Robustness test.

CO_2	FID	FIA	FIE	FMD	FMA	FME
Renewable energy consumption, financial development and CO_2 emissions						
Financial Development Index	0.4594*** (8.34)	0.5303*** (11.16)	0.0180 (0.66)	0.1634*** (4.99)	0.1083*** (3.66)	0.1048*** (5.58)
Financial Development Index *RENEW	-0.0062*** (-3.99)	-0.0035** (-2.54)	0.0008 (0.98)	-0.0039*** (-3.29)	-0.0022** (-2.11)	-0.0019*** (-2.75)
RENEW	-0.0119*** (-18.51)	-0.0122*** (-18.03)	-0.0141*** (-20.34)	-0.0128*** (-23.08)	-0.0131*** (-24.06)	-0.0133*** (-25.81)
POP	0.9413*** (79.39)	0.9440*** (87.27)	0.9599*** (106.45)	0.9472*** (89.63)	0.9463*** (85.42)	0.9533*** (107.68)
URBAN_POP	0.0460*** (49.63)	0.0448*** (52.05)	0.0504*** (77.70)	0.0485*** (61.99)	0.0483*** (58.53)	0.0505*** (80.03)
GDPGR	0.0023*** (8.17)	0.0023*** (7.91)	0.0020*** (6.04)	0.0022*** (7.20)	0.0022*** (7.52)	0.0020*** (6.02)
Constant	-7.7136*** (-37.85)	-7.7612*** (-41.67)	-8.1901*** (-51.51)	-7.8802*** (-42.71)	-7.8313*** (-40.87)	-8.1056*** (-52.11)
Wald test	70.22***	127.01***	0.49	24.86***	13.05***	31.65***
N	4086	4086	4086	4086	4086	4086
Economic growth, financial development and CO2 emissions						
Financial Development Index	0.3234*** (7.70)	0.5511*** (13.71)	0.0289 (1.47)	0.0866*** (3.40)	0.0581*** (2.68)	0.0568*** (4.19)
Financial Development Index *GDPGR	0.0031** (2.42)	0.0040*** (3.35)	0.0041** (2.17)	0.0047*** (3.59)	0.0030** (2.52)	0.0035*** (3.89)
RENEW	-0.0134*** (-26.84)	-0.0133*** (-26.70)	-0.0136*** (-27.36)	-0.0135*** (-26.98)	-0.0135*** (-26.97)	-0.0137*** (-27.66)
POP	0.9446*** (80.02)	0.9500*** (95.25)	0.9598*** (106.08)	0.9506*** (93.32)	0.9481*** (86.53)	0.9554*** (110.44)
URBAN_POP	0.0458*** (49.62)	0.0447*** (55.17)	0.0504*** (77.26)	0.0487*** (64.00)	0.0483*** (59.09)	0.0506*** (81.43)
GDPGR	0.0017*** (4.21)	0.0012*** (2.66)	-0.0003 (-0.24)	0.0013*** (3.16)	0.0016*** (4.22)	0.0012*** (2.76)
Constant	-7.7286*** (-38.11)	-7.8748*** (-45.84)	-8.1924*** (-51.54)	-7.9365*** (-44.65)	-7.8530*** (-41.41)	-8.1379*** (-53.45)
Wald test	60.66***	191.27***	2.86*	13.06***	8.11***	20.41***
N	4086	4086	4086	4086	4086	4086

T-value in the brackets, Wald test shows the Chi-squared statistics, and * p<10%, **p<5%, ***p<1%.

the coefficients of the interaction variable between FD and RENEW are negative and statistically significant at a 1% level. This finding shows that renewable energy consumption may reduce CO_2 emissions – increasing financial development. As the demand for renewable energy increases, firms and households may tend to use external funds to invest in renewable energy projects, while financial development creates more opportunities for them to access cheap finance. Moreover, a country with a well-developed financial system may tend to broaden the scope of green credit for environmentally friendly projects at low costs-consequently, the number of energy-efficient technologies increases, leading to a reduction in CO_2 emissions.

In Table 2, renewable energy consumption (RENEW) is negatively correlated with CO_2 emissions at a 1% level. This result is in line with reality, that is, total energy consumption as a sum of the consumption of non-renewable and renewable energy sources; thus, an increase in the latter source will reduce the share of the non-renewable source. In other words, a higher ratio of renewable energy usage reflects a shift from non-renewable to renewable energy consumption. This study finds that the population (POP) also has a statistically significant and positive impact on CO_2 emissions, and this result indicates that the population accentuates CO_2 emissions because an increase in population may lead to an increase in energy usage related to cars/vehicles or public transport [43]. This impact is supported by the previous findings of Aluko and Obalade (2020) [43] and Khan and Ozturk (2021) [22]. Concerning urbanization (URBAN_POP), its elasticity is positive and statistically significant. Higher urbanization may decrease the forest area and be related to a decrease in CO_2 sequestration, in line with the evidence found by Al-mulali et al. (2015) [45] and Jiang and Ma (2019) [18]. While financial development, population, urbanization, and economic growth worsen the environmental quality, renewable energy usage decrease CO_2 emissions. Besides, the coefficients of the interaction variable between FD and GDPGR are positive and statistically significant at a 1% level in all models. These sign coefficients imply that economic growth may boost CO_2 emissions – increasing financial development. That is, higher financial development may provide better financial services, influencing accessible loan opportunities and thus increasing production and consumption [46]. This increase leads to higher energy usage demand and emits more CO_2 emissions.

Then, this study uses dimensions of financial development (financial institution depth, financial institution access, financial institution efficiency, financial market depth, financial market access, and financial efficiency), presented in Table 3. Dimensions of financial development significantly positively affect CO_2 emissions at a 10% level, excluding financial institution efficiency (FIE). The coefficients of interaction variables between dimensions of financial development and renewable energy consumption are significantly

Table 4. Heterogeneity test.

CO_2	High-income countries			Middle-income countries			Low-income countries		
	FD	FI	FM	FD	FI	FM	FD	FI	FM
	Effect of renewable energy consumption								
Financial Development Index	0.1834*** (3.27)	0.1430** (2.02)	0.1006*** (2.78)	0.8065*** (8.64)	0.5737*** (6.62)	0.4138*** (6.46)	0.3625 (0.50)	0.1393 (0.36)	2.5390 (1.15)
Financial Development Index *RENEW	-0.0052*** (-2.87)	-0.0027 (-1.20)	-0.0034*** (-2.83)	-0.0187*** (-4.41)	-0.0060* (-1.85)	-0.0180*** (-5.14)	0.0131 (0.71)	0.0082 (0.81)	-0.0042 (-0.07)
RENEW	-0.0109*** (-9.10)	-0.0124*** (-8.02)	-0.0118*** (-13.85)	-0.0112*** (-10.82)	-0.0128*** (-11.40)	-0.0132*** (-17.93)	-0.0075*** (-3.52)	-0.0076*** (-3.55)	-0.0068*** (-4.54)
POP	0.9843*** (69.18)	0.9798*** (60.22)	0.9891*** (78.75)	0.9942*** (104.68)	1.0080*** (107.48)	0.9987*** (96.84)	1.1226*** (24.71)	1.1278*** (26.29)	1.0945*** (19.48)
URBAN_POP	0.0089*** (6.01)	0.0086*** (5.16)	0.0094*** (7.07)	0.0305*** (34.44)	0.0302*** (33.41)	0.0314*** (33.75)	0.0437*** (14.80)	0.0442*** (15.88)	0.0426*** (11.54)
GDPGR	0.0030*** (6.45)	0.0031*** (6.90)	0.0030*** (6.21)	0.0023*** (5.18)	0.0021*** (4.95)	0.0023*** (5.51)	0.0016** (2.07)	0.0016** (2.06)	0.0015** (2.21)

Table 4. Continued.

Constant	-5.1252***	-5.0065***	-5.1932***	-7.9901***	-8.1906***	-7.9849***	-12.1336***	-12.2282***	-11.6051***
	(-21.21)	(-18.20)	(-24.15)	(-48.98)	(-50.03)	(-45.46)	(-16.06)	(-17.17)	(-12.47)
Wald test	10.57***	4.1**	7.59***	75.38***	44.98***	41.11***	0.28	0.15	1.36
N	1126	1126	1126	2465	2465	2465	495	495	495
Effect of economic growth									
Financial Development Index	0.0571 (1.42)	0.0674 (1.40)	0.0123 (0.49)	0.5509*** (7.45)	0.4543*** (6.82)	0.1622*** (3.50)	1.3090*** (2.65)	0.5859** (2.20)	2.7672** (2.02)
Financial Development Index *GDPGR	0.0070*** (2.84)	0.0081*** (2.84)	0.0048** (2.50)	0.0116*** (3.54)	0.0123*** (3.73)	0.0065*** (3.17)	-0.1035*** (-2.91)	-0.0501** (-2.25)	-0.1240*** (-2.81)
RENEW	-0.0132*** (-20.45)	-0.0136*** (-21.04)	-0.0130*** (-20.38)	-0.0142*** (-21.18)	-0.0144*** (-21.30)	-0.0144*** (-21.28)	-0.0062*** (-4.81)	-0.0062*** (-4.89)	-0.0070*** (-5.01)
POP	0.9903*** (79.42)	0.9889*** (72.97)	0.9925*** (85.78)	0.9957*** (108.89)	1.0081*** (106.70)	1.0024*** (96.58)	1.1156*** (24.70)	1.1244*** (25.76)	0.9915*** (13.38)
URBAN_POP	0.0096*** (7.28)	0.0093*** (6.47)	0.0099*** (8.05)	0.0305*** (35.89)	0.0302*** (33.25)	0.0315*** (33.72)	0.0436*** (14.96)	0.0440*** (15.64)	0.0415*** (8.23)
GDPGR	-0.0010 (-0.65)	-0.0019 (-1.05)	0.0007 (0.66)	-0.0005 (-0.61)	-0.0014 (-1.34)	0.0012** (2.07)	0.0119*** (3.22)	0.0105** (2.57)	0.0038*** (3.53)
Constant	-5.2188*** (-24.59)	-5.1727*** (-22.45)	-5.2568*** (-26.46)	-7.9638*** (-50.74)	-8.1575*** (-49.72)	-8.0147*** (-45.03)	-12.1093*** (-16.23)	-12.2453*** (-16.98)	-9.8624*** (-8.12)
Wald test	2.58	2.51	0.48	58.7***	49.17***	13.52***	6.27**	4.27**	3.74*
N	1126	1126	1126	2465	2465	2465	495	495	495

T-value in the brackets, Wald test shows the Chi-squared statistics, and * p<10%, **p<5%, ***p<1%.

negative at a 10% level, excluding FIE. These results show that renewable energy consumption may diminish the worsened effect of financial development on environmental quality.

Table 3 also shows that the coefficients of interaction variables between dimensions of financial development and economic growth are significantly positive at a 5% level in all specifications. These results show that economic growth may aggravate the problem of environmental degradation of financial development. Considering that differences in income groups may cause differences in the effect of renewable energy consumption and economic growth on the relationship between financial development and environmental quality, the sample is separated into high-, middle- and low-income groups. Then, Eq. (2) and (3) are re-estimated and presented in Tables 4. The coefficients of the interaction variable between FD and RENEW are negative and statistically significant at a 10% level, excluding low-income groups. This result shows that in high- and middle-income groups, an increase in renewable energy consumption may reduce the worsening impact of financial development on environmental quality. Besides, while the coefficients of the interaction variable between FD and GDPGR are positive in high- and middle-income groups, the coefficients of these variables are negative in low-income groups.

Conclusions

Few studies have examined the effects of financial development, while the majority have examined the relationship between economic growth and carbon dioxide emissions. Indeed, new factors must be considered to provide a comprehensive picture of CO_2 emissions and achieve global sustainable development. This study examines, on the one hand, the effect of financial development on CO_2 emissions and, on the other, the differences between renewable energy use and economic development. The study confirms what previous research has shown: that economic growth can increase CO_2 emissions [33, 20, 23]. In other words, financial development facilitates access to capital, boosting consumption, investment in business activities, and energy consumption. Increasing renewable energy consumption can reduce CO_2 emissions through direct and indirect channels, namely CO_2 emissions and development finance. This demonstrates that economic growth coupled with renewable energy is the key to sustainable development. In addition, the study found that economic development is frequently accompanied by environmental degradation, which policymakers should consider. Other indirect channels confirmed in our study that increased CO_2 emissions result from urbanization and population growth.

Therefore, the study strongly recommends some specific implications based on the research findings. First, it is necessary to tighten existing CO_2 emission control regulations and add new ones when consumers, investors, and businesses access financial markets for capital. Second, renewable energy consumption helps reduce CO_2 emissions, so consumption and investment activities must be encouraged alongside using cleaner, lower-carbon-emitting energy sources through preferential loans. Thirdly, economic activities must be regulated, and policymakers must synchronously ensure coherence between policies of environment, economic growth, and financial development to foster sustainable development. Fourthly, urbanization and population growth need to be accompanied by clean and renewable energy solutions to minimize adverse impacts on the environment. Finally, the study also has certain limitations regarding methods and approaches. This study does not consider issues related to cointegration, country-specific characteristics and long-term relationships. Future research can be expanded by employing cointegration estimates and determining the long-term causal relationships for a sample of multi-countries.

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Conflict of Interest

The authors declare no competing financial interest.

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