

Innovations

Impact of Financial Development on Carbon Emissions: Evidence from Middle Income Countries (1991-2022)

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Abstract: *The study examines the impact of financial development on carbon emissions: Evidence from middle income countries. This research applies the system generalised method of moments (SGMM) to examine the impact of financial development on carbon emissions in 63 middle income countries from 1991 to 2022. The study adopted four indicators of financial development - domestic credit to the private sector percentage of GDP (FD1), total financial system deposits to GDP (FD2), deposit money bank assets to GDP (FD3), and liquid liabilities to GDP (FD4).*

Research findings: *The conclusion of our research reveal that for lower middle income, trade openness, foreign direct investment and urbanisation have insignificant effect on carbon emissions in all specifications. The results show that financial development increases carbon emissions in the middle income countries. Additionally, financial development has an inverted U-shaped relationship with carbon emissions. Finally, the evidence from the study shows that the curvilinear effect of financial development on carbon emissions differ across income groups. The outcome of our research does not only increase insight, however it presents a number of policy suggestions for environmental sustainability. This study are vital from the view point of developing and industrialising countries which have allowed a number of policy implications. To escape the damaging effect of financial development on environmental sustainability, some integral weaknesses of the middle income countries' financial system such as misallocation of financial resources should be resolved to reverse the adverse effect of financial development on the environment. The financial sector, especially the banking sector should be encouraged to engage in interest discounts for investment in technology development that are energy cost-efficient. The financial sector should place more*

emphasis on effective and useful actions that stimulate more low-carbon financing among firms and households

1. Introduction

Climate change debates have been on the front burner in policy discussions with the declining quality of the environment globally (Efobi et al. 2018). Several proofs have shown signs of climate change such as the melting ice caps, rising atmospheric temperature, increasing sea levels, declining fresh water supplies and varying patterns of rainfalls (Özokcu and Özdemir 2017). Carbon dioxide (CO₂) and other greenhouse gases (GHGs) are the major contributors of this climate change (Intergovernmental Panel on Climate Change 2013). According to OECD (2008), with no additional policies to checkmate climate change, greenhouse gas emissions in 2050 must have grown by about 52% with CO₂ emissions contributing about 76% of these total greenhouse gases.

However, climate change is no longer an environmental issue alone; it is also a developmental issue. It poses a sustainable development threat to many developing countries. According to the Internal Displacement Global Report in 2016, 27.8 million persons were displaced in 2015 out of which 19.2 million were related to disasters. Most of the displaced persons are in developing countries (United Nations Environment Programme 2016). Also, the International Organisation of Migration envisages that 200 million persons may be environmentally - displaced with key impacts on every country involved in the migration process (from country of origin to receiving country) by the year 2050. So, definitely, environmental degradation is a concern for everybody.

Undoubtedly, it has been envisaged that the level of economic activities and growth in human numbers have greatly initiated and sustained the rising level of GHGs emissions (Adom et al. 2012). But it is too simplistic to examine just the relationship between carbon emissions and economic growth short of other pieces of economic development (Abbasi and Riaz, 2016). Such other pieces of economic development are changes in the financial sector (Acheampong 2019). While development of the financial sector is contended to have a significant consequence for the environment, it is still contentious its role in the growth of carbon emissions. Several studies have either reported a negative or a positive impact of financial development on carbon emissions (Bayar et al. 2020; Li and Ouyang 2019).

Further, within the framework of the linkages between carbon emissions and financial development; middle income countries require a well-developed financial sector for its continuous economic growth. Over time, the import of middle-income economies is rising in the world growth paradigm. These countries have seen their economies grow significantly in the past three decades

contributed by financial development. Table 1 evidently reveals that middle-

Variables	Lower Income			Middle Income			Higher Income			World		
	1991-1999	2000-2008	2009-2022	1991-1999	2000-2008	2009-2022	1991-1999	2000-2008	2009-2022	1991-1999	2000-2008	2009-2022
CO2Gr	-2.94	3.49	-3.31	-0.64	5.7	2.89	1.13	0.72	-0.94	0.95	3.17	1.47
GDPGr	2.07	5.66	4.15	2.87	6.15	4.87	2.56	2.43	1.41	2.62	3.37	2.5
DCGr	1.82	5.25	-7.51	0.76	3.39	-4.52	2.34	-0.46	-9.36	1.44	-0.80	-9.20

income countries on a nine year average grew by 2.87%, 6.15% and 4.87% during 1991 – 1999, 2000 – 2008 and 2009 – 2017 respectively. Whereas, the world average growth within the same period was at 2.62%, 3.37% and 2.50% while the higher income countries (low income countries) was at 2.56% (2.07%), 2.43 (5.66%) and 1.41% (4.15%). The vast change in economic growth could be seen reflected in the the contribution of financial development in the middle income countries (see Table 1).

Table 1 Average of lower/middle/higher income countries and the world in emissions growth rate, GDP growth rate, and Domestic credit to the private per GDP.

Note: CO2Gr = carbon emission growth, GDPGr = GDP growth, DCGr = domestic credit growth

Therefore, this article is to offer new insights with respect to the dynamics between carbon emissions, financial development from 1991–2022 in the middle income countries. In specific terms, the study contributes in three (3) areas. First, this study presents is the first to the best of our knowledge to consider both the linear and non-linear (environmental Kuznet curve hypothesis) impact of financial development on carbon emissions and the first to consider the middle income countries. Secondly, majority of empirical literature have used a single measure of financial development in their conclusion of financial development – carbon emissions nexus probably leading to biasness (Acheampong 2019; Shahbaz et al. 2016). According to Levine and Zervos (1998) and Chang (2015), different financial development measures could have diverse result on economic growth and energy consumption which could also be applicable to carbon emissions. Therefore, this study uses four (4) measures of financial development to capture efficiency and depth of the financial system. Fourth, in the study sample, we account for further income heterogeneity within the middle income countries (dividing it into lower middle income and upper middle income countries). The division of the middle income countries into lower-middle income and upper middle income according to World Bank’s categorisation 2018 will give insight how the stages of the production process and structural change could influence carbon emissions. Finally, for improved and efficient policy formulation and

guideline, reliable and consistent findings are imperative. Therefore, this study employs the dynamic system GMM technique to correct for endogeneity in the models and two stage least squares (2SLS) for robustness.

The remainder of this study has been organised as follows: section 2 the literature reviews on CO₂ emissions and financial development relationships. Section 3 methodology. In section 4, we discuss the empirical results. Section 5 will be for the conclusions and policy implications from our findings.

1. Literature Review

Grossman and Krueger (1991) introduced the Environmental Kuznets Curve (EKC), proposing an inverse U-shaped relationship between environmental quality and income. The hypothesis suggests that while short-term environmental quality might suffer due to economic growth, in the long run, as income rises, the environment will improve (Beckerman 1992). Numerous studies, including those by Holtz-Eakin and Selden (1992), Panayotou (1993), Shahbaz et al. (2012), Heidari et al. (2015), among others, have tested the EKC. However, these studies show varied results in terms of magnitude, direction, and significance. Researchers have used different indicators (Huang et al. 2008; Akbostanci et al. 2009), regressors (Galeotti et al. 2006; Tamazian et al. 2009), methods (Luzzati and Orsini 2009), time periods, and geographical locations to assess environmental quality. While the primary focus has been on the relationship between environmental degradation and income, studies like those by Saboori et al. (2012), Duarte et al. (2013), Saidi and Hammami (2015), among others, reveal varying results based on indicators and countries, suggesting the EKC might be specific to indicators and countries. Additionally, many studies use population, trade openness, and energy consumption as control variables to address specification bias.

Financial development affects carbon emissions through various channels, as highlighted in existing literature. Firstly, it can influence emissions directly and through wealth effects (Frankel and Romer 1999; Sadorsky 2011). For instance, the stock market, as part of the financial system, facilitates lower financing costs and increased credit access for listed companies, encouraging investments in new facilities and production, subsequently amplifying energy consumption and carbon emissions (Gokmenoglu et al. 2015; Islam et al. 2013). Additionally, financial development's link to increased foreign direct investments stimulates economic activity, further contributing to emissions (Frankel and Romer 1999). Moreover, the accessibility of loans through efficient financial intermediation enables the purchase of goods and services that contribute to emissions (Sadorsky 2010). Several empirical studies reinforce the notion that financial development exacerbates environmental degradation (Shen et al. 2021; Bui 2020; Godil et al. 2020b; Khan, Khan and Binh 2020; Bayar et al. 2020; Ehigiamusoe and

Lean 2019; Abokyi et al. 2019; Ali et al. 2019; Phong 2019; Jiang and Ma 2019; Cetin et al. 2018). For example, Shen et al. (2021) investigated 30 Chinese provinces from 1995 to 2017, revealing that financial development increases carbon emissions in the long run using cross-sectional ARDL (CS-ARDL). Similarly, Bui (2020) analyzed 100 countries globally, finding a positive impact of financial development on emissions using two-stage least squares (2SLS) and three-stage least squares (3SLS), considering energy consumption and income inequality as transmission channels. In Turkey, Godil et al. (2020b) employed quantile autoregressive distributed lag technique (QARDL) from 1995 to 2018, concluding that financial development escalates ecological footprints. Moreover, Khan, Khan, and Binh (2020) examined 192 countries from 1980 to 2018, indicating a relationship between financial development and carbon emissions. However, Hao et al. (2016) adopted the GMM method to explore financial development's impact on carbon emissions in Chinese provinces from 1995 to 2012. Their findings indicated that financial development increases emissions at higher levels of economic growth but decreases them at lower growth levels.

On the other hand, another argument about the link between carbon emissions and financial development is the structure and technical effect argument (Tamazian et al. 2009; Tamazian and Rao 2010). One of the important channels a firm uses to raise funds is the financial intermediation channel. Financial intermediation, particularly when firms raise funds through the banking sector, tends to lead to greater energy efficiency and subsequently lower carbon emissions (Tamazian et al., 2009; Claessens and Feijen, 2007). Government initiatives leveraging the developed financial sector for environment-friendly projects also contribute to reducing carbon emissions at a lower cost (Tamazian and Rao, 2010). Furthermore, financial development stimulates technological innovations in energy-efficient products, potentially reducing environmental degradation (Tadesse, 2005; Kumbaroglu et al., 2008) and encouraging practices like carbon trading (Claessens and Feijen, 2007). Several empirical studies support this theoretical argument. Godil et al. (2020a) found that financial development decreased carbon emissions in Pakistan from 1995 to 2018 using a quantile autoregressive distributed lag technique. Li and Ouyang (2019) discovered a negative impact of financial development on carbon emissions in China from 1978 to 2015 through ARDL analysis. Similarly, studies in Turkey by Gokmenoglu and Sadeghieh (2019) and Dar and Asif (2018) also identified a negative association between financial development and carbon emissions for different periods. Mahmood et al. (2019) examined six East Asian countries from 1991 to 2014 and found that financial development reduced carbon emissions using Spatial Fixed Effect and Spatial Random Effect models. Zaidi et al. (2019) analyzed 17 Asia Pacific Economic Cooperation nations from 1990 to 2016, concluding that financial development could reduce carbon emissions both in the

short and long term using specific econometric techniques. In the GCC region, Alsamara et al. (2018) discovered, through Panel Cointegration and Causality tests spanning from 1980 to 2017, that financial development contributed to reducing carbon emissions. Overall, the integrated findings from these studies across various regions and timeframes provide empirical support for the notion that financial development is associated with lower carbon emissions.

However, the relationship between financial development and the environment has been explored by various schools of thought, revealing diverse perspectives beyond a simple linear connection. Chunyu et al. (2021) identified an inverted U-shaped relationship between financial development and carbon emissions in developing European and Central Asian economies. Similarly, Raggad (2020) found in Saudi Arabia that negative shocks to financial development exacerbate carbon emissions in the long run, while positive shocks improve emissions in the short term. Echoing this time frame and approach, Omoke et al. (2020) in Nigeria observed that positive changes in financial development reduce ecological footprints, while negative changes increase them. However, Acheampong (2019) studying 46 sub-Saharan African countries found no non-linear impact of financial development on the environment. Additionally, Shahbaz et al. (2018) in France identified an inverted U-shaped relationship between financial development and carbon emissions in data spanning from 1955 to 2016. Furthermore, Xu et al. (2021) explored how financial development influences carbon emissions across 42 countries from 1990 to 2018, revealing that at lower levels of industrialization and energy consumption, financial development reduces emissions, but increases them at higher levels.

Empirically, the relationship between financial development and carbon emissions varies, showcasing positive, negative, or nonlinear tendencies. The direction and magnitude of this impact rely on factors such as the measurement indicators of financial development, estimation methods, time frames, and specific regional or national contexts. Given these nuances, it is crucial to evaluate both linear and non-linear impacts of financial development on carbon emissions.

2. Model Specification, Methodology and Data

The linear functional form of our study follows that of Bayar et al (2020) expressed in in Equation (3.1)

$$\ln CO_{2it} = \beta_0 + \beta_1(\ln FD)_{it} + \beta_2(\ln EC)_{it} + \beta_3(\ln POP)_{it} + \beta_4(\ln TROP)_{it} + \beta_5(\ln FDI)_{it} + \beta_6(\ln URB)_{it} + \gamma_t + \delta_i + \varepsilon_{it} \quad (3.1)$$

Following Acheampong (2019), the study includes the squared term financial development $(\ln FD)^2$ to examine the presence of EKC in the model. Therefore, Eq.(3.1) is extended to Eq.(3.2);

$$\begin{aligned} \ln CO_{2it} = & \beta_0 + \beta_1(\ln FD)_{it} + \beta_2(\ln FD)_{it}^2 + \beta_3(\ln EC)_{it} + \beta_4(\ln POP)_{it} + \beta_5(\ln TROP)_{it} \\ & + \beta_6(\ln FDI)_{it} + \beta_7(\ln URB)_{it} + \gamma_t + \delta_i \\ & + \varepsilon_{it} \end{aligned} \quad (3.2)$$

Where $\ln(CO_2)$ is the natural log of carbon emissions, and $\ln(FD)$ is the financial development measured by a battery of indicators. As control variable, $\ln(EC)$ is the natural log of energy consumption from fossil fuel, $\ln(POP)$ is the natural log of total population size, $\ln(TROP)$ is the natural log of trade openness, $\ln(FDI)$ is the natural log of foreign direct investment and $\ln(URB)$ is the natural log of urban population. γ , δ and ε are time fixed effect, country specific effect and the disturbance term respectively, while i is $1, \dots, N$ and t is $1, \dots, T$. Following standard practice, we expressed the variables in natural log form to reduce heteroscedasticity, stationarity of the variance – covariance matrix, and to obtain consistent and reliable elasticity values (Shoaib et al. 2020; Halicioglu 2009; Ang 2009; Shahbaz and Lean 2012).

In measuring financial development, we adopt four indicators of financial development - domestic credit to the private sector percentage of GDP (FD1), total financial system deposits to GDP (FD2), deposit money bank assets to GDP (FD3), and liquid liabilities to GDP (FD4). Several researchers (e.g, Lee et al. 2015; Sadorsky 2011; Creane et al. 2007; Beck et al. 2000) have used these measures as proxies for financial development. First, the domestic credit to the private sector percentage of GDP measures the efficiency of the financial sector (Zhang 2011). It is the capacity of the financial system to transform deposits to funds for investment (Asongu 2012). But, this measures only the allocation of capital and it is not an indicator of depth. We therefore include total financial system deposits to GDP, deposit money bank assets to GDP and liquid liabilities to GDP as measures of depth. Different studies have used several indicators to measure the financial depth. Li and Ouyang (2019) and Shahbaz et al. (2016) used broad money as a percentage of GDP in the environmental literature to replicate financial depth. Nevertheless, in developing countries, larger portion of the broad money is made up of currencies. According to Demetriades and Hussein (1996), a rise in the broad money may not actually signify financial depth but monetization.

Considering the potential endogeneity problems, inference from the fixed effects (FE) and random effects (RE) models in Eq. (3.1), (3.2) and (3.3) may be inaccurate. The dynamic model permits the inclusion of lagged-dependent variable as part of the regressors to overcome the traditional panel (FE and RE) estimators' biasness. By construction, there is correlation between the unobserved effects in the panel with the dependent variable's lag(s); it possibly makes the traditional panel regression estimation methods inconsistent (Arellano and Bond 1991). However, the dynamic models requires including appropriate instrumental variables for the regressors that are endogeneous. In order to solve

the problem of endogeneity, we use Arellano and Bover (1995), and Blundell and Bond (1998) two-step system generalized method of moments (GMM). It is a dynamic panel regression method that is more robust than the one step method. The system GMM (SGMM henceforth) estimator is preferred over FE or RE estimators due to the biasness observed when lagged-dependent variables are included in the FE or RE models. The SGMM estimator includes the first-differenced equation, choosing the appropriate instruments as the lagged levels, with a further level equation and suitable instruments as the lagged first-differences. The SGMM estimator resolves the endogeneity problems caused by time-invariant and country-specific effects on the right hand side. The instrument validity for over-identifying restrictions could be tested using the Hansen test, while the AR(1) and AR(2) tests checks for the presence of serial correlation. The coefficients' standard errors are robust to heteroscedasticity (Roodman 2009). The SGMM estimator also is compatible with micro data, ($T < N$).

Our sample comprised 63 unbalanced data set from middle income countries, covering the period 1991–2017. The World Bank grouped every country into four categories with respect to their income levels (World Bank, 2017). Countries with incomes of \$1005 and below is categorised as low income, incomes between \$1006 and \$3955 are categorised as lower middle income, incomes between \$3956 and \$12,235 is seen as upper middle income, and incomes of \$12,236 and above is categorised as high income. The focus of this study is on the lower and upper middle income countries. To mitigate the problem of persistence, we divide the 27 years data into non-overlapping 3-year averages. The import of averages is that it reduces the effect of shocks and business cycles (Haini 2020). The selection of the countries included is subject to availability of data. All included countries are available in Appendix A. The financial development data is from the World Bank financial structure database while the remaining variables are from the World Bank world development indicator (WDI) and.

Table 2 presents the descriptive statistics of all the variables in logarithm. In middle income countries, the descriptive statistics indicates that carbon emissions ($\ln\text{CO}_2$) within the period averaged about 4.461% and a coefficient of variation (CV) of about 5.394% which could be seen as volatile. The first measure of financial development - domestic credit to the private sector percentage of GDP (FD1) shows a mean of 1.36% and a CV of 26.12%. The second measure of financial development - total financial system deposits to GDP (FD2) has a mean of 1.411% and a CV of 4.409%. On average, the third measure of financial development - deposit money bank assets to GDP (FD3) reveals a mean of about 1.468% and a CV of 4.305%. Finally, the fourth measure of financial development - liquid liabilities to GDP (FD4) has a mean of 1.523% and a CV of about 5.478%. Furthermore, energy consumption from fossil fuel ($\ln\text{EC}$) in middle income countries averaged 1.727% and a CV of 6.060%. Additionally, total population

(lnPOP) averaged 7.285% and a CV of 11.347%. The trade openness (lnTROP) within the income group is about 1.851% and a CV of 8.768%. The average FDI inflow (lnFDI) is about 0.319% and a CV of about 0.635% which is highly volatile. The urbanisation growth (lnURB) shows a mean 1.688% and a CV of 8.884%.

Table 2: Descriptive Statistics

Variables	Mean	SD	CV	Min	Max	Obs
lnCO2	4.461	0.827	5.394	2.901	7.008	567
lnFD1	1.337	0.370	3.614	0.039	2.183	560
lnFD2	1.411	0.320	4.409	0.327	2.353	560
lnFD3	1.468	0.341	4.305	0.209	2.233	560
lnFD4	1.523	0.278	5.478	0.699	2.366	559
lnEC	1.727	0.285	6.060	0.588	2.000	504
lnPOP	7.285	0.642	11.347	6.001	9.134	567
lnTROP	1.815	0.207	8.768	1.138	2.343	557
lnFDI	0.319	0.502	0.635	-1.854	1.679	543
lnURB	1.688	0.190	8.884	0.982	1.962	567

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct investment and ln(URB) is urban population. SD = standard deviation, CV = Coefficient of Variation

The correlation matrix in Table 4 indicates that there is no strong correlation between the regressors except the financial development indicators. There is a strong positive relationship between the financial development indicators, therefore; estimating the model with all the financial development indicators will lead to multicollinearity. It will cause inconsistent and false estimates. However, for consistent estimates, each of the financial indicator variables is used on a separate model.

Table 3: Correlation Matrix

	lnCO2	lnIND	lnFD1	lnFD2	lnFD3	lnFD4	lnEC	lnPOP	lnTROP	lnFDI	lnURB
lnCO2	1										
lnFD1	0.337	-0.025	1								
lnFD2	0.259	-0.052	0.761	1							
lnFD3	0.349	-0.051	0.875	0.824	1						
lnFD4	0.324	-0.015	0.810	0.897	0.868	1					
lnEC	0.539	0.308	0.385	0.306	0.370	0.331	1				

lnPOP	0.800	0.169	0.184	0.116	0.200	0.202	0.073	1			
lnTROP	-0.331	0.172	0.106	0.053	0.048	0.117	0.119	-0.556	1		
lnFDI	-	0.067	0.093	0.125	0.010	0.067	0.071	0.174	-0.244	0.404	1
lnURB	0.306	0.367	0.126	0.087	0.087	0.018	0.596	-0.126	0.061	0.239	1

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct investment and ln(URB) is urban population.

3. Empirical Results and Discussions.

4.1 Basic Results

Table 4 presents the linear models (Models 1–4), and non-linear models (Models 5–8) from Eq. (3.1),and Eq. (3.2) respectively. The coefficients of the lagged CO2 emissions are positive and significant at 1% statistical level in all the models ranging from 0.699 and 0.777. This shows that the previous level of carbon emissions influences the current level of carbon emissions supporting existing empirical results such as Hao et al (2016) and Acheampong (2019). For the linear models (1 – 4), financial development indicators measuring both efficiency and depth exact a positive significant impact on carbon emissions. The results reveal that a 1% increase in financial development indicators increases carbon emissions between 0.125% and 0.263% in the middle income countries. Interestingly, our findings support Shahbaz et al. (2016) who discovered that bank-based financial development indicators deteriorate the environment. Also, our finding supports the empirical results of Ehigiamusoe and Lean (2019) in low and middle income countries and many others such as Bui (2020), Khan, Khan and Binh (2020), and Bayar, Maxim and Maxim (2020). In providing explanation for our result, we do say that the financial sector in middle income countries is not enabling or attracting green technology for sustainable environment. A lot of the middle income countries still have poorly liberalised financial system which has hindered the capacity of the financial institutions to back green technologies (Akinsola and Odhiambo 2017; Kim and Park 2016). According to Tamazian et al. (2009), when the financial sector is highly liberalised, it boosts competitiveness and transfer of technological innovation, therefore, provide the needed environment for carbon emissions mitigation. On the other hand, our study is not consistent with some other existing empirical research that presents financial development have improved the environment (Godil et al. 2020a; Li and Ouyand 2019; Gokmenoglu and Sadeghieh 2019; Dar and Asif 2018, and many others).

Table 4 System GMM estimated models for carbon emissions and financial development (full sample)

Variable	Linear Models				Non-linear Models			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.lnCO2	0.757** * (0.043)	0.777** * (0.055)	0.729** * (0.069)	0.750** * (0.064)	0.768** * (0.072)	0.699** * (0.076)	0.726** * (0.071)	0.747** * (0.064)
lnFD1	0.125** * (0.036)				0.408** * (0.124)			
lnFD2		0.165** (0.070)				0.306 (0.278)		
lnFD3			0.145** * (0.054)				0.238 (0.160)	
lnFD4				0.263** * (0.090)				0.751** (0.358)
(lnFD1) ²					- 0.123** (0.052)			
(lnFD2) ²						-0.092 (0.101)		
(lnFD3) ²							-0.068 (0.059)	
(lnFD4) ²								-0.217* (0.119)
lnEC	0.287** (0.138)	0.339** (0.154)	0.396* (0.206)	0.368** (0.162)	0.060** (0.026)	0.419** (0.207)	0.341* (0.193)	0.275 (0.176)
lnPOP	0.214** (0.081)	0.193** (0.080)	0.250** (0.110)	0.217** (0.149)	0.267** * (0.083)	0.343** * (0.109)	0.280** (0.109)	0.281** (0.113)
lnTROP	0.027 (0.115)	0.033 (0.105)	-0.036 (0.130)	-0.018 (0.107)	0.009 (0.123)	0.094 (0.112)	-0.036 (0.104)	0.010 (0.110)
lnFDI	0.005 (0.019)	0.011 (0.027)	0.007 (0.021)	0.012 (0.021)	0.187 (0.143)	0.044 (0.029)	0.020 (0.022)	0.028 (0.027)
lnURB	0.027 (0.156)	-0.094 (0.129)	0.011 (0.154)	0.049 (0.206)	0.151 (0.181)	0.010 (0.204)	0.016 (0.223)	0.073 (0.220)
Constant	-	-	-	-	-	-	-	-

	1.615** (0.738)	1.592** (0.750)	1.920** (0.846)	2.025** (2.526)	3.878** * (1.172)	5.076** * (1.801)	3.884** (1.556)	4.743** (1.899)	
Time effect	Yes	yes	yes	yes	yes	yes	yes	yes	
Observations	427	427	427	427	427	427	427	427	
No. of countries	63	63	63	63	63	63	63	63	
No. of instruments	61	62	61	62	60	60	59	60	
F test	304.41* **	521.22* **	490.18* **	33.48** *	386.17* **	214.60* **	262.69* **	288.07* **	
AR(1)	0.008	0.026	0.042	0.018	0.004	0.017	0.015	0.012	
AR(2)	0.274	0.251	0.240	0.176	0.145	0.330	0.346	0.259	
P(Hansen test)	0.174	0.157	0.157	0.157	0.236	0.151	0.239	0.124	

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct investment and ln(URB) is urban population. Windmeijer (2005) finite sample standard errors of the estimates are in parenthesis.***, ** and * at 1%, 5% and 10% Level of significance at respectively.

Also, regarding financial development, the signs of the linear term and the squared term of financial development provide an indication of an inverted U-shaped relationship between CO₂ and financial development in middle income countries. However, it is domestic credit to the private sector and liquid liabilities that are significant, at least by 10% (see Model 5 and 8). The implication is that the level of carbon emissions rises at an early stage of financial development reaching a turning point; with the outcome changing from positive to negative in middle income countries. Although not all financial development measures are significantly non-monotonic, it is obvious that financial development in middle income countries degrades the environment up to a turning point. The degrading effect of early stages of financial development could mirror the lack of capacity of the financial institutions in middle income countries to fund projects environmental sustainability projects at lower cost causing carbon emissions. This findings stands in supports with recent empirical results(Chunyu et al., 2021; Boufateh and Saadaoui 2020; Omoke et al 2020; Shahbaz et al 2018) which

confirmed inverted U-shaped relationship between financial development and carbon emissions. On the other hand, it is in contradiction with Hao et al. (2016) that found a U-shaped relationship and Acheampong (2019) that confirm no non-linear relationship between financial development and carbon emissions.

For energy consumption, the estimated coefficient is positive and significant by 10% or better in every of the models. The coefficient for the energy consumption ranges between 0.060 and 0.396. The findings is not surprising due to the rise in industrialisation in the income group (Sohag et al. 2017). This finding supports similar recent empirical studies that concluded that energy consumption from fossil fuel increases carbon emissions (Alharthi et al. 2021, Boufateh and Saadaoui 2020; Anser et al. 2020, Acheampong 2019). Again, the size of the population exerts a positive and significant impact on carbon emissions at 5% in every of the model estimations. Consequently, the more the increase in the population size, the more carbon emissions increases in middle income countries. Our findings is in line with earlier empirical studies, for instance, Dong et al. (2018) and Zhu and Peng (2012) affirming the increasing effect of population size on carbon emissions. Trade openness exerts a non-significant effect on carbon emissions in all the models. This result is consistent with the findings of Acheampong, Amponsah and Boateng (2020) which shows that the impact of trade openness is possibly negligible in frontier financial economies. The study's result negates the findings of Ahmed et al. (2017) and Solarin et al. (2017) that found trade openness to have significantly degraded environmental quality. Then again, it contradicts Acheampong (2018), which revealed that trade openness increases environmental sustainability.

Further, foreign direct investment exerts positive and insignificant impact on carbon emissions. The result is consistent with Abbasi and Riaz (2016) and Acheampong (2019), however, it is in contradiction to the empirical studies of Zhang and Zhou (2016), Solarin et al. (2017) and Shahbaz et al. (2018), which show that foreign direct investment significantly influence carbon emissions. Lastly, urbanisation does not affect the environment significantly. Although the result is insignificant, it points to the ecological modernisation theory that the increase in urban expansion will deteriorate the environment. According to Poumanyong and Kaneko (2010), urbanisation causes overcrowding and traffic congestions, subsequently increasing the consumption of energy and carbon emissions.

Finally, post-estimation statistics signify reliability of the estimates after taken cognizance of country specific factors and endogeneity. Thus, the Hansen test indicates no instruments over-identification with the number of instruments not exceeding the number of groups (Kripfganz 2017). The Arellano and Bond's (1991) test for serial correlation revealed no second-order serial correlation in the models.

4.2 Sensitivity Analysis

For the sensitivity analysis, this paper applies the two-stage least squares (2SLS) as an alternate technique to estimate Eq.(3.1), and (3.2) for the reliability and credibility to the basic result. The choice of 2SLS is due to the possible reverse causality inherent in carbon emissions studies (Acheampong, Amponsah and Boateng 2020). The 2SLS econometric method is an instrumental variable regression, therefore, the lagged terms of the possible endogenous variables are used as instruments (Zakaria and Bibi 2019). They may be correlation existing between the error term and the regressors, however, correlation between error term and the lagged variables may be zero. The regression is estimated with the Huber-White method (robust options) to obtain efficient coefficient due to possible heteroscedasticity. Also, to account for income heterogeneity in the middle income countries, the study divides the income group into lower middle income countries and upper middle income countries. We divide the country groupings into two – 32 lower middle income and 31 upper middle-income countries. We followed the same econometric approach like our earlier basic result.

Alternative econometric technique

Table 5 presents the results from a 2SLS technique to re-estimate Eq.(3.1), and (3.2). Generally, in terms of signs, our result did not significantly overturn the outcome of the previous result (see Table 4). The linear models (Models 1- 4) show that both industrial output and financial development have positive and significant effect on carbon emissions in the middle income countries. For the curvilinear impact of financial development on carbon emissions, the results report a U-shaped relationship which is inconsistent with our earlier result from the system GMM technique (see Table 4). For the control variables, energy consumption and population size have significant and positive impact on carbon emissions, Also, trade openness and foreign direct investment exerts insignificant impact on carbon emissions. Finally, urbanisation has positive and significant impact on carbon emissions. The result for the control variables is consistent with the basic result except for urbanisation that is statistically significant in the 2SLS technique (see Table 5).

The diagnostic check shows that the model is well fitted where the R-squared (R²) value and Fisher test (F-stat) are quite high and statistically significant respectively. To check for weak instrument identification, Kleibergen-Paap/Cragg-Donald Wald F-statistics shows that the instruments are not weak with very high values. The Hansen J test for instrument validity with high p-values shows that the instruments are valid.

Table 5 2SLS estimated models for carbon emissions and financial development (full sample)

Variable	Linear Models				Non-linear Models			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
lnFD1	0.106** (0.052)				-0.518** * (0.187)			
lnFD2		0.106** (0.051)				-0.107 (0.222)		
lnFD3			0.108 (0.068)				-0.404 (0.294)	
lnFD4				0.116* (0.064)				-0.488 (0.393)
(lnFD1) ²					0.232** * (0.070)			
(lnFD2) ²						0.070 (0.075)		
(lnFD3) ²							0.180* (0.097)	
(lnFD4) ²								0.184 (0.120)
lnEC	1.063** * (0.070)	1.083** * (0.667)	1.063** * (0.072)	1.076** * (0.071)	1.096** (0.061)	1.090** * (0.058)	1.073** * (0.062)	1.097*** (0.063)
lnPOP	1.011** * (0.038)	1.021** * (0.037)	1.014** (0.040)	1.014** * (0.040)	0.993** * (0.037)	1.020** * (0.035)	0.995** * (0.039)	1.008*** (0.038)
lnTROP	0.125 (0.104)	0.150 (0.100)	0.143 (0.102)	0.132 (0.106)	0.087 (0.102)	0.165* (0.097)	0.117 (0.101)	0.144 (0.101)
lnFDI	0.002 (0.032)	0.009 (0.027)	0.003 (0.032)	0.012 (0.021)	-0.027 (0.030)	-0.004 (0.030)	-0.020 (0.030)	-0.015 (0.030)
lnURB	0.706** * (0.137)	0.697** * (0.133)	0.714** * (0.130)	0.722 (0.127)	0.679** * (0.125)	0.678** * (0.125)	0.676** * (0.122)	0.678 (0.123)
Constant	-26.529 (17.065)	-28.067* (16.749)	-28.106* (17.669)	-29.759* (16.949)	-30.620* * (14.576)	-22.987 (14.280)	-24.749* (14.753)	-28.226* (14.585)
Time	Yes	yes	yes	yes	yes	yes	yes	yes

effects								
Observations	364	364	364	364	421	421	421	421
R ²	0.899	0.898	0.898	0.898	0.903	0.900	0.902	0.900
F-Stat	465.52* **	490.49* **	529.63* **	545.60* **	479.32* **	448.92* **	528.85* **	541.97** *
Wald-Stat	584.98	808.64	422.081	781.050	1562.54 3	1809.00	1736.36 4	1736.751
J	1.950	0.018	1.378	0.538	2.049	0.211	0.462	0.070
J P-value	0.163	0.893	0.2404	0.463	0.152	0.646	0.497	0.792

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct investment and ln(URB) is urban population. In parenthesis is the heteroscedasticity robust standard errors, F-stat is the Fisher statistics for overall model significance, Wald - statis the Kleibergen-Paap/Cragg-Donald F-statistics for weak instrument identification, J is Hansen J-statistics andJP-value is the Hansen J-statistics' p-value.***, ** and * at 1%, 5% and 10% level of significance at respectively.

Accounting for Income Heterogeneity

The impact of financial development on carbon emissions is most likely different across heterogeneous income levels. Based on different income levels as grouped by the World Bank, we divide the middle income countries further into lower middle income and upper middle income countries to examine if the results are different. Table 6 and Table 7 present the estimates for lower middle income countries and upper middle income countries respectively. For both the lower middle income and the upper middle income countries, the coefficient for the lagged dependents variable (carbon emissions) is statistically significant and positive at 1% in all the models. At 10% significant level, private sector credit and liquid liabilities as indicators of financial development (see Models 5 and 8 in Table 7) exerts a positive significant effect on carbon emissions while the squared terms of financial development (private sector credit and liquid liabilities) revealed a negative and significant effect on carbon emissions in upper middle income countries. It means that financial development deteriorates the environment at the early stage of financial development but it will start to improve the environment after a threshold. However, the case is different for lower middle income countries where there is no non-linear relationship between financial development and carbon emissions. The results in the lower middle income countries support the empirical findings of Acheampong (2019) in sub-

Saharan Africa that comprise mostly of low income and lower middle income countries. Thus, the financial development EKC hypothesis is valid for upper middle income countries but invalid for lower middle income countries. For the upper middle income countries, relative standard and tough regulatory framework that benefits the environment may have spurred the inverted U-shaped relationship between financial development and carbon emissions.

Further, the result suggests that energy consumption and population size exerts positive and statistically significant impact on carbon emissions in both lower and upper middle income countries for all specifications. The findings reveal that for lower middle income, trade openness, foreign direct investment and urbanisation have insignificant effect on carbon emissions in all specifications (see Table 6). However, trade openness, foreign direct investment and urbanisation increases carbon emissions significantly in upper middle income countries (see Table 7). The results indicate that trade liberalisation worsens environmental quality in upper middle income countries. Also, the implication of the result is that foreign investments in upper middle income countries provide high energy consuming capital most times, thereby increasing carbon emissions. While rapid urbanisation does not support the compact city hypothesis economies of scale in urban infrastructure exist to reduce carbon emissions. Finally, the post-estimation statistics in both the lower middle income and upper middle income countries reveal that the estimates are reliable and consistent. The Hansen test shows no instrument over-identification and the number of instruments did not exceed the number of groups (Kripfganz 2017). The Arellano and Bond's (1991) test for serial correlation revealed no second-order serial correlation in the models.

Table 6 System GMM estimated models for carbon emissions and financial development (lower middle income countries)

Variable	Linear Models				Non-linear Models			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.lnCO2	0.770** * (0.074)	0.829** * (0.072)	0.736** * (0.163)	0.788** * (0.159)	0.625** * (0.096)	0.576** * (0.123)	0.505** * (0.157)	0.544** * (0.122)
lnFD1	0.196** * (0.067)				0.011 (0.109)			
lnFD2		0.248** (0.114)				0.231 (0.263)		
lnFD3			0.217* (0.120)				0.084 (0.177)	
lnFD4				0.329* (0.173)				-0.367 (0.591)

(lnFD1) ²					0.023 (0.044)			
(lnFD2) ²						-0.042 (0.105)		
(lnFD3) ²							0.004 (0.070)	
(lnFD4) ²								0.166 (0.196)
lnEC	0.235* (0.133)	0.050 (0.186)	0.084 (0.166)	0.030** (0.138)	0.278** (0.136)	0.206 (0.208)	0.146 (0.271)	0.316* (0.184)
lnPOP	0.185** (0.093)	0.160 (0.102)	0.199 (0.180)	0.217 (0.205)	0.433** * (0.154)	0.376** (0.176)	0.487** * (0.152)	0.443** (0.199)
lnTROP	-0.078 (0.076)	0.059 (0.105)	-0.051 (0.180)	-0.147 (0.219)	0.021 (0.094)	-0.043 (0.123)	-0.044 (0.108)	-0.055 (0.128)
lnFDI	0.018 (0.019)	0.008 (0.020)	0.007 (0.052)	-0.004 (0.012)	0.001 (0.021)	0.006 (0.022)	0.004 (0.017)	-0.007 (0.020)
lnURB	-0.053 (0.005)	-0.033 (0.228)	0.319 (0.424)	0.448 (0.469)	0.400 (0.316)	0.560 (0.388)	0.828 (0.504)	0.519 (0.478)
Constant	10.265 (9.195)	11.212 (9.889)	8.079 (16.538)	14.977 (22.422)	-6.878 (11.296)	-9.419 (14.892)	-12.110 (13.703)	-7.375 (17.184)
Time effect	Yes	yes	yes	yes	yes	yes	yes	yes
Observations	212	212	212	212	212	212	212	212
No. of countries	32	32	32	32	32	32	32	32
No. of instruments	27	25	28	29	31	29	31	29
F test	717.67* **	831.78* **	116.03* **	161.49* **	112.80* **	121.42* **	59.31** *	77.52** *
AR(1)	0.045	0.032	0.020	0.155	0.174	0.255	0.399	0.266
AR(2)	0.223	0.302	0.165	0.284	0.480	0.535	0.483	0.681
P(Hansen test)	0.544	0.631	0.721	0.693	0.199	0.116	0.131	0.167

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct

investment and ln(URB) is urban population. Windmeijer (2005) finite sample standard errors of the estimates are in parenthesis. ***, ** and * at 1%, 5% and 10% Level of significance at respectively.

Table 7 System GMM estimated models for carbon emissions and financial development (upper middle income countries)

Variable	Linear Models				Non-linear Models			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
L.lnCO2	0.526** * (0.175)	0.569** * (0.107)	0.515** * (0.104)	0.557** * (0.181)	0.559** * (0.135)	0.537** * (0.162)	0.683** * (0.076)	0.644** * (0.152)
lnFD1	0.087** (0.032)				0.220** * (0.052)			
lnFD2		0.104** (0.050)				0.367 (0.341)		
lnFD3			0.065** (0.022)				0.175* (0.094)	
lnFD4				0.166* (0.090)				0.175* (0.094)
(lnFD1) ²					-0.059* (0.034)			
(lnFD2) ²						-0.103 (0.142)		
(lnFD3) ²							- 0.018** (0.008)	
(lnFD4) ²								- 0.018** (0.008)
lnEC	0.479* (0.251)	0.759** * (0.251)	0.665** (0.196)	0.481** (0.242)	0.304** (0.116)	0.203* (0.114)	0.315* (0.158)	0.217* (0.101)
lnPOP	0.276** (0.123)	0.321* (0.169)	0.296* (0.162)	0.184* (0.104)	0.638** * (0.158)	0.557** (0.212)	0.334** * (0.081)	0.580** (0.161)
lnTROP	0.041* (0.022)	0.060* (0.033)	-0.042 (0.106)	-0.050 (0.087)	0.117* (0.062)	0.096* (0.053)	0.066 (0.138)	0.053 (0.104)
lnFDI	0.014	0.020 (0.016)	0.019 (0.028)	0.033 (0.022)	0.026 (0.026)	0.039** (0.018)	0.019** (0.008)	0.047** (0.019)

	(0.021)							
lnURB	0.193 (0.245)	0.301** (0.128)	-0.054 (0.341)	0.066 (0.469)	0.596* (0.318)	0.637 (0.602)	0.395 (0.339)	0.557 (0.442)
Constant	-14.320 (11.938)	-21.354 (14.406)	-24.803 (13.468)	-14.377 (14.957)	-5.777 (15.047)	-2.076 (20.839)	-3.110 (17.690)	-3.171 (17.160)
Time effect	Yes	yes	yes	yes	yes	yes	yes	yes
Observations	215	215	215	215	215	215	215	215
No of countries	31	31	31	31	31	31	31	31
No. of instruments	30	30	30	28	27	30	29	30
F test	29.74** *	59.62** *	49.35** *	42.74** *	48.64** *	21.67** *	70.66** *	39.90** *
AR(1)	0.051	0.076	0.064	0.080	0.076	0.041	0.044	0.081
AR(2)	0.395	0.106	0.414	0.102	0.309	0.386	0.437	0.261
P(Hansen test)	0.477	0.488	0.471	0.253	0.283	0.130	0.276	0.270

Note:ln(CO2)is the natural log of carbon emissions, ln(FD1)is domestic credit to the private sector percentage of GDP, ln(FD2)is total financial system deposits to GDP, ln(FD3)is deposit money bank assets to GDP, ln(FD4)is liquid liabilities to GDP, ln(EC) is energy consumption from fossil fuel, ln(POP) is the total population size, ln(TROP) is trade openness, ln(FDI) is the natural log of foreign direct investment and ln(URB) is urban population. WindMeijer (2005) finite sample standard errors of the estimates are in parenthesis. ***, ** and * at 1%, 5% and 10% Level of significance at respectively.

3. Conclusion and policy implications

With the increasing environmental degradation, efforts have precipitated into several empirical research to detect factors that improve or impede environmental quality. This research applies the system generalised method of moments (SGMM) to examine the impact of financial development on carbon emissions in 63 middle income countries from 1991 to 2022. The study controlled for energy consumption, population size, trade openness, foreign direct investment, and urbanisation. To improve validity of the impact of financial development on carbon emissions, three financial development indicators are used to measure both depth and efficiency. For further insight, sensitivity

analyses were carried out by using two stage least squares as an alternative technique and also income heterogeneities was accounted for among the middle income countries. Consequently, the results that emanated from this research are as follows:

Firstly, financial development increases carbon emissions in middle income countries. However, only domestic credit to the private sector percentage of GDP and liquid liabilities to GDP as measures of financial development have significant curvilinear effect on carbon emissions while total financial system deposits to GDP and deposit money bank assets to GDP exert a curvilinear effect although not significant. Secondly, the evidence from the empirical study shows that the curvilinear effect of financial development on carbon emissions differ across income groups. For the lower middle income, the non-monotonic effect of financial development did not hold. On the other hand, in upper middle income, domestic credit to the private sector percentage of GDP and liquid liabilities to GDP as measures of financial development have significant curvilinear effect on carbon emissions.

Finally, the outcomes of this study are vital from the view point of developing and industrialising countries which have allowed a number of policy implications. To escape the damaging effect of financial development on environmental sustainability, some integral weaknesses of the middle income countries' financial system such as misallocation of financial resources should be resolved to reverse the adverse effect of financial development on the environment. Presently, misallocation of financial resources is one of the most significant problems of developing countries' financial system. For instance, public enterprises in developing countries easily acquire low-cost loans than the more productive and efficient private enterprises. With such financial resources misallocation, private firms find it difficult to investment in environmental-friendly technologies. Therefore, the irrational financial misallocation should be fixed within the middle income countries to benefit sustainable environment. The financial sector, especially the banking sector should be encouraged to engage in interest discounts for investment in technology development that are energy cost-efficient. The financial sector should place more emphasis on effective and useful actions that stimulate more low-carbon financing among firms and households.

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Appendix A

Country Grouping			
Lower Middle Income Countries		Upper Middle Income Countries	
Algeria	Kyrgyz Republic	Albania	Iran, Islamic Rep.
Angola	Moldova	Argentina	Jamaica
Bangladesh	Mongolia	Azerbaijan	Jordan
Benin	Morocco	Belarus	Kazakhstan
Bolivia	Nepal	Bosnia and Herzegovina	Lebanon
Bulgaria	Nicaragua	Botswana	Malaysia
Cambodia	Nigeria	Brazil	Mexico
Cameroon	Pakistan	China	Namibia
Congo, Rep.	Philippines	Colombia	Paraguay
Cote d'Ivoire	Senegal	Costa Rica	Peru
Egypt, Arab Rep.	Sri Lanka	Dominican Republic	Russian Federation
El Salvador	Tanzania	Ecuador	South Africa
Ghana	Tunisia	Gabon	Thailand
Honduras	Ukraine	Georgia	Turkey
India	Vietnam	Guatemala	Venezuela, RB
Kenya	Zambia	Indonesia	