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Carbon neutrality targets, optimal environmental management strategies & the role of financial development: New evidence incorporating non-linear effects and different income levels

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ABSTRACT

Financial development has been found to have mixed effects on CO2 emissions. One reason appears to be the relationship is not linear, as is assumed in most earlier studies. This paper re-examines the relationship between financial development and CO2 emissions based on a panel data of 61 countries categorised as high- and middle-income economies, from 1990 to 2018. This study uses the linear ARDL and nonlinear ARDL (NARDL) methods to analyse the impact of positive and negative shocks in financial development on CO2 emissions. Additionally, the panel causality between the variables is also investigated. The analyses from ARDL and NARDL reveal that in the long run, financial development helps to minimise CO2 emissions for high income economies, but it raises CO2 emissions and thereby decreases environmental quality for middle-income economies. Supporting our nonlinear hypothesis, we find that both negative and positive shocks of financial development have significant impacts on CO2 emissions, while the latter have a more profound effect. In particular, the findings suggest that the impacts of financial development on CO2 emissions are distinctive in high- and middle-income economies, leading to useful policy implications, including the suggestion that international development bodies help middle-income countries to incorporate consideration of environmental effects into the operation of their financial institutions and systems at an earlier stage of development than would generally be the case.

1. Introduction

At the G7 Summit in Carbis Bay, England, in June 2021, it was agreed to take genuine action on tackling climate change and a pledge was made to raise $100 bn a year to help poor countries cut carbon dioxide (CO2) emissions. The pledge is a recognition that there is a huge gap between developed countries and developing nations in relation to energy use efficiency and environmental quality, caused by the economic development level.

Many researchers have studied the relationship between economic growth and CO2 emissions, to find the factors influencing CO2 emissions and explore remedies for improving environmental quality. These factors include energy consumption, population growth, GDP, trade openness, FDI, urbanisation, productivity, and new technology adoption. In recent years, more and more research has paid attention to the role of financial development in the increase or decrease of CO2 emissions. Researchers have argued that financial development, consisting of financial institutions and financial markets, is a crucial determinant affecting CO2 emissions.

However, results are mixed (Abbasi and Riaz, 2016; Haseeb et al., 2018; Shoaib et al., 2020). Several studies report that financial development leads to a decrease in CO2 emissions (Shahbaz et al., 2013a, 2013b, 2013c, 2018, 2013b; Charfeddine and Kahia, 2019), while others suggest that financial development tends to result in environmental degradation (Xu et al., 2018; Nasir et al., 2019; Shahbaz et al., 2020). Thus, there are alternative accounts of the relationship between financial development and CO2 emissions.

On the one hand, some studies suggest that financial development increases CO2 emissions, because a well-developed financial sector mitigates information asymmetry and funds more production, which stimulates energy supplies and consumption (Sadorsky, 2010; Zhang, 2011; Dogan and Turkekul, 2016). Overall, financial development

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facilitates greater economic activity, which is associated with increased emissions.

On the other hand, financial institutions (e.g., banks) can provide funds to support energy-efficient companies, projects and technologies (Tamazian et al., 2009; Islam et al., 2013; Jiang and Ma, 2019); and if there is a well-functioning stock market, energy-efficient firms can quickly raise money to invest more in green energy technologies (Jiang and Ma, 2019). Furthermore, with greater financial development, governments can set appropriate financial and monetary regulations and policies as part of the institutional framework (Nguyen et al., 2021), to influence financial institutions and stock markets in order to achieve a nation's ultimate CO2 emission targets.

Various other explanations might exist for the differing empirical results. The findings could be affected by many specific factors such as the countries and regions studied, data coverage, and associated variables. A further explanation might lie in the modelling approaches taken by previous studies. Most have assumed an underlying linear relationship between variables. However, as Jiang and Ma (2019) hint, that the nonlinear features of the relationship between financial development and CO2 emissions might reflect in institutions, governmental policies, or income level of a country. As such, linear analytic approaches should have a bias in estimation, and the results could be misleading because they might miss heterogeneous impacts of financial development on CO2 emissions. The evidence so far is suggestive, but not conclusive.

In response, this paper uses econometric techniques – including ARDL (autoregressive distributed lag) and NARDL (nonlinear ARDL) models, and a panel causality test – to examine the impact of financial development on CO2 emissions. The data sample covers 61 countries, comprising 36 high-income countries and 25 middle-income countries, during the period 1990–2018. The models also incorporate other variables; energy use, FDI and GDP. We pay special attention to the difference in results between linear ARDL and nonlinear ARDL (NARDL) models. In particular, our fresh evidence using NARDL shows that the relationship between financial development and CO2 emissions is asymmetric, and the positive shocks of financial development have a more profound effect. The results also reveal that the roles of financial development in CO2 emissions are distinctive between high- and middle-income economies. In the long run, financial development helps to minimise CO2 emissions for high income economies, but it raises CO2 emissions and thereby decreases environmental quality for middle-income economies.

The remainder of the paper is structured as follows. Section 2 reviews relevant literature about the linkages between financial development, CO2 emissions and economic growth. Section 3 provides theoretical reasoning for the selection of broad money and stock market capitalisation as the proxies for financial development. Section 4 discusses data and methodology. Section 5 presents the empirical results. In this section, we present both linear and nonlinear ARDL models. Section 6 highlights contributions, limitations and policy implications.

2. Linkages between financial development, CO2 emissions and economic growth

Countries' CO2 emissions tend to vary with their level of economic development (Blackburn et al., 2012; Berdiev and Saunoris, 2016; Canh et al., 2020). In the literature, considerable attention has been paid to the association between financial development (represented by the financial sector) and CO2 emissions or other, broader effects such as environmental pollution, environmental quality, environmental degradation, etc. Financial development can provide effective financing at a lower cost to both enhance long-run economic growth and help improve environmental quality (Agyapong and Bedjabeng, 2019; Nasir et al., 2021).

In the literature, financial development is measured by multiple proxies in different studies. Examples include private credit by deposit money banks, financial system deposits, broad money supply, and deposit money bank assets, all in relation to GDP; credit market capitalisation; and stock market capitalisation (Agyapong and Bedjabeng, 2019; Maskus et al., 2019). Financial resources supporting a nation's economic growth are largely channelled through financial institutions (e.g. banks, insurance companies, funds/venture capital firms, and non-bank financial institutions) and financial markets (e.g. stock markets, bond markets, wholesale money markets, and non-traditional bank lending). As such, the impact of financial development on CO2 emissions should, in the economic context, consider both financial institutions and financial markets. However, earlier studies usually measured only one aspect of financial development (i.e. either financial institutions or financial markets) (Svirydzenka, 2016), which could overlook any heterogeneous impact of financial institutions and financial markets on environmental issues (Canh and Thanh, 2020).

Responding to the call from scholars such as Svirydzenka (2016), more recent research has taken a more holistic approach and expanded the measures of financial development in order to obtain deeper insights into its impact on the environment in the economic context (Botev et al., 2019; Nasir et al., 2019; Canh et al., 2020). These studies are diverse in terms of measurements, samples, periods, regions/countries, methodologies, findings, and implications. Below are some examples of key studies.

Canh et al. (2020) examine the relationship between financial development and energy intensity using a sample of 81 economies, divided into high-, upper-middle-, lower-middle- and low-income countries between 1997 and 2013. In addition to investigating the influence of both financial institutions and financial markets on energy intensity, including energy production and consumption, an interesting feature of this study is that it applies multiple financial dimensions (i.e. financial depth, financial access, and financial efficiency) to explore the relationship. Their findings reveal that, although financial development and energy intensity have a long-run relationship by generally increasing production energy intensity when financial depth and financial access reduce consumption energy intensity, financial efficiency increases consumption energy intensity. Moreover, while financial institutions increase consumption energy intensity, financial markets have the opposite effect. Furthermore, the results are different in different income groups; for instance, financial development decreases production energy intensity in high-income countries but increases in upper-middle-income nations, with mixed effects in lower-middle-income countries. Methodologically, their analysis is based on the IPAT (Human Impact, Population, Affluence and Technology) model (Ehrlich and Holdren, 1971) and the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model (Dietz and Rosa, 1997).

Nasir et al. (2019) aim to evaluate the influence of financial development, economic growth and FDI on CO2 emissions in ASEAN countries, drawing on panel data from 1982 to 2014 and using Dynamic Ordinary Least Squares (DOLS) and Fully Modified OLS (FMOLS) analyses. This paper measures financial development by multiple variables (i.e. bank credit to bank deposit (%), the number of listed companies per 10,000 population, and international debt issued over total GDP). They find financial development, economic growth and FDI can cause environmental degradation (CO2 emissions), showing a long-run cointegrating relationship. However, an inverted-U shaped Environmental Kuznets Curve (EKC) is confirmed; the negative impact of economic growth on environmental degradation is shown in the quadratic term, suggesting that the level of environmental degradation starts reducing after a certain point of economic growth.

In another study conducted using Australian data over the period 1980–2014, Nasir et al. (2021) investigate the influence of economic growth, trade openness, industrialisation and energy consumption on CO2 emissions. They measure financial development by three dimensions (financial efficiency, financial access and financial depth) in two subsectors (financial institutions and financial markets) and use STIRPAT as an analytical approach. The findings indicate bidirectional causality between economic growth, stock market development, energy use, and CO2 emissions, but there is no significant evidence of EKC.

There are other studies of both developed and developing countries, including Indonesia (Shahbaz et al., 2013a), China (Shahbaz et al., 2013b), Malaysia (Shahbaz et al., 2013c), Pakistan (Shahbaz et al., 2016), France (Shahbaz et al., 2018) and the UK (Shahbaz et al., 2020), with the latter dating back to 1870. These studies select from the various proxies for financial development mentioned earlier and adopt a range of different methods to analyse the short-run and long-run relationships between the variables of interest. Econometric methods used include the Zivot–Andrews unit root test, the ARDL bounds testing approach, and the VECM Granger causality technique. In these research papers, although there are specific findings in each study relating to different variables, strong and consistent empirical evidence show that in the long run, financial development decreases CO2 emissions while energy consumption and economic growth increase CO2 emissions; in some cases, the EKC hypothesis was confirmed and a U-shaped relationship between financial development and CO2 emissions observed.

Three key points emerge from this review of previous studies. First, financial development can be measured in various ways, but when evaluating its influence on CO2 emissions, proxies representing both financial institutions and financial markets are to be preferred. Second, many different economic variables (e.g., FDI, trade openness, industrialisation, energy production and consumption, exports, imports, R&D expenditures) can affect the relationship between financial development and CO2 emissions. Some influences might be country-specific, but when conducting cross-country research, it is impossible to include all or most of the variables relevant to all sample countries. In this case, dividing samples into different sub-sample groups based on certain criteria (e.g., income) might be a good solution to capture shared characteristics from that group in terms of their economic development level. Third, the relationship between financial development and CO2 emissions is complicated, and it may not always be linear – evident from the confirmation of the Environmental Kuznets Curve and an inverted-U shaped relationship in Nasir et al. (2019) and Shahbaz et al. (2020). However, many of the statistical and econometric analysis methods used in previous studies assume an underlying linear relationship between variables; a nonlinear analytic approach might help minimise bias in estimation. Furthermore, in the cases where nonlinearity has been addressed, there is a need for further evidence and comprehensive statistical analysis. This paper attempts to provide that.

3. Theoretical foundation

According to Friedman and Schwartz (1963), the Quantity Theory of Money (QTM) is described by Irwing Fischer's 'equation of exchange' (Fisher, 1911). The theory may be useful in offering a deeper understanding of how financial development affects an economy. In the formula M.VT = Σi (pi. qi) = pTq, M represents the total sum of money circulating in an economy at a given point in time; VT denotes the money's transaction velocity, which shows how rapidly it changes hands in an economy (M); p denotes the price level related to the transaction; and q indicates the transaction quantity at a given point in time. M, VT, and q are more likely to improve in a country under financial development, while p would decrease. Hicks (1937) introduced the Investment-Saving (IS) and Liquidity preference-Money supply (LM) macro-economic theory to explain how an economy's goods and money markets behave. The theory includes the three main exogenous variables – consumption, investment and liquidity – and states that liquidity is based on the velocity (VT) of the supply of money (M) while the level of investment and consumption are the decision of individual actors. The IS curve indicates the relationship between interest and GDP. In contrast, the LM curve shows the discrepancy between GDP and interest rates, in order to reach an equilibrium condition of both goods and money markets. When money supply increases due to financial development, interest rates decrease, and money's transaction velocity increases alongside consumption and investment. Thus, financial development can affect the economy differently, such as shifts in investment, wealth, scale, and trade-embodied effects.

The QTM and IS-LM theories can also be used to describe the relationship between financial development and CO2 emissions. Xiong and Qi (2016) assert that the level of financial development can be assessed by the effects of wealth and scale. With regards to the wealth effect, a strengthened financial market would alleviate liquidity constraints and increase wealth and resources, which in turn enables consumers to buy more 'large-ticket' items (i.e. high-priced items) such as cars and bigger houses. These activities would lead to increases in energy use and a rise in carbon emissions (Coban and Topcu, 2013). The scale effect occurs when industrial units increase their purchase of large-scale machinery to develop products and introduce new lines of production and implement rigorous marketing activities financed by financial institutions or funds raised from financial markets (Xing et al., 2017). Additionally, the development of the stock market is a leading indicator of the overall economy. The stock market is functional for obtaining enhanced economic growth through increased investment that results in money supply, increased income, capital accumulation, and risk diversification. Hamilton and Turton (2002) argue that listed companies can get access to inexpensive finance for their investments from the stock markets, which boosts economic activities, goods production and consumption. Consequently, it would increase demand for energy and lead to a rise in CO2 emissions. On the other hand, stock market development could provide funds for green energy adoption, sustainable energy infrastructure and innovative technology, resulting in the improvement of environmental quality and reduction of CO2 emissions (Shahbaz et al., 2013c). As such, financial development can play a significant role in both promoting and curbing carbon emissions (Ziaei, 2015).

From the theoretical foundation and discussions above, it is clear that money supply and stock market capitalisation are two important measures of financial development. Our paper, therefore, uses broad money and stock market capitalisation as the proxies of financial development. This is in line with the point made in the previous section, that the measurement of financial development should cover both financial institutions and financial markets.

4. Data and methodology

4.1. Data and descriptive statistics

Based on data availability, we employ a panel dataset of 61 countries categorising as high, upper-middle, and lower-middle incomes for the 1990–2018 period, utilising The World Bank Group (2021a) data from the World Development Indicators. The detail of selected countries for all three groups classified by The World Bank Group (2021b) is reported in Table 1. However, to achieve optimal panel analysis, we subsequently merge the upper-middle and lower-middle income countries into one 'middle-income' group.

In our estimations, CO2 emissions are measured in tonnes per capita, and financial development is measured by broad money (% of GDP) and the market capitalisation of domestic listed companies (% of GDP). Other explanatory variables include energy use (per capita kilograms of oil equivalent), GDP per capita (current USD), and FDI (net inflows, % of GDP). Descriptive statistics are presented in Table 2. All the variables are considerably higher in high-income than in middle-income countries. A bell-shaped curve is called symmetric if the skewness of distribution is zero and kurtosis equals three. Our findings show that skewness values are positive for all variables in the two panels indicating that the variables have a long tail in the positive direction (skewed right). The kurtosis values for most variables indicate the conclusion of non-normal distributions as they are much higher than three. These imply that most variables considered have excess kurtosis (fat tail behaviour). The Jarque-Bera test's null hypotheses and the values of probability that the time series are distributed normally are rejected for all variables and are

Table 1
Sample countries.

No.	High income	Upper middle income	Lower middle income
1	Australia	Argentina	Algeria
2	Austria	Brazil	Bangladesh
3	Bahrain	China	Egypt, Arab Rep.
4	Belgium	Colombia	Ghana
5	Canada	Indonesia	India
6	Chile	Iran, Islamic Rep.	Kenya
7	Denmark	Jordan	Nigeria
8	Finland	Lebanon	Pakistan
9	France	Malaysia	Philippines
10	Germany	Mexico	Sri Lanka
11	Greece	Peru	Tunisia
12	Hong Kong SAR, China	South Africa	
13	Iceland	Thailand	
14	Ireland	Turkey	
15	Israel		
16	Italy		
17	Japan		
18	Korea, Rep.		
19	Kuwait		
20	Mauritius		
21	Netherlands		
22	New Zealand		
23	Norway		
24	Oman		
25	Poland		
26	Portugal		
27	Romania		
28	Saudi Arabia		
29	Singapore		
30	Spain		
31	Sweden		
32	Switzerland		
33	Trinidad and Tobago		
34	United Kingdom		
35	United States		
36	Uruguay		

thus non-normal.

The correlations between the variables for the two categories of country are presented in Table 3, which indicates that CO2 emissions are highly correlated with energy use for both panels: high income (0.84) and middle-income (0.93). CO2 emissions are also positively correlated with GDP (0.33) and market capitalisation of domestic listed companies (0.01) in high-income economies, and positively related to all variables in those characterised by middle incomes. However, CO2 emissions are negatively correlated with broad money (−0.05) and FDI (−0.03) in high-income economies. The correlation analysis suggests that there are differences in effects between the two types of economy. Financial and economic development enhance environmental quality via CO2 reduction for the high-income economies but are harmful to the environment in the middle-income economies. This evidence provides the rationale that we should proceed with the linear and nonlinear ARDL analyses.

4.2. ARDL model

Since this study is based on the panel data taking both time series and cross-sectional dimensions, the problems of endogeneity, heteroscedasticity, serial correlation, and multicollinearity would be controlled in better ways (Baltagi, 2013). The functional form of the econometric model is described as:

$$CO2_{it} = f(ENR_{it},\ FDI_{it},\ GDP_{it},\ BM_{it},\ MC_{it}) \tag{1}$$

It can be stated more formally as:

Table 3
Correlation matrices.

HIE	CO2	Broad money	Energy Use	FDI	GDP	Market Cap
CO2	1.00	−0.05	0.84	−0.03	0.33	0.01
Broad money	−0.05	1.00	−0.11	0.29	0.36	0.67
Energy Use	0.84	−0.11	1.00	−0.02	0.50	−0.02
FDI	−0.03	0.29	−0.02	1.00	0.13	0.42
GDP	0.33	0.36	0.50	0.13	1.00	0.20
Market Cap	0.01	0.67	−0.02	0.42	0.20	1.00
MIE	**CO2**	**Broad money**	**Energy Use**	**FDI**	**GDP**	**Market Cap**
CO2	1.00	0.41	0.93	0.20	0.78	0.44
Broad money	0.41	1.00	0.32	0.54	0.24	0.31
Energy Use	0.93	0.32	1.00	0.14	0.76	0.43
FDI	0.20	0.54	0.14	1.00	0.25	0.23
GDP	0.78	0.24	0.76	0.25	1.00	0.26
Market Cap	0.44	0.31	0.43	0.23	0.26	1.00

Note: HIE and MIE represent high- and middle-income economies.

Table 2
Descriptive statistics.

HIE	CO2	Broad Money	Energy Use	FDI	GDP	Market Cap
Mean	10.124	85.633	4602.209	5.157	28453.540	86.210
Median	8.812	75.793	4001.902	2.400	26009.270	63.197
Maximum	36.089	363.366	18157.600	86.589	102913.500	1254.465
Minimum	1.270	26.131	657.624	−7.392	1599.890	0.000
Std. Dev.	6.112	47.566	2757.810	8.537	17201.540	120.192
Skewness	1.713	2.328	1.633	3.887	0.999	6.363
Kurtosis	6.434	10.413	6.664	25.811	4.687	52.678
Jarque-Bera	769.689	2506.698	787.936	18996.200	223.674	86017.080
Probability	0.000	0.000	0.000	0.000	0.000	0.000
MIE	**CO2**	**Broad Money**	**Energy Use**	**FDI**	**GDP**	**Market Cap**
Mean	2.858	64.630	1101.848	2.664	3540.835	46.066
Median	2.400	50.379	909.893	2.029	2745.791	26.073
Maximum	9.979	244.098	3060.387	23.537	13245.610	320.992
Minimum	0.146	9.063	126.799	−2.757	220.070	0.053
Std. Dev.	2.296	45.819	689.774	2.703	2958.272	53.595
Skewness	1.094	1.771	0.918	2.681	1.183	2.381
Kurtosis	3.633	6.270	3.073	14.294	3.872	9.075
Jarque-Bera	109.783	491.886	71.430	3308.484	134.565	1261.304
Probability	0.000	0.000	0.000	0.000	0.000	0.000

Note: HIE and MIE represent high- and middle-income countries, respectively. ‘Probability’ refers to the probability that the time series are distributed normally.

$$CO2_{it} = \alpha_0 + \alpha_1 FDI_{it} + \alpha_2 ENR_{it} + \alpha_3 GDP_{it} + \alpha_4 BM_{it} + \alpha_5 MC_{it} + \varepsilon_{it} \tag{2}$$

where $CO2_{it}$ is ln (natural logarithm) CO2 emissions (per capita metric tons), FDI_{it} refers to FDI (net inflows, % of GDP), ENR_{it} is ln energy usage (per capita kilograms of oil equivalent), GDP_{it} is ln per capita GDP (current US$), BM_{it} is broad money (% of GDP), and MC_{it} is the market capitalisation of domestic listed companies (% of GDP). The i = 1,2 … N, t = 1,2 …. T, here, N is the individual country in the three panels, T is the analytical time spans in the years. The ARDL technique is based on Pesaran et al.'s (2001) seminal work and is utilised for two purposes: (i) to determine the short- and long-term cointegration correlations amongst the variables; and (ii) the short-term dynamics are identified by acquiring the panel's error correction version. The traditional methods of cointegration are widely used to evaluate the long-term relations; however, there are many advantages of using the panel ARDL method. This approach can be employed irrespective of the variables being cointegrated at order I (0), I (1), or even if the variables are cointegrated at both levels. The panel ARDL can contain different lags, as opposed to the standard cointegration test. Furthermore, the panel ARDL determines coefficients of a short- and long-term nature simultaneously. The ARDL approach is also advantageous since it can be used for a small dataset.

4.3. Bounds test for cointegration

Based on Aristei and Martelli (2014), the panel ARDL model is evaluated for the bounds test method using the following equation:

$$\Delta CO2_{it} = \beta_1 + \sum_{i}^{k} a_{ij}\Delta CO2_{j,t-1} + \sum_{i=0}^{k} \beta_{ij}\Delta FDI_{j,t-i} + \sum_{i=0}^{k} X_{ij}\Delta ENR_{j,t-i} + \sum_{i=0}^{k}\delta_{ij}\Delta GDP_{j,t-i} + \sum_{i=0}^{k}\partial_{ij}\Delta BM_{j,t-i} + \sum_{i=0}^{k}\gamma_{ij}\Delta MC_{j,t-i} + \emptyset_1 CO2_{j,t-i} + \emptyset_2 FDI_{j,t-i} + \emptyset_3 ENR_{j,t-i} + \emptyset_4 GDP_{j,t-i} + \emptyset_5 BM_{j,t-i} + \emptyset_6 MC_{j,t-i} \tag{3}$$

where Δ represents the first variation factor, and k signifies the optimum lag length.

The following hypotheses have been proposed to examine the long-term cointegration correlation amongst the variables: H0: θ1 = θ2 = θ3 = θ4 = θ5 = 0 (no cointegration); H1: θ1≠θ2≠θ3≠θ4≠θ5≠0 (cointegration exists). Using the F test, it is possible to test the 'no cointegration' null hypothesis and the 'cointegration exists' alternative hypothesis. When the F-statistic is above the upper critical bound, a relationship amongst the variables of a long-term nature is verified. Once the variables show a long-term relationship, estimation of the models is possible via the following two equations given estimations of a long- and short-term nature simultaneously:

$$CO2_{it} = \beta_2 + \sum_{i}^{k} a_{i2} CO2_{j,t-1} + \sum_{i=0}^{k}\beta_{i2} FDI_{j,t-i} + \sum_{i=0}^{k} X_{i2} ENR_{j,t-i} + \sum_{i=0}^{k}\delta_{i2} GDP_{j,t-i} + \sum_{i=0}^{k}\partial_{i2} BM_{j,t-i} + \sum_{i=0}^{k}\gamma_{i2} MC_{j,t-i} + \varepsilon_{it2} \tag{4}$$

$$\Delta CO2_{it} = \beta_3 + \sum_{i}^{k} a_{i3}\Delta CO2_{j,t-1} + \sum_{i=0}^{k} \beta_{i3}\Delta FDI_{j,t-i} + \sum_{i=0}^{k} X_{i3}\Delta ENR_{j,t-i} + \sum_{i=0}^{k}\delta_{i3}\Delta GDP_{j,t-i} + \sum_{i=0}^{k}\partial_{i3}\Delta BM_{j,t-i} + \sum_{i=0}^{k}\gamma_{i3}\Delta MC_{j,t-i} + \rho ECT_{j,t-i} + \varepsilon_{it3} \tag{5}$$

4.4. NARDL model

The asymmetric cointegration model is formulated as:

$$CO2_{it} = \alpha_0 + \alpha_1 FDI_{it} + \alpha_2 ENR_{it} + \alpha_3 GDP_{it} + \alpha_4 BM_{it}^{+} + \alpha_5 BM_{it}^{-} + \alpha_6 BM_{it}^{-} + \alpha_7 BM_{it}^{-} + \varepsilon_{it} \tag{6}$$

where most of the definitions are the same as above. Financial development, represented by BM_{it} (broad money) and MC_{it} (market capitalisation of domestic listed companies), is converted into positive and negative partial sums by decomposition as:

$$BM_t = BM_0 + BM_t^{+} + BM_t^{-} \tag{7}$$

$$BM_t = \sum_{i=1}^{t}\Delta BM_i^{+} = \sum_{i=1}^{t}\max\left(\Delta BM_{i,}0\right) \tag{8}$$

$$BM_t^{-} = \sum_{i=1}^{t}\Delta BM_i^{-} = \sum_{i=1}^{t}\min\left(\Delta BM_{i,}0\right) \tag{9}$$

$$MC_t = MC_0 + MC_t^{+} + MC_t^{-} \tag{10}$$

$$MC_t^{+} = \sum_{i=1}^{t}\Delta MC_i^{+} = \sum_{i=1}^{t}\max\left(\Delta MC_{i,}0\right) \tag{11}$$

$$MC_t^{-} = \sum_{i=1}^{t}\Delta MC_i^{-} = \sum_{i=1}^{t}\min\left(\Delta MC_{i,}0\right) \tag{12}$$

where Δ is the difference operator, $\Delta BM_i = BM_t - BM_{t-1}$, $\Delta MC_i = MC_t - MC_{t-1}$, + and − represent the partial amounts of positive and negative variations in broad money (BM_t) and market capitalisation of domestic listed companies (MC_t). The NARDL model proposed describes the following asymmetric error-correction estimation (Shin et al., 2014):

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{k}\alpha_{1j}\Delta CO2_{t-1} + \sum_{i=0}^{k}\alpha_{2i}\Delta FDI_{t-i} + \sum_{i=0}^{k}\alpha_{3i}\Delta ENR_{t-i} + \sum_{i=0}^{k}\alpha_{4i}\Delta GDP_{t-i} + \sum_{i=0}^{k}\alpha_{5i}\Delta BM_{t-1}^{+} + \sum_{i=0}^{k}\alpha_{6i}\Delta BM_{t-i}^{-} + \sum_{i=0}^{k}\alpha_{7i}\Delta MC_{t-i}^{+} + \sum_{i=0}^{k}\alpha_{8i}\Delta MC_{t-i}^{-} + \rho_1 CO2_{t-1} + \rho_2 FDI_{t-1} + \rho_3 ENR_{t-1} + \rho_4 GDP_{t-1} + \rho_5 BM_{t-1}^{+} + \rho_6 BM_{t-1}^{-} + \rho_7 MC_{t-1}^{+} + \rho_8 MC_{t-1}^{-} + \varepsilon_t \tag{13}$$

where k is the optimal lag length. The Akaike information criteria is chosen to select the ideal lag order because of its superior explanatory power and properties.

4.5. Panel causality test

We use the Dumitrescu-Hurlin (DH) test (Dumitrescu and Hurlin,

Table 4
Cross-sectional dependence tests.

CD Tests	Panel of Economies		
	High Income Economies		
Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	2507.791	630	0.000
Pesaran scaled LM	52.901		0.000
Pesaran CD	10.983		0.000
	Middle Income Economies		
Test	**Statistic**	**d.f.**	**Prob.**
Breusch-Pagan LM	2243.407	300	0.000
Pesaran scaled LM	79.339		0.000
Pesaran CD	31.628		0.000

2012) for panel causality, which allows us to identify the direction of causality amongst the variables. This test assumes non-causality is averaged across the cross-sectional units and based on individual Wald statistics. The mathematical equation can be described as:

$$y_{it} = \alpha_i + \sum_{j-1}^{j} \lambda_i^j y_{i(t-j)} + \sum_{j=1}^{j} \beta_i^j X_{i(t-j)} + \varepsilon_{it} \quad (14)$$

where: y and x are observables; λ_i^j describes the autoregressive parameters; and β_i^j represents the regression coefficient estimates, which are presumed to differ between the cross-sections. No causal relationship exists for any subgroup according to the null hypothesis, while based on the alternative hypothesis one or more subgroup of the panel has a causal relationship. An average Wald statistic is applied to test the hypothesis:

$$W_{N.T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,T}$$

where $W_{i,T}$ indicates the singular Wald statistic in terms of each cross-sectional unit.

5. Empirical results

This section presents the results of the tests described in the previous section.

5.1. Cross-sectional dependence tests

Rauf et al. (2018) state that for panel data, the initial step to construct empirical analysis is to detect and resolve cross-sectional dependence before proceeding with the unit root tests. The null

Table 5
Panel unit root tests.

High-income economies					
Variables	Tests	Intercept		Intercept and trend	
		At level	At 1st difference	At level	At 1st difference
CO2	IPS	3.519	−13.472***	3.355	−12.3433***
	ADF	50.804	322.670***	50.021	280.191***
	PP	60.183	626.731***	63.680	840.619***
Broad money	IPS	3.348	−15.157***	−1.100	−11.712***
	ADF	39.894	362.267***	91.665*	269.324***
	PP	68.856	679.624***	401.094***	1531.460***
Energy Use	IPS	1.535	−11.6661***	4.436	−11.930***
	ADF	68.592	273.215***	41.217	269.360***
	PP	95.058**	601.471***	68.374	1222.090***
FDI	IPS	−6.314***	−21.3993***	−4.922***	−18.202***
	ADF	155.552***	523.625***	140.926***	410.893***
	PP	262.283***	884.195***	508.862***	2858.110***
GDP	IPS	2.800	−14.510***	0.032	−10.524***
	ADF	31.218	341.451***	59.970	236.214***
	PP	32.733	407.788***	40.804	288.064***
Market Cap	IPS	−4.319***	−19.0779***	−1.843**	−16.459***
	ADF	117.264***	468.136***	85.160	379.864***
	PP	131.652***	849.286***	119.551***	2256.780***
Middle-income economies					
Variables	**Tests**	**Intercept**		**Intercept and trend**	
		At level	**At 1st difference**	**At level**	**At 1st difference**
CO2	IPS	1.816	−11.211***	0.104	−8.417***
	ADF	33.320	221.413***	51.207	163.001***
	PP	38.178	456.953***	59.583	429.835***
Broad money	IPS	0.173	−10.595***	−0.555	−8.251***
	ADF	69.035**	209.169***	63.414*	159.220***
	PP	52.152	409.529***	69.228**	377.085***
Energy Use	IPS	4.251	−8.87475***	2.861	−7.194***
	ADF	26.393	174.916***	28.236	142.736***
	PP	41.064	396.087***	42.865	666.036***
FDI	IPS	−6.156***	−16.806***	−4.093***	−14.025***
	ADF	125.525***	341.946***	98.642***	263.346***
	PP	149.319***	559.0000***	121.638***	2057.190***
GDP	IPS	3.709	−8.780***	1.515	−5.585***
	ADF	19.118	171.585***	30.839	115.521***
	PP	32.670	308.239***	37.971	268.625***
Market Cap	IPS	−2.942***	−13.7459***	−2.185**	−11.071***
	ADF	75.299**	280.703***	73.544**	218.561***
	PP	118.777***	539.830***	126.179***	1227.910***

Note: The symbols *, **, and *** denote significance at the 10 %, 5 %, and 1 % levels, respectively. Regarding, Im-Pesaran-Shin (IPS) unit-root test, ADF and Phillips-Perron (PP) individual unit root tests, H_0: All panels contain unit roots (or all the series are non-stationary) and H_1: Some panels are stationary.

Table 6
Linear ARDL estimation.

Variable	Panel-ARDL Analysis Results					
	All Economies		High Income		Middle Income	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Long Run Equation						
Broad money	0.048	1.341	−0.048**	−2.104	0.409***	4.642
Energy Use	0.533***	12.137	1.081***	45.613	0.426***	7.373
FDI	1.179***	4.489	−0.211***	−2.655	0.064	0.166
GDP	0.106***	8.740	−0.081***	−7.586	0.162***	11.074
Market Cap	0.041	1.628	−0.026***	−3.678	0.030	1.030
Short Run Equation						
ΔBroad money	−0.046	−0.651	−0.019	−0.278	−0.093	−0.655
ΔEnergy Use	0.941***	8.640	0.794***	9.042	0.848***	3.544
ΔFDI	−0.074	−0.432	−0.013	−0.063	0.227	1.078
ΔGDP	0.009	0.283	0.033	0.684	0.046	1.040
ΔMarket Cap	−0.790	−1.020	−0.005	−0.241	−2.180	−1.013

Note: The symbols *, **, and *** denote the significance at the 10 %, 5 %, and 1 % levels, respectively.

hypothesis is cross-sectional independence in the panel, so the rejection of the null hypothesis implies the existence of cross-sectional dependency. The results of the two tests are shown in Table 4, where cross-sectional independence is rejected, and the presence of cross-sectional dependency is confirmed in the two panels.

5.1.1. Unit root tests

Cointegration tests require that all variables are integrated into order. Thus, determination of the integration order is essential for each variable. First-generation panel unit root tests can no longer be implemented, because of the presence of cross-sectional dependence and poor size properties. Instead, we apply alternative unit root tests (including the Fisher-ADF, Fisher-PP, and the Im, Pesaran, and Shin (IPS) tests) from the second generation to detect the order of integration. These tests can determine the cross-sectional dependence and heterogeneity (Pesaran, 2021). If two variables are individually not stationary but stationary when linearly combined, then the order (1,1) cointegration is identified for these variables.

The results of unit root tests can be found in Table 5 when applied in the level form and in the first difference form. At the 1 % significance level, with strict assumptions and a broad set of tests from ADF, PP, and IPS, all variables at the first difference can be noted as stationary for the two panels.

5.2. Linear ARDL estimation

Table 6 presents the linear ARDL results, first using the full dataset to obtain an overall view and then split into high- and middle-income economies.

Table 6 shows that financial development (both broad money and domestic market capitalisation) has no significant impact on CO2 emissions when all countries are considered together. However, when the results for high-income and middle-income countries are examined separately, this overall result is shown to mask two different effects. Notably, as suggested earlier, financial development is positively associated with CO2 emissions in middle-income economies while negative in high-income countries. In the high-income economies and long run, both broad money and domestic listed companies' market capitalisation result in a significantly negative correlation with the emission of CO2, implying that financial development would decrease CO2 emissions, and therefore enhance environmental quality. This finding is dissimilar to the study of Shahbaz et al. (2020), which shows that broad money (as per our study) in the UK has a positive relationship with CO2 emissions.

For our middle-income sample economies, broad money has a significantly positive relationship to CO2 emissions but not for stock market capitalisation. The findings partially confirm the work of Khan et al. (2017), who discover a significantly positive association between broad money and CO2 emissions in India, but not in Bangladesh and Pakistan, and Abbasi and Riaz (2016), who find an insignificant effect of stock market capitalisation on CO2 emissions in Pakistan. Nonetheless, our results disagree with that of Hafeez et al. (2018), who conclude that where the stock market allows easy access to finance, it has beneficial impacts on investment in production and increases the CO2 emissions level. Arguably, our results are understandable in an economic sense because, in middle-income countries, the scales and maturity of the stock market are limited compared to their high-income counterparts. For example, in low- or middle-income economies, investors' behaviours are often driven by psychological factors and stock markets' prices are easily influenced by the local political situation and illegal activities. It is also evident that the stock market policies in low- or middle-income economies are inconsistent and non-transparent because of unreasonable government actions (Thampanya et al., 2020). These immature features would affect the relationship between financial development and CO2 emissions. Moreover, financial sectors, representing the level of financial development, in the high-income economies are comparatively larger than in the middle-income economies. In the high-income economies, broad money (% of GDP) is 1.33 times larger than those of the middle-income countries. Similarly, their market capitalisation of listed domestic companies (% of GDP) is 1.87 times larger than those of the middle-income countries (as shown in Table 2). This scale and importance are reflected in their impacts in Table 6, discussed above. Overall, financial development decreases (increases) environmental degradation in the high-income (middle-income) economies. In short, our results indicate that financial development is a crucial prerequisite for enhancing environmental quality in the long run.

As shown in Table 6, all explanatory variables of the three panels have long- and short-run relationships with CO2 emissions. Overall, the findings are consistent with relevant studies discussed earlier (e.g., Shahbaz et al., 2013a, 2013b; Nasir et al., 2019; Nguyen and Lee, 2021). Specifically, the findings from the full data set reveal that energy use, FDI, and GDP, in the long run, are positively associated with CO2 emissions, indicating that increases in all three explanatory variables raise environmental pollution. In the short run, an increase in CO2 emissions can be explained by an increase in energy use, as for all sample countries, increased energy use raises CO2 emissions. It is understandable that energy consumption and GDP growth can positively and directly cause the increase of CO2 emissions (Shahbaz et al., 2013a; Canh et al., 2020).

Notably, there are large coefficients of broad money and GDP in middle-income economies compared to high-income group. This suggests that financial and economic variables have more predictive power in explaining CO2 emissions for middle-income economies. The results align with those of Shoaib et al. (2020), who find emissions of CO2 due to financial development to be more prevalent in developing economies

Table 7
Nonlinear ARDL estimation.

Variable	Panel-NARDL Analysis Results					
	All Economies		High Income		Middle Income	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Long Run Equation						
Broad Money_Pos	0.302***	5.003	−0.092***	−3.992	0.128	1.530
Broad Money_Neg	−0.512***	−9.117	0.054**	2.037	−0.048	−0.702
Energy Use	0.580***	13.760	1.085***	73.714	0.699***	12.775
FDI	−0.114***	−5.556	−0.309***	−5.083	1.194***	3.431
GDP	0.005	0.328	−0.082***	−11.497	−0.018	−0.857
Market Cap_Pos	−0.082***	−10.139	0.005	0.781	0.181***	4.797
Market Cap_Neg	0.060***	3.960	−0.018***	−2.891	−0.069	−1.487
Short Run Equation						
ΔBroad Money_Pos	0.187	1.047	−0.025	−0.176	0.635	1.596
ΔBroad Money_Neg	−0.129	−0.823	−0.125	−1.072	−0.609*	−1.817
ΔEnergy Use	0.908***	12.603	0.772***	9.147	0.687***	4.640
ΔFDI	0.081	0.428	0.139	0.907	−0.019	−0.044
ΔGDP	0.031	0.678	0.049	0.685	0.025	0.449
ΔMarket Cap_Pos	−0.519	−1.047	0.054	0.900	−0.897	−1.338
ΔMarket Cap_Neg	−0.576	−1.003	−0.024	−0.716	0.748	1.225

Note: The symbols *, **, and *** denote the significance at the 10 %, 5 %, and 1 % levels, respectively.

than in their developed counterparts.

Regarding FDI's relationship with CO2 emission (same as with energy consumption and GDP growth), in the literature, they usually show an inverted-U EKC curve, suggesting that inward FDI to the host countries, which have weak environmental regulations and policies, generally leads environment degradation (the pollution-haven hypothesis) before there is a turn to decreases in CO2 emissions through innovative environmental technologies and efficiencies attributable to FDI companies or improved environmental standards and practices in the host country (i.e., the pollution-halo hypothesis) (Naughton, 2014, cited in Nasir et al., 2019). Our findings support this argument. As shown in Table 6, increasing FDI helps reduce CO2 emissions in the high-income economies but has no significant impact in the middle-income economies. Interestingly, no cointegration exists between financial and economic development and CO2 emissions in all three panels.

5.3. Nonlinear ARDL estimation

In the existing literature, the relationship between financial development and CO2 emissions has been mainly examined in a linear framework. However, assuming an underlying linear relationship could lead to bias in estimations because regime adjustments and changeable economic conditions can induce possible asymmetries. The variables themselves can be unevenly linked or complexly interrelated. Hence, we apply the nonlinear ARDL (NARDL) model to ascertain an asymmetric association in the short- and long-run between financial development (broad money and market capitalisation of domestic listed companies) and CO2 emissions while using additional explanatory variables (energy usage, FDI, and GDP per capita) in the function of the CO2 emissions.

The results of the NARDL model are reported in Table 7. As specified in Eqs. (7) and (10), broad money and market capitalisation of domestic listed companies are split into positive and negative shocks. We find that, in the long run, both negative and positive shocks of financial development have significant impacts on CO2 emissions, while the latter have a more profound effect. In the case of the full dataset, the findings are quite different from the results of the ARDL model where, in Table 6, financial development has no significant impact on CO2 emissions. However, it turns out to be significant when a nonlinear assumption is applied (Table 7). This indicates that financial development does not linearly affect CO2, implying that nonlinear assumption is more critical than linear one in the analysis of the role of financial development on environmental quality. Moreover, positive and negative shocks perform differently in the country groups with different income levels. For example, regarding the high-income economies, the positive (negative) shock of broad money decreases (increases) CO2 emissions. However, impact of positive shock (−0.092) is greater than that of negative shock (0.054), demonstrating that positive shocks have more profound effects than negative shocks. It is also observed that the negative shock of domestic listed companies' market capitalisation helps reduce CO2 pollution. Contrarily, for the middle-income economies, there is no significant effect, from either positive or negative shocks, of broad

Table 8
Pairwise Dumitrescu-Hurlin panel causality tests.

All Economies		
Null Hypothesis:	W-Stat.	Prob.
Broad money does not homogeneously cause CO2	2.677	0.000
CO2 does not homogeneously cause Broad money	2.761	0.000
Energy use does not homogeneously cause CO2	2.799	0.000
CO2 does not homogeneously cause Energy use	2.549	0.000
FDI does not homogeneously cause CO2	1.174	0.715
CO2 does not homogeneously cause FDI	1.933	0.000
GDP does not homogeneously cause CO2	3.919	0.000
CO2 does not homogeneously cause GDP	2.756	0.000
Stock market cap. does not homogeneously cause CO2	2.525	0.000
CO2 does not homogeneously cause Stock market cap.	2.135	0.000
High Income Economies		
Null Hypothesis:	**W-Stat.**	**Prob.**
Broad money does not homogeneously cause CO2	3.121	0.000
CO2 does not homogeneously cause Broad money	2.307	0.000
Energy use does not homogeneously cause CO2	3.245	0.000
CO2 does not homogeneously cause Energy use	3.306	0.000
FDI does not homogeneously cause CO2	1.366	0.332
CO2 does not homogeneously cause FDI	2.064	0.001
GDP does not homogeneously cause CO2	4.355	0.000
CO2 does not homogeneously cause GDP	2.758	0.000
Stock market cap. does not homogeneously cause CO2	2.086	0.001
CO2 does not homogeneously cause Stock market cap.	1.497	0.192
Middle Income Economies		
Null Hypothesis:	**W-Stat.**	**Prob.**
Broad money does not homogeneously cause CO2	2.036	0.005
CO2 does not homogeneously cause Broad money	3.416	0.000
Energy use does not homogeneously cause CO2	2.156	0.002
CO2 does not homogeneously cause Energy use	1.459	0.297
FDI does not homogeneously cause CO2	0.897	0.552
CO2 does not homogeneously cause FDI	1.744	0.052
GDP does not homogeneously cause CO2	3.291	0.000
CO2 does not homogeneously cause GDP	2.754	0.000
Stock market cap. does not homogeneously cause CO2	3.157	0.000
CO2 does not homogeneously cause Stock market cap.	3.055	0.000

money on the CO2 emissions. Nevertheless, the positive shock of domestic listed companies' market capitalisation significantly increases CO2 emissions, while negative shock is insignificant. Moreover, in the short run, the positive and negative shocks of financial development do not significantly affect CO2 emissions for high-income economies, and only the negative shock of broad money affects CO2 emissions at 10 % statistically significance level.

In summary, compared to the linear ARDL estimation, the NARDL estimation captures richer insights into the asymmetric effects of financial development on CO2 emissions in both economy groups. We can now conclude that an increase in broad money in the high-income economies would enhance environmental quality, while environmental degradation would increase significantly by the rise in domestic listed companies' market capitalisation in the middle-income economies. These findings can perhaps be explained by the efficiency of financial resource allocation, either via broad money or through stock markets in the high- and middle-income countries, which directly affect CO2 emissions.

5.4. Panel causality test results

To investigate heterogeneous causal effects between the variables, the DH panel causality test is applied for the three panels. The results in Table 8 indicate that, for the full dataset, only FDI has a unidirectional relationship to CO2 emissions while other four explanatory variables (i.e. broad money, energy use, GDP, and stock market capitalisation) have bidirectional relationships with CO2 emissions.

With regards to the high-income economies, FDI and stock market capitalisation have unidirectional associations with CO2 emissions; however, other three variables (broad money, energy use, and GDP) have a bidirectional relationship with CO2 emissions. For the middle-income economies, FDI and energy use have unidirectional relations with CO2 emissions, while the other three variables (broad money, GDP, and stock market capitalisation) have bidirectional relationships with CO2 emissions.

Notably, financial development and CO2 emissions are strongly related in all of the three panels. The market capitalisation of domestic listed companies causes CO2 emissions in all two groups of economies. Our findings are consistent with those of Zhang (2011) in China, which suggests that stock market scale has a meaningful influence on CO2 emissions. The descriptive statistics in Table 2 shows that the means of the market capitalisation of domestic listed companies (% of GDP) for high- and middle-income economies are 86.21 % and 46.07 %, respectively, and this would reflect the importance of stock market development in the reduction of CO2 emissions.

5.5. Robustness check

Financial development can be proxied in various ways. We selected proxies for financial institutions and financial markets. It was important to measure the two types of financial development separately, but other proxies are available. The useful one for a robustness check is the IMF's financial development index (International Monetary Fund, 2020), which captures various aspects of financial development in a single number. Table 9 displays a robustness check that uses this alternative measure.

Running ARDL and NARDL models confirms our nonlinear hypothesis that CO2 emissions can be explained by financial development, but linearity is not inherent in its structure. As expected, the IMF's financial development index is associated with increases in environmental quality in high-income countries, and, conversely, with higher CO2 emissions in middle-income countries.

6. Discussion and conclusion

Unlike most similar studies (see some examples in Section 2), which examine the impact of financial development on CO2 emissions using a linear framework, the current paper is one of just a few pioneer studies that adopt both linear and nonlinear approaches. This means that the bias from linear analysis can be minimised, and richer explanations of

Table 9
Linear and nonlinear ARDL estimations: robustness check.

Variable	Panel-ARDL Analysis Results					
	All Economies		High Income		Middle Income	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Long Run Equation						
Energy Use	0.879***	28.304	1.008***	24.909	0.829***	21.161
FDI	−0.003	−0.244	−0.655***	−4.104	−0.155	−0.868
GDP	−0.079***	−9.291	−0.101***	−6.664	0.049***	4.563
FD	0.025	0.652	0.121**	1.972	−0.031	−0.768
Short Run Equation						
Energy Use	0.873***	9.434	0.939***	13.436	0.772***	3.915
FDI	0.005	0.052	0.051	0.304	0.472**	1.989
GDP	0.201**	2.014	0.007	0.311	0.036	1.208
FD	0.021	0.224	−0.036	−1.468	0.073	0.322
Variable	**Panel-NARDL Analysis Results**					
	All Economies		**High Income**		**Middle Income**	
	Coef.	**t-Stat**	**Coef.**	**t-Stat**	**Coef.**	**t-Stat**
Long Run Equation						
Energy Use	0.897***	30.798	1.074***	33.431	0.759***	20.967
FDI	−0.006	−0.470	−0.034	−0.645	−0.061	−0.523
GDP	−0.085***	−7.844	−0.068***	−8.527	0.076***	7.456
FD_Pos	−0.185***	−5.987	−0.178***	−6.637	0.079*	1.876
FD_Neg	−0.140***	−4.155	−0.130***	−4.513	0.252***	3.141
Short Run Equation						
Energy Use	0.879***	9.478	0.854***	11.430	0.794***	3.970
FDI	0.004	0.043	0.015	0.081	0.533**	2.102
GDP	0.234**	2.191	0.003	0.122	0.038	1.142
FD_Pos	0.023	0.135	0.041	0.736	−0.106	−0.255
FD_Neg	−0.055	−0.241	−0.112	−1.119	−0.007	−0.013

Note: The symbols *, **, and *** denote the significance at the 10 %, 5 %, and 1 % levels, respectively. FD represents Financial Development.

the relationship can be provided. Herewith, we summarise our findings and discuss contributions and policy implications.

First, the paper argues that although CO2 emissions can be explained by financial development, linearity is not inherent in its structure. This argument is demonstrated when the nonlinear assumption is applied in our analyses. For example, the effects of financial development on CO2 emissions change from not significant under linear ARDL estimation to significant when nonlinear estimation, NARDL, is applied. This finding is consistent in the case of full data set with all economic groups. As such, the substantial evidence suggests that the relationship between financial development and environmental quality (here, CO2 emissions) is dynamic and asymmetric, implying that a nonlinear assumption is more critical than a linear one in the analysis of the role of financial development on environmental quality. Indeed, the results from nonlinear analytical approaches should have more explanatory power than those based on linear assumption. Therefore, we can conclude that financial development, measured by broad money and market capitalisation of domestic listed companies, *does* significantly affect CO2 emissions in the countries at different development stages – a finding that is likely to be missed, or confusing at best, in solely linear analysis. Moreover, NARDL model results show that in the long run, although both negative and positive shocks of financial development have significant impacts on CO2 emissions, the positive shocks have a more profound effect than the negative ones. This sets economic meaning that increasing in financial development plays crucial role to reduce CO2 emissions and to achieve carbon neutrality targets. The results support a number of studies discussed earlier (see Section 2), which claimed that financial development can have an impact on environmental quality through CO2 reductions. However, the analysis in the current paper is particularly comprehensive.

Second, we find that financial development has different impacts on CO2 emissions in countries with different income levels. Specifically, the analyses from ARDL and NARDL reveal that in the long run, financial development helps to minimise CO2 emissions for high income economies, but it raises CO2 emissions and thereby decreases environmental quality for middle-income economies. From the more insightful NARDL model, we can now conclude that an increase in broad money in the high-income economies would enhance environmental quality, while environmental degradation would increase significantly by the rise in domestic listed companies' market capitalisation in the middle-income economies. These findings perhaps can be explained by the efficiency of financial resource allocation, either via broad money or through stock markets in the high- and middle-income countries, which directly affect CO2 emissions and general environments.

Third, the panel causality test also reports causality between the financial and economic variables and CO2 emissions. To be specific, with regards to the full dataset, only FDI has a unidirectional relationship to CO2 emissions contrasting to bidirectional relationship from broad money, energy use, GDP, and stock market capitalisation. However, for the high-income economies, FDI and stock market capitalisation have unidirectional relations with CO2 emissions, while broad money, energy use, and GDP have a bidirectional relationship with CO2 emissions. For the middle-income economies, FDI and energy use have unidirectional relations with CO2 emissions, but broad money, GDP, and stock market capitalisation show bidirectional relationships to CO2 emissions. The overarching evidence of FDI's unidirectional effects on CO2 in all sample countries supports the argument in Nasir et al. (2019, p.132) that 'whether the FDI decreases or increases environmental degradation is contingent'. Notably, financial development causes CO2 emissions in all two groups of economies.

Generally, the results suggest that countries at different development stages should opt for differential environmental strategies. For countries having high-income economies, supporting the financial sector via monetary policy is a vital macroeconomic strategy to lower CO2 emissions and enhance environmental quality. On the contrary, the governments of middle-income countries should pay more attention to how to create better financial regulations and policies to progress the development of their stock markets and achieve effective financial resource allocations, which also help enterprises invest in innovative new energy technologies.

Therefore, the key implications of our findings are for policy makers and senior finance professionals. Given global warming, it is important that the financial system supports efforts to stem the rise of CO2 (and other greenhouse cases). Much of the current effort internationally is focused on adjusting the lending policies of banks in developed countries and, likewise, upon shifting equity investment priorities in the form of ESG (Environmental, Social, and Governance) criteria. While much remains to be done, our results suggest that financial development in richer countries can have a helpful effect on CO2 emissions. Our results are an encouragement to both finance professionals and policy makers to redouble their efforts.

The implications for middle-income countries are rather different. Other things being equal, it is good for such countries – together with low-income countries, which were not part of our dataset – to grow economically, thus providing a higher standard of living and greater opportunities for their populations. However, as this growth is accompanied, and facilitated by, a financial system at a relatively early stage of development, our results show that it will tend to be associated with higher CO2 emissions. Policy makers and senior finance professionals should be encouraged to develop attitudes and skills that would not, in the ordinary course of the process, be characteristic of a particular stage of financial development. This is something that might usefully be supported by international development agencies.

As with any study, there are limitations in our paper. The first limitation refers to sample size. From a global perspective, a sample of 61 countries means that we should be cautious in generalising the findings. The second limitation follows on from this. Owing to data availability, we could not obtain balanced subgroups in terms of high, upper-middle and lower-middle income countries. Therefore, we combined the last two to form a 'middle-income' group. Because of this, any differences in the influence of financial development on CO2 emissions between upper-middle and lower-middle income economies could not be identified. All categories or groups contain members with widely different per capita income, but this data merging exacerbated the phenomenon. Third, low-income countries were not examined. Fourth, although we also ran a robustness check using an alternative measure, the two proxies (i.e. broad money and stock market capitalisation) used here might limit the representation of financial development. These limitations could be addressed in future research.

Credit author statement

All the authors have made significant contribution to the paper. The details of tasks are as follows: Natthinee Thampanya: Conceptualisation, Data collection, Methodology, Software, Formal analysis, Writing – original draftpreparation. Junjie Wu: Informal Formal analysis, Writing – review & editing. Christopher Cowton: Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abbasi, F., Riaz, K., 2016. CO2 emissions and financial development in an emerging economy: an augmented VAR approach. Energy Pol. 90, 102–114.

Agyapong, D., Bedjabeng, K.A., 2019. External debt stock, foreign direct investment and financial development: evidence from African economies. J. Asia Bus. Stud. 27 (1), 81–98.

Aristei, D., Martelli, D., 2014. Sovereign bond yield spreads and market sentiment and expectations: empirical evidence from euro area economies. J. Econ. Bus. 76, 55–84.

Baltagi, B.H., 2013. Econometric Analysis of Panel Data, fifth ed. JohnWiley & Sons Ltd., England.
Berdiev, A.N., Saunoris, J.W., 2016. Financial development and the shadow economy: a panel VAR analysis. Econ. Modell. 57, 197–207.
Blackburn, K., Bose, N., Capasso, S., 2012. Tax evasion, the underground economy and financial development. J. Econ. Behav. Organ. 83, 243–253.
Botev, J., Égert, B., Jawadi, F., 2019. The nonlinear relationship between economic growth and financial development: Evidence from developing, emerging and advanced economies. Int Econ. 160, 3–13.
Canh, N.P., Thanh, S.D., 2020. Financial development and the shadow economy: a multidimensional analysis. Econ. Anal. Pol. 67, 37–54.
Canh, N.P., Thanh, S.D., Nasir, M.A., 2020. Nexus between financial development & energy intensity: two sides of a coin? J. Environ. Manag. 270, 110902.
Charfeddine, L., Kahia, M., 2019. Impact of renewable energy consumption and financial development on CO2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis. Renew. Energy 139, 198–213.
Coban, S., Topcu, M., 2013. The nexus between financial development and energy consumption in the EU: a dynamic panel data analysis. Energy Econ. 39, 81–88.
Dietz, T., Rosa, E.A., 1997. Effects of population and affluence on CO2 emissions. Proc. Natl. Acad. Sci. Unit. States Am. 94, 175–179.
Dogan, E., Turkekul, B., 2016. CO2 emissions, real output, energy consumption, trade, urbanisation and financial development: testing the EKC hypothesis for the USA. Environ. Sci. Pollut. Res. 23, 1203–1213.
Dumitrescu, E.I., Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. Econ. Modell. 29 (4), 1450–1460.
Ehrlich, P.R., Holdren, J.P., 1971. Impact of population growth. Science 171, 1212–1217.
Fisher, I., 1911. The Purchasing Power of Money, second ed. Augustus M. Kelley, New York.
Friedman, M., Schwartz, A.J., 1963. A Monetary History of the United States, 1867-1960. Princeton University Press.
Hafeez, M., Chunhui, Y., Strohmaier, D., Ahmed, M., Jie, L., 2018. Does finance affect environmental degradation: evidence from one belt and one road initiative region? Environ. Sci. Pollut. Res. 25 (10), 9579–9592.
Hamilton, C., Turton, H., 2002. Determinants of emissions growth in OECD economies. Energy Pol. 30, 63–71.
Haseeb, A., Xia, E., Danish Baloch, M.A., Abbas, K., 2018. Financial development, globalisation, and CO2 emissions in the presence of EKC: evidence from BRICS economies. Environ. Sci. Pollut. Res. 25 (31), 31283–31296.
Hicks, J.R., 1937. Mr. Keynes and the classics: a suggested interpretation. Econometrica 5 (2), 147–159.
Islam, F., Shahbaz, M., Ahmed, A.U., Alam, M.M., 2013. Financial development and energy consumption nexus in Malaysia: a multivariate time series analysis. Econ. Modell. 30, 435–441.
Jiang, C., Ma, X., 2019. The impact of financial development on carbon emissions: a global perspective. Sustainability 11, 5241. https://doi.org/10.3390/su11195241.
Khan, S.A.R., Qianli, D., SongBo, W., Zaman, K., Zhang, Y., 2017. Environmental logistics performance indicators affecting per capita income and sectoral growth: evidence from a panel of selected global ranked logistics countries. Environ. Sci. Pollut. Res. 24, 1518–1531.
Maskus, K.E., Milani, S., Neumann, R., 2019. The impact of patent protection and financial development on industrial R & D. Res. Pol. 48 (1), 355–370.
Nasir, M.A., Huynh, T.L.D., Tram, H.T.X., 2019. Role of financial development, economic growth & foreign direct investment in driving climate change: a case of emerging ASEAN. J. Environ. Manag. 242, 131–141.
Nasir, M.A., Canh, N.P., Le, T.N.L., 2021. Environmental degradation & role of financialisation, economic development, industrialisation and trade liberalisation. J. Environ. Manag. 277, 111471.
Naughton, H.T., 2014. To shut down or to shift: multinationals and environmental regulation. Ecol. Econ. 102, 113–117.
Nguyen, C.P., Lee, G.S., 2021. Uncertainty, financial development, and FDI inflows: global evidence. Econ. Modell. 99, 105473.
Nguyen, C.P., Su, T.D., Bui, T.D., Nguyen, B.Q., 2021. Financial development and energy poverty: global evidence. Environ. Sci. Pollut. Res. 1–38.
Pesaran, M.H., 2021. General diagnostic tests for cross section dependence in panels. Empir. Econ. 60, 13–50.
Pesaran, M.H., Shin, Y., Smith, R., 2001. Bound testing approaches to the analysis of level relationships. J. Appl. Econ. 16, 289–326.
Rauf, A., Liu, X., Amin, W., Ozturk, I., Rehman, O.U., Hafeez, M., 2018. Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from Belt and Road Initiative economies. Environ. Sci. Pollut. Res. 25, 32066–32080.
Sadorsky, P., 2010. The impact of financial development on energy consumption in emerging economies. Energy Pol. 38, 2528–2535.
Shahbaz, M., Hye, Q.M.A., Tiwari, A.K., Leitão, N.C., 2013a. Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. Renew. Sustain. Energy Rev. 25, 109–121.
Shahbaz, M., Khan, S., Tahir, M.I., 2013b. The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis. Energy Econ. 40, 8–21.
Shahbaz, M., Solarin, S.A., Mahmood, H., Arouri, M., 2013c. Does financial development reduce CO2 emissions in Malaysian economy? A time series analysis. Econ. Modell. 35, 145–152.
Shahbaz, M., Shahzad, S.J.H., Ahmad, N., Alam, S., 2016. Financial development and environmental quality: the way forward. Energy Pol. 98, 353–364. https://doi.org/10.1016/j.enpol.2016.09.002.
Shahbaz, M., Nasir, M.A., Roubaud, D., 2018. Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ. 74, 843–857.
Shahbaz, M., Nasir, M.A., Hille, E., Mahalike, M.K., 2020. UK's net-zero carbon emissions target: investigating the potential role of economic growth, financial development, and R&D expenditures based on historical data (1870–2017). Technol. Forecast. Soc. Change 161, 120255.
Shin, Y., Yu, B., Greenwood-Nimmo, M., 2014. Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Sickles, R., Horrace, W. (Eds.), Festschrift in Honor of Peter Schmidt. Springer, New York, pp. 281–314.
Shoaib, H.M., Rafique, M.Z., Nadeem, A.M., Huang, Sh, 2020. Impact of financial development on CO2 emissions: a comparative analysis of developing economies (D8) and developed economies (G8). Environ. Sci. Pollut. Res. 27 (11), 12461–12475.
Svirydzenka, K., 2016. Introducing a new broad-based index of financial development (Vol. IMF Working Paper). International Monetary Fund.
Tamazian, A., Chousa, J.P., Vadlamannati, K.C., 2009. Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. Energy Pol. 37, 246–253.
Thampanya, N., Wu, J., Nasir, M.A., Liu, J., 2020. Fundamental and behavioural determinants of stock return volatility in ASEAN-5 countries. J. Int. Financ. Mark. Inst. Money 65, 101193.
The World Bank Group, 2021a. DataBank: World development indicators [online]. https://databank.worldbank.org/reports.aspx?source=2&series=CM.MKT.LCAP.CD&country=AFG%2CALB&fbclid=IwAR1rhBw53bxN7sk8NACml_zMWIkheSotI8Gxn6ZsNjU_w0QgpX2qcgbvla0#.
The World Bank Group, 2021b. World Bank country and lending groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
Xing, T., Jiang, Q., Ma, X., 2017. To facilitate or curb? The role of financial development in China's carbon emissions reduction process: a novel approach. Int. J. Environ. Res. Publ. Health 14 (10), 1222.
Xiong, L., Qi, S.Z., 2016. Financial development and carbon emissions of Chinese provinces: based on STIRPAT model and dynamic panel data analysis. J. China Univ. Geosci. 16, 63–73.
Xu, Z., Baloch, M.A., Danish Meng, F., Zhang, J., Mahmood, Z., 2018. Nexus between financial development and CO2 emissions in Saudi Arabia: analysing the role of globalisation. Environ. Sci. Pollut. Res. 25, 28378–28390.
Zhang, Y.J., 2011. The impact of financial development on carbon emissions: an empirical analysis in China. Energy Pol. 39, 2197–2203.
Ziaei, S.M., 2015. Effects of financial development indicators on energy consumption and CO2 emissions of European, East Asian and Oceania economies. Renew. Sustain. Energy Rev. 42, 752–759.