



Do financial inclusion and environmental regulations affect the green economy? An empirical study with a generalized linear model

Yineng Xiao^{1,2}

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Abstract

Reducing carbon emissions is an efficient strategy to cope with global warming, which continues to be a frightening element for environmental protection. However, the energy industry is responsible for a lot of pollution in the atmosphere. To promote a low-carbon growth model, it is essential to endorse financial inclusion and environmental regulations. This research uses panel data from 70 nations, covering 1995 to 2021, to examine the interplay between economic growth, human capital, urbanization, trade openness, and environmental regulation as the primary defining element of efficient energy. Several tests have been used to ensure that the data are typically distributed; these include the cross-sectional dependence test, the KMO test, and the Bartlett test. The generalized linear model and Driscoll-Kraay standard errors have also been implemented for interim and final analysis. Results show that low-carbon energy sources are guaranteed for certain economies when financial inclusion and environmental regulation are implemented. Economic development, urbanization, trade openness, and human capital significantly impact green economic recovery. In light of these findings, policymakers are working to increase energy efficiency and boost their citizens' living standards by promoting financial inclusion and environmental regulation like imposing environmental taxes and governmental laws for industries.

Keywords Environmental regulation · CO₂ emission · Trade openness Financial inclusion · Human capital · GLM regression

Introduction

Climate change is widely recognized as one of the greatest and most pressing threats to all forms of species on Earth. Despite the undeniable reality of rapid climate change, humans continue to drill miles deep into the ocean floor, fracture rocks from the Earth's crust, and transport fuel in massive ships and pipelines to power the machinery used to generate electricity (Tang et al. 2022). Large-scale reliance on fossil fuels may be to blame for global change. Scientists and academics have focused on carbon (CO₂) as a possible cause of global warming (Xing et al. 2023). Over the past few decades, rising CO₂ emissions have been mainly

attributable to the expanding economies of various nations. Consumption of energy is the single most influential factor in economic growth. It is essential to factor in socioeconomic inclusion (Ameer et al. 2023), rent on natural resources, and energy intensity when estimating CO₂ emissions. Access to affordable and sustainable financial services and goods (transactions, payments, savings, credit, and insurance) is what we mean when we talk about financial inclusion for people and businesses (The World Bank Group 2022).

Today, FIN is recognized as a critical factor in individual and national long-term sustainability progress. Expanding access to financial resources is commonly supposed to foster long-term economic growth. The current literature also acknowledges the significance of FIN in supporting socially equitable growth by lowering income disparity (Zhang et al. 2023). In addition, it is widely acknowledged that FIN is necessary for countries to respond to and recover from global economic crises. When it comes to social development (Mngumi et al. 2022), financial inclusion (FIN) is seen as essential for accomplishing goals like poverty reduction, monetary stability, human progress, and gender parity (Yi et al. 2022).

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✉ Yineng Xiao
xiaoyineng@pku.edu.cn

¹ Present Address: The Global Intellectual Property Institute, Nanjing University, Suzhou 215163, China

² Advanced Institute of Information Technology, Peking University, Hangzhou 311200, China

Furthermore, environmental progress, notably in air pollution prevention (Li et al. 2023a), has been linked to more FIN. The potential for positive social, economic, and environmental outcomes suggests that financial inclusion could be critical in attaining the United Nations' Sustainable Development Goals (SDGs) by 2030 (He et al. 2022).

On the one hand, as low-carbon competition around the world heats up, many experts believe that cutting back on our reliance on natural resources will have positive environmental effects (Xie et al. 2023a). However, other researchers (Shang et al. 2023) argue that resource-based regions can support green recovery in China by promoting industrial diversification through environmental policies and external influences. To help achieve carbon neutrality by 2060 (Xie et al. 2023b), the government has introduced a number of environmental rules to limit the greenhouse gas effect. Most research ignores the NRD in favor of discussing environmental and natural resource challenges in connection to one another (Zhang and Qiu 2022). There is a large disparity in the exploitation and consumption of China's natural resources among areas due to their diversity (Wen and Zhang 2022). This highlights the importance of studying climate change's effects throughout China's many regions. In addition, the path of carbon emission reduction needs to be explored from the twin perspectives of NRD and ER in order to achieve CO₂ emission reduction and green development.

Energy consumption is one of the most crucial elements that improve people's quality of life, and its availability is crucial to any nation's economic and social well-being. Rising carbon emissions and global warming challenges have boosted the profile of nuclear energy's potential to handle energy security and climate change as an alternative to fossil fuels. Fewer studies have explored the role of FIN, environmental regulation, and human capital in green economic recovery, even though many have documented the effect of financial development on green economic recovery and the impact of these factors on economic growth (Li and Sun 2020; Chen et al. 2023). The primary aim of this study is to observe the results of these three factors on climate change and environmental pollution in the panel data of 70 countries between 1995 and 2021. In addition to the deficiency of empirical evidence on these countries, the developed and developing countries' commitment to becoming a carbon-neutral continent by 2050 through increased renewable energy and financial inclusion and the adoption of green technologies led to their selection for this analysis. The paper's secondary goals are to answer the following study questions: (1) How much do FIN and the environmental regulations affect CO₂ emissions in the panel of 70 countries? (2) How much of an effect does the human capital have on CO₂ emissions in the panel of 70 countries? (3) To what extent do the factors consider in favor of a sustainable environment in a panel of 70 countries contribute?

Consistent with the prior, this paper's primary contribution is an initial effort to fill the literature gap concerning the nexus between FIN, environmental regulation, and environmental pollution, all of which are critical for bolstering the green environment idea. It was identified as one of the top objectives of the United Nations Sustainable Development Goals for these countries to combat climate change. In addition to the primary contribution, a novel research technique is also presented, precisely, a generalized linear method (GLM) which delivers more effective and robust estimates by more accurately representing the stochastic relationship between the variables. Therefore, this analysis will add new variables and factual findings to the existing literature. The first analysis for a panel of 70 countries provides the third contribution by showing that the variables studied do have a substantial effect on carbon emissions, with a focus on financial inclusion. Based on these findings, policymakers are given suggestions that could help implement the sustainable environment idea across all 70 selected countries. Lastly, the fourth input is confirmed by the Environmental Kuznets Curve (EKC) hypothesis for CO₂ emissions.

The leftover sections of the document are arranged as follows. The literature review is presented in the "Literature review" section after a short introductory section. The materials and techniques are defined in the "Research methodology and data collection" section, and the empirical conclusions are presented in the "Results and discussions" section. The "Conclusion and policy implications" section draws to a close and discusses the policy consequences, limitations, and suggestions for future studies.

Literature review

The carbon problem is no longer just an environmental subject due to the growing concern of governments and academics over environmental issues and carbon emissions. It poses several intriguing financial questions studied by academics in the field. Some academics study the carbon market. Future carbon prices are predicted, and the variables that affect carbon prices are discussed. The potential carbon price in Europe is estimated by Li et al. (2021) using a mixed model. The outcomes highlight the superior forecast performance of the combination-MIDAS model. To determine the cost of carbon trading quotas, Huang et al. (2021) construct a forecasting model that outperforms standard ARIMA forecasts.

Financial inclusion and environmental pollution

These previous studies have some limitations, the most notable being that they have only considered loans, not all financial products and services. However, to investigate the link between FIN and carbon dioxide emissions, a few studies

have recently investigated the environmental effects of various products associated with the financial sector. Hailiang et al. (2023) found that financial inclusion increases climate risks by leading to more CO₂ emissions in the setting of the BRICS, which lies in South Africa, India, Brazil, China, and Russia. Improving FIN is only effective in reducing CO₂ emission in low CO₂-emitting emerging nations, as Li et al. (2022) noted. More specifically, the panel quantile regression estimates findings revealed that FIN negatively affects CO₂ emission only up to the 50th quantile. The FIN-CO₂ emission nexus depicts heterogeneity across alternative financial services and products, as Bo Li et al. (2022) discovered, using data from five emerging Asian countries. CO₂ emission decreases over time when there are more commercial bank branches per 1000 people, and bank credit accounts for a more significant percentage of total bank deposits. The opposite was true when looking at the correlation between CO₂ emissions and the worth of insurance premiums as a percentage of GDP. There have been some parallel investigations into China's developing economy. Gao et al. (2021), using data on multiple FIN-related products, found that increases in the proportion of bank credits to deposits and the proportion of life and non-life insurance premiums to GDP all contribute to lowering China's CO₂ emission. Zhao et al. (2023) used data from 284 Chinese towns to make a similar case for digital financial inclusion being a barrier to CO₂ emission in China. The effects of FIN on CO₂ emissions in a sample of 103 nations are studied by Nasir et al. (2022). Using the GMM technique applied to annual statistics from 2004 to 2014, they conclude that FIN helps reduce CO₂ emissions. The authors contend that a rise in environmental consciousness brought about by financial inclusion can mitigate some of the adverse effects of economic development. Organization for Economic Cooperation and Development (OECD): Hai Ming et al. (2022) investigate yearly data from 2004 to 2014 using dynamic common correlated effects estimation.

The authors discover that long- and short-term CO₂ emissions are decreasing due to FIN. The research on the link between FIN and carbon dioxide emissions is mixed. FIN has been found to hurt CO₂ emissions in Chinese regions by Lu et al. (2023). To reduce carbon dioxide (CO₂) emissions in Sub-Saharan African (SSA) nations, FIN is presented as helpful by Liu et al. (2023). Liu et al. (2023a) discover that FIN raises CO₂ emissions in the G7. Wei et al. (2022) compare two studies examining how FIN affects carbon dioxide emissions. The authors discover that FIN is associated with poorer air quality in developed countries.

In addition to the previously indicated linear relationship between FIN and environmental pollution, a non-linear relationship between the three may also emerge. The U-shaped bond between FIN and carbon emission was examined for a sample of 103 countries by Jin et al. (2023). From 1990 to

2017, Pata and Samour (2022) verified EKC in a panel of South Asian countries. It also suggested that while increased economic activity initially raises emission levels, this process ultimately leads to lower CO₂ output. In APEC countries, Pata et al. (2023) found support for the EKC hypothesis. Liu et al. (2022a) and (Pata and Samour 2023) are other examples of such research.

There is also some doubt about how widespread access to banking services correlates with increased pollution. Also, access to financial services is seen as a critical factor in achieving the SDGs. There may be both positive and negative effects of FIN on environmental pollution (Kara et al. 2021).

Environmental regulation and environmental pollution

Carbon emissions have negative effects that can be mitigated through regulatory measures that promote energy efficiency and sustainable energy use. It can help control emissions and potentially cause a slow decline over time. (Li et al. 2020) used the spatial Durbin model to find that environmental control results in efficient energy usage, with the amount of R&D investment serving as a mediator. The effectiveness of China's environmental legislation in combating air and haze pollution was evaluated by (Wang and Zhang 2020). They discovered that it motivates businesses to invest in R&D in order to cut down on wasteful spending. Due to the high cost of compliance, enterprises that are pollution-intensive or have poor levels of technology are pushed to minimize their CO₂ emissions (Ramzan et al. 2022). These findings indicate that emission reductions are the primary effect of environmental legislation. Energy usage, technological advancement, and rules protecting the environment were all determined to be interconnected by Qiu et al. (2021). The "green paradox" is discussed, in which tight regulatory measures can either drive out non-compliant enterprises and minimize emissions or speed up exploitation to curb short-term losses and raise emissions. Compliance costs are high with the mandatory rules mentioned by Ngo (2022), reducing expenditures in R&D and making it impossible to effectively cut CO₂ emissions. These contradictory results further demonstrate that the total effect of environmental regulation on carbon emissions is speculative and is strongly determined by the degree of R&D expenditure and energy usage.

Reduced carbon dioxide emissions are a direct result of environmental regulation. In particular, economically deprived places may experience negative ecological effects from environmental legislation (Siddiqua et al. 2022). The "green paradox" has become the "reverse of pollution reduction," demonstrating that environmental control has an effect on carbon emissions (Qiu et al. 2022). This reveals a large inverted "U" curve connection between environmental

regulation and carbon emissions. Therefore, environmental regulations have varying impacts depending on location. Some locations see greater carbon emissions due to the increased severity of environmental policies (Dong et al. 2021). To attain eco-efficiency at the regional level, strong environmental regulatory frameworks must be prioritized. Therefore, Wang and Wei (2020) argued that a lag in the implementation of the policy is caused by an ineffectively set carbon emission price, which affects administrative actions to reduce the demand for fossil fuels. There is a strong correlation between environmental regulation and environmental performance, as evidenced by the positive effects environmental policies have on ecological productivity, business technical advancement, energy efficiency, and pollution reduction (Wu et al. 2020).

Human capital and environmental pollution

Ecological sustainability and human capital development are intertwined in that less environmental deterioration would come from increased community education and awareness concerning the conservation and efficient use of natural resources (Wang et al. 2022). However, the present literature on human capital's effect on sustainability provides conflicting results. Over the past 30 years, Yu and Tang (2023) have zeroed down on 73 developing economies. Based on these estimates, it is clear that future policies should prioritize human capital growth while ensuring that it is in harmony with the goals of sustainable environmental growth. Agyekum et al. (2021) use education metrics and the rate of return on education as critical indicators of human capital to back up the rising ecological footprints. The consequences of this study show that human capital has a statistically significant inverse relationship with carbon dioxide emissions. Hussain et al. (2023) use an ARDL estimate technique to examine the long- and short-term connections between human capital, bio-capacity, and ecological footprint. Human capital is credited with lowering CO₂ emissions, particularly in the immediate future. Chuc et al. (2021) analyze the economy of the USA during the previous half-century, with human capital as one of the leading causes of ecological footprint. The results demonstrate that the ecological footprint level in the USA has decreased due to human development and rich natural resources.

Several researches during COVID-19 have looked at patterns in carbon dioxide emissions. Banna et al. (2021) argue, for instance, that China, like other economies, is under environmental pressure due to rising carbon emissions. However, identifying elements that can lessen environmental pollution is vital to promote sustainable and green growth. Based on the EKC hypothesis, they examine how human capital, energy use, trade, and globalization affect the natural world. Increases in human capital are

shown to lessen environmental stress dramatically. According to Vo et al. (2021), rapid economic and social development is the primary driver of ecological footprint overshoot, necessitating considerable policy implications. The authors assume cross-sectional dependency and slope heterogeneity in their research into CO₂ emissions in the Economic Community of West African States (ECOWAS). Human capital accumulation was a crucial indicator for tackling environmental sustainability in the form of low CO₂ emissions in Burkina Faso and The Gambia, according to empirical evidence gathered by augmented mean group estimation (AMG). To calculate the state of human capital development in 110 countries from a global viewpoint in light of ecological footprint, Liu et al. (2022b) compiles data. In addition, subgroup analyses of their estimates reveal that investment in human capital reduces CO₂ emissions in high-income nations. However, human capital contributes more to increased CO₂ emissions in economies with a large population but low per capita income. Because of this, developing nations need to pay more attention to reducing pollution in their economy.

From the above literature review, we have concluded that the effect of financial inclusion, RE, and human capital on CO₂ emission has not been taken by previous research. So, here, in this study, we have used two tests (Kaiser-Meyer-Olkin (KMO) test and Bartlett's sphericity test (BS) to check the normality of the data. In the second step, GLM and Driscoll-Kraay standard errors (D-K) were used to get robust results. The data has been taken from a panel of 70 developed and developing countries. This study has divided the country's panel into regions and markets based on their financial standing. The heterogeneous and nonlinear connection between carbon emissions and FIN is explored in our research for the first time.

Literature gap

After reviewing the existing material, some voids become apparent. To begin, while most prior research has focused on the correlation between financial growth and CO₂ emissions, very few studies have focused on financial inclusion and renewable energy at the same time. Most significantly, no research has looked at how financial inclusion and environmental regulation affect CO₂ emissions for 70 countries using panel data. In addition, while many researchers have focused on the benefits of using environmental regulation, relatively few have looked at the production and cost aspect. Concurrently, the panel data analysis in this study uses the generalized linear model (GLM) and Driscoll-Kraay standard errors (D-K). This method produces reliable findings by considering the cross-sectional reliance among the panel data.

Research methodology and data collection

This study has used data from 70 heterogeneous countries, ranging from 1995 to 2021, consisting of developed and developing countries worldwide. The analysis has been done in two steps; in the first step, economies have been classified based on market category. Four kinds of markets have been established, which are 21 developed markets, 21 emerging markets, 18 frontier markets, and ten standalone markets. This classification has been derived from the MSCI classification system. In the second step, their diverse countries were divided into three categories. Asia and American countries comprise 12 countries; Europe, South Africa, and the Middle East comprise 48 countries; and finally, Oceania consists of 10 countries. The list of the countries has been given in Appendix Table 15.

In this research, the dependent variable is CO2 emission which is a proxy for environmental pollution, and the independent variables are financial inclusion (FIN), urbanization (URB), environmental regulation (ER), economic growth (GDP), human capital (HC), and trade openness (TO). The data for CO2 emission has been collected from carbon emission accounts and data sets (CEADs). The data for FIN has been collected from the IMF database, and FIN has been measured using three financial inclusion proxies like number of ATMs per 10,000 adults, the number of bank branches per 10,000 adults, and banks’ outstanding loans divided by the GDP of the country. All the other variables except human capital, including REC, economic growth, urbanization, and trade openness data, have been composed of the world development indicators (WDI) database. Human capital data has been collected from the Penn World table. A complete description, symbols, and sources of the variables are given below in Table 1, and Fig. 1 shows the study’s conceptual framework.

A series of pre-estimation techniques determined the study’s dataset’s suitability for model estimation before principal component analysis (PCA) was applied. As a first step, we conducted the Kaiser-Meyer-Olkin (KMO) test

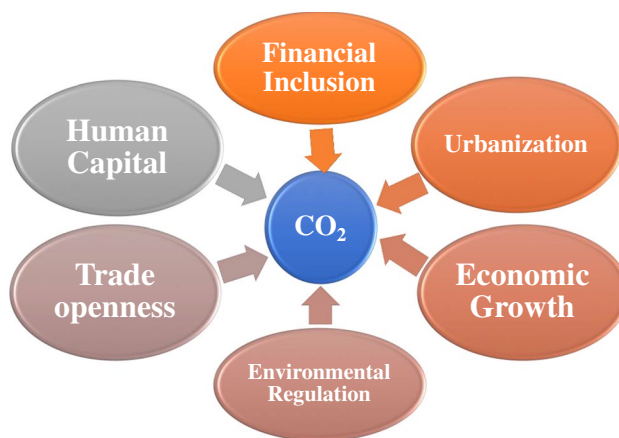


Fig. 1 Conceptual framework of the study

and Bartlett’s sphericity test (BS) to examine the significance of the research variables suggested by the elements of CO2 emissions. Table 2 shows that the predicted outcomes fall within reasonable parameters. The PCA results reveal that the independent factors play a significant role in predicting the dependent variables.

The extracted factors have good explanatory power for the development stage of digital villages. The results showed a cumulative variance contribution rate of 73.566% based on the eigenvalue being more significant than 1. It can be seen in Tables 3 and 4.

Econometric model

Expanding on the IPAT model, the STIRPAT model holds that rising environmental stress is due to rising populations, expanding economies, and financial inclusion. Current research into environmental pollution causes and future pattern forecasting relies heavily on this model. The model, in its simplest version, is as follows:

Table 1 Variable description and source

Variables	Symbol	Description	Source
Carbon emission	CO2	CO2 in MC/capita	CEADs
Financial inclusion (Proxy 01)	FIN-1	Number of ATMs per 100,000 adults	IMF
Financial inclusion (Proxy 02)	FIN-2	Banks’ branches for 100,000 adults	IMF
Financial inclusion (Proxy 03)	FIN-3	Commercial loans divided by GDP	IMF
Urbanization	URB	Increasing rate of population in urban areas	WDI
Economic growth	GDP	GDP per capita	WDI
Environmental regulation	ER	The sum of money spent to reduce pollution, or the Cost of its output.	WDI
Trade openness	TO	The ratio of total exports and imports to GDP	WDI
Human capital	HC	The yields to education	Penn World Table

Table 2 Results of KMO and Bartlett tests

	Variable		FIN
Full sample	KMO test		0.715
	Bartlett’s sphericity test	Approx. chi-square	1139.108***
		df	7.0000
		Sig	0.0000
Developed markets	KMO test		0.746
	Bartlett’s sphericity test	Approx. chi-square	122.630***
		df	7.0000
		Sig	
Emerging markets	KMO test		0.549
	Bartlett’s sphericity test	Approx. chi-square	320.425***
		df	7.0000
		Sig	0.0000
Frontier markets	KMO test		0.669
	Bartlett’s sphericity test	Approx. chi-square	476.429***
		df	7.0000
		Sig	0
Standalone market	KMO test		0.673
	Bartlett’s sphericity test	Approx. chi-square	693.261***
		df	7.0000
		Sig	0.0000
Europe, Middle East, and Africa	KMO test		0.76
	Bartlett’s sphericity test	Approx. chi-square	234.228***
		df	7.0000
		Sig	0.0000
	KMO test		0.775
	Bartlett’s sphericity test	Approx. chi-square	296.721***
		df	7.0000
		Sig	0.0000
Asia	KMO test		0.76
	Bartlett’s sphericity test	Approx. chi-square	409.424***
		df	7.0000
		Sig	0.0000
American	KMO test		0.751
	Bartlett’s sphericity test	Approx. chi-square	296.721***
		df	7.0000
		Sig	0.00000

*, **, and *** means level of significance at 1%, 5% and 10%

$$I = aP^b A^c T^d e \tag{1}$$

where *I* stands for natural impacts, *P* for the human population, *A* for economic success and technological advancement, and *T* for the passage of time. The model coefficients: *b*, *c*, and *d* are the population, wealth, and technology elasticity coefficients; *e* is the temporal elasticity coefficient; and *f* is the random error term (Ahmad and Satrovic 2023).

The STIRPAT model for CO2 emission prediction in 70 economies is built by selecting GDP, HC, CO2 emission, TO, ER, URB, and financial inclusion based on the work of Dabuo et al. (2023) as well as the development characteristics.

$$\ln CE_t = \ln FIN + b \ln GDP_t + c \ln TO_t + d \ln IND_t + e \ln URB_t + e \ln ER_t + f \ln HC_t + \ln e_t \tag{2}$$

This paper employs the common least square technique to estimate all variables to determine if there is multicollinearity between CO2 emission and FIN, GDP, ER URB, HC, and TO.

Estimation techniques

This study has followed a process of estimation; in the first step, two tests, including cross-sectional dependence (CD) and KMO and Bartlett tests, have been employed to know

Table 3 Total variance described and pattern matrix (sub-sample)

	Component	Comp1	Comp2	Comp3	Comp4
Full sample	Eigenvalue	2.33668	0.788853	0.471182	0.403286
	Proportion	0.5842	0.1972	0.1178	0.1008
	Cumulative	0.5842	0.7814	0.8992	1
Developed markets	Eigenvalue	1.63028	1.07342	0.839009	0.457292
	Proportion	0.4076	0.2684	0.2098	0.1143
	Cumulative	0.4076	0.6759	0.8857	1
Emerging markets	Eigenvalue	1.76535	1.36809	0.587542	0.279015
	Proportion	0.4413	0.342	0.1469	0.0698
	Cumulative	0.4413	0.7834	0.9302	1
Frontier markets	Eigenvalue	2.56218	0.898357	0.306533	0.232925
	Proportion	0.6405	0.2246	0.0766	0.0582
	Cumulative	0.6405	0.8651	0.9418	1
Standalone markets	Eigenvalue	2.21768	1.08312	0.513759	0.185448
	Proportion	0.5544	0.2708	0.1284	0.0464
	Cumulative	0.5544	0.8252	0.9536	1
Europe, Middle East, and Africa	Eigenvalue	2.21074	0.89968	0.463803	0.425777
	Proportion	0.5527	0.2249	0.116	0.1064
	Cumulative	0.5527	0.7776	0.8936	1
Asia	Eigenvalue	2.86239	0.491131	0.447267	0.199207
	Proportion	0.7156	0.1228	0.1118	0.0498
	Cumulative	0.7156	0.8384	0.9502	1
Americas	Eigenvalue	2.86239	0.491131	0.447267	0.199207
	Proportion	0.7156	0.1228	0.1118	0.0498
	Cumulative	0.7156	0.8384	0.9502	1

the normality of the data. In the second step, two models, (1) Driscoll-Kraay (D-K) standard errors and (2) GLM (generalized linear model), have been applied to get robust results.

(D-K) standard errors are used for the whole sample in the presence of CD. This method addresses three kinds of issues: serial correlation, heteroscedasticity, and simultaneous correlation. GLM has been used to measure the effect of FIN and RE on CO₂ emission in the studies' whole samples and subsamples. Figure 2 shows the estimation process.

Results and discussions

Summary statistics

Table 5 displays the results of each variable's summary data. The standard and average deviation of carbon emissions (SD = 6.341, M = 7.374) is lower than those for the entire group reported in Ahmad et al. (2022). According to the data presented, there are more commercial bank ATMs and branches per 100,000 adults than were recorded (Li et al. 2023b). The outstanding deposits and loans (as a percentage of GDP) in Asia are also higher than those stated in (Ahmad et al. 2022). This demonstrates that some nations have more accessible banking systems than others. Control variables

include the mean and standard variation of TO (M = 90.435, SD = 55.717). In addition, there is a nonlinear, inverted U-shaped association between carbon emissions and FIN over the sample time. Carbon emissions also continued to rise, although financial participation fell from 2009 to 2013, albeit only slightly. The growth rate for CO₂ emissions was comparatively high compared to that of FIN, although both have been on the rise since 2008. COVID-19.6 caused an immediate drop in CO₂ emissions and socioeconomic inclusion in 2020. Subsamples, such as established, frontier, and emerging markets, show a nonlinear trend in CO₂ emissions and FIN. However, FIN and CO₂ emissions follow a linear trend in individual nations.

Cross-sectional dependence tests

Observing the panel data set for difficulties of cross-sectional reliance and heterogeneous slope coefficients is crucial before developing an econometric strategy. These two issues compromise the reliability and objectivity of the statistical findings. First, the method Pesaran (2004) developed for analyzing cross-sectional dependencies (CSDs) is applied. For each variable, this technique forecasts a test statistic that can be used to evaluate the null hypothesis of independence across periods. Table 6 displays the findings

Table 4 PCA pattern matrix

	Variable	FIN-1	FIN-2	FIN-3
Full sample	PC1	0.4913	0.4961	0.5358
	PC2	0.4979	0.4781	-0.3275
	PC3	0.7118	-0.6952	-0.0713
Developed markets	PC1	0.6272	0.582	0.2615
	PC2	0.193	-0.4221	0.8572
	PC3	-0.3909	-0.3055	0.1596
Emerging markets	PC1	0.1539	0.3584	0.666
	PC2	0.714	0.6027	-0.2274
	PC3	0.6507	-0.6601	-0.131
Frontier markets	PC1	0.5368	0.4527	0.5538
	PC2	-0.3091	-0.6251	0.2761
	PC3	-0.6638	0.6349	-0.1657
Standalone markets	PC1	0.4896	0.411	0.607
	PC2	0.3719	0.6351	-0.2366
	PC3	-0.7869	0.5766	0.2169
Europe, Middle East, and Africa	PC1	0.5336	0.476	0.5421
	PC2	-0.3204	-0.5914	0.2753
	PC3	0.6759	-0.3276	-0.6007
Asia	PC1	0.4789	0.5453	0.4774
	PC2	-0.7119	-0.0351	0.6994
	PC3	-0.2649	-0.2484	-0.3476
Americas	PC1	0.4797	0.4817	0.511
	PC2	0.3954	0.613	0.5862
	PC3	0.7575	0.5428	0.1436

Table 5 Description of variables

Symbol	Obs	Mean	Std. dev.	Min	Max
CO2	1258	7.374	6.341	0.209	47.7
FIN-1	1258	65.121	44.534	0.129	228.417
FIN-2	1258	22.146	16.359	0.41	104.34
FIN-3	1258	71.00	40.873	0.186	304.575
URB	1258	1.173	1.861	-2.258	17.512
GDP	1258	26.061	1.69	22.208	30.696
ER	1258	28.409	10.436	7.241	74.812
TO	1258	90.435	55.717	20.723	437.327
HC	1258	2.919	0.522	1.578	4.352

FIN and carbon emissions (full and subsamples)

In order to get reliable and efficient approximations in the existence of serial correlation, heteroscedasticity, and cross-sectional dependence, we analyzed the original Eq. (2) using state-of-the-art statistical methods on the whole data set and subsamples. Table 7 displays the overall sample’s conclusions on the exponential effect of FIN on CO2 emissions. The coefficient for FIN is highly positive and statistically significant. However, the link between CO2 and financial inclusion was discovered to be inverted U-shaped, with a negative coefficient of a square of FIN ($1 > 0, 20$). Ultimately, our findings lend credence to the EKC theory across the board. Our results also jibe with the idea that a stable financial system initially facilitates risk management and efficient resource sharing, thereby encouraging industrial activities that improve economic prospects but degrade environmental quality. Eventually, after a tipping point, economic growth guarantees the protection of the natural world.

The correlation between FIN growth and CO2 emission is reported for developed, frontier, emerging, and isolated capital markets in Tables 8, 9, 10, and 11. The financial inclusion coefficients and squared term indicate that the EKC hypothesis holds across developed, emerging, and frontier countries. However, the EKC theory fails to hold in economies that operate independently. The study outcomes are consistent with the theoretical expectation that various countries may impact green economic growth, technological progress, and capital accumulation regarding financial development. For instance, the cost of obtaining credit is lower for individuals and businesses in countries with well-established financial systems. Technological advancement is higher, and economic growth is more widespread in these countries than in those with less developed financial systems. Since countries are at vastly different points in their financial development, it is unrealistic to assume that inclusive financial growth will have the same impact on carbon emissions across the board. Developed, frontier, emerging, and standalone capital

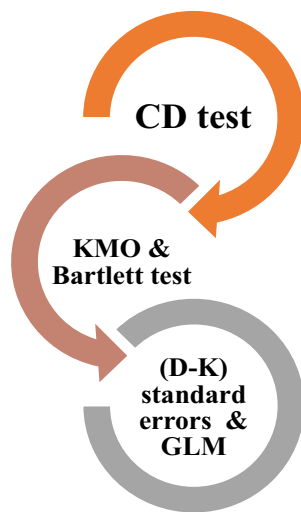


Fig. 2 Estimation process

of the CSD analysis, which shows that the expected test statistic is statistically significant for all variables, indicating that the problem of CSD is identified in the panel dataset used in this investigation.

Table 6 Results from cross-section independence tests

Variables	CO2	FIN	GDP	URB	ER	TO	HC
Full sample	2.39***	2.60***	156.93***	2.35***	84.93***	31.75***	7.60***
Developed	9.64***	5.23***	41.60***	2.09***	34.90***	19.61***	12.981***
Emerging	2.73***	21.84***	47.62***	1.87*	29.46***	4.52***	2.26***
Developing	7.96***	9.65***	42.52***	3.323***	19.71***	8.17***	2.50***
Standalone	6.21***	1.93***	23.57***	4.21***	5.02***	2.74***	8.76***
Europe, Africa, and Middle East	3.01***	4.81***	102.54***	9.444***	55.31***	33.94***	1.87**
Asia	5.01***	9.92***	30.97***	3.6***	13.82***	10.75***	2.18***
Americas	5.24***	7.78***	26.45***	2.17**	12.69***	4.26***	8.30***

*, **, and *** means level of significance at 1%, 5% and 10%

Table 7 The nonlinear association between FIN and CO2EM (full sample)

Variables	D-K			GLM		
Z_FIN	0.292***			0.292***		
	-0.0154			-0.0168		
Z_FIN2	-0.0602***			-0.0602***		
	-0.00222			-0.00654		
Soft_FIN		0.265***			0.265***	
		-0.0127			-0.0152	
Soft_FIN2		-0.0596***			-0.0596***	
		-0.00192			-0.00694	
mmx_FIN			0.290***			0.290***
			-0.0163			-0.0164
mmx_FIN2			-0.0621***			-0.0621***
			-0.00243			-0.00671
URB	0.0334**	0.0317**	0.0320**	0.0334***	0.0317**	0.0320**
	-0.0145	-0.0139	-0.0149	-0.0129	-0.0129	-0.0128
GDP	0.0989	0.0878	0.177***	0.0989	0.0878	0.177**
	-0.0596	-0.0587	-0.025	-0.0761	-0.0758	-0.0772
ER	0.0403***	0.0403***	0.0413***	0.0403***	0.0403***	0.0413***
	-0.00182	-0.00183	-0.00161	-0.00219	-0.00221	-0.00218
TO	0.000872**	0.000748**	0.000970***	0.000872**	0.000748**	0.000970***
	-0.000314	-0.000324	-0.000275	-0.000373	-0.000372	-0.000368
HC	0.857***	0.865***	0.859***	0.857***	0.865***	0.859***
	-0.0339	-0.0322	-0.0339	-0.0431	-0.0427	-0.0427
Constant	-4.635***	-4.351**	2.513***	-4.635**	-4.351**	2.513
	-1.521	-1.498	-0.663	-1.996	-1.991	-2.036
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.696	0.698	0.699			
Observations	1148	1148	1148	1148	1148	1148
No of countries	70	70	70	70	70	70

*, **, and *** means level of significance at 1%, 5% and 10%

markets, except standalone countries, all show an inverted U-shaped connection between FIN and CO2 emission

Last, we estimate using the GLM approach, which already includes corrections for heteroskedasticity. FIN and urbanization produce positive and statistically significant

results in generalized linear model (GLM) estimates at the 1% significance level. It demonstrates that a 1% increase in tourist arrival will result in a 3.15% rise in CO2 emission and that a 1% increase in urbanization will result in a 3.67% increase in CO2 emission. Our prior estimates

Table 8 The nonlinear association between FIN and CO2 emission (developed markets)

Variables	D-K			GLM		
Z_FIN	0.0990*			0.0990**		
	-0.0557			-0.0482		
Z_FIN2	-0.0269**			-0.0269**		
	-0.0137			-0.0121		
Soft_FIN		0.145*			0.145**	
		-0.0872			-0.0573	
Soft_FIN2		-0.0412*			-0.0412***	
		-0.0243			-0.0157	
mmx_FIN			0.138***			0.138***
			-0.0465			-0.0468
mmx_FIN2			-0.0374***			-0.0374***
			-0.0128			-0.0119
URB	0.0566***	0.0528***	0.0549**	0.0566*	0.0528*	0.0549*
	-0.0191	-0.0177	-0.0199	-0.029	-0.029	-0.0286
GDP	0.0321	0.0462	0.00011	0.0321	0.0462	0.00011
	-0.0424	-0.0485	-0.0305	-0.0896	-0.0899	-0.0883
ER	0.0124***	0.0139***	0.0142***	0.0124**	0.0139***	0.0142***
	-0.0023	-0.0031	-0.00226	-0.00527	-0.00536	-0.00521
TO	0.000135	0.00003	0.0001	0.000135	0.0000375	0.0001
	-0.00017	-0.000209	-0.00016	-0.0003	-0.000304	-0.00029
HC	0.304***	0.315***	0.306***	0.304***	0.315***	0.306***
	-0.0675	-0.0659	-0.0675	-0.0675	-0.0669	-0.0669
Constant	-0.231	-0.676	0.553	-0.231	-0.676	0.553
	-1.124	-1.293	-0.825	-2.374	-2.39	-2.315
R-squared	0.23	0.236	0.244			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	367	367	367	367	367	367
No of countries	22	22	22	22	22	22

*, **, and *** means level of significance at 1%, 5% and 10%

were likewise in line with these findings. The estimated coefficient is consistent with Baskaya (2022) and Zeraibi et al. (2023). The fundamental correlations are consistent with prior research, but the magnitudes vary widely. The selected South Asian countries’ developmental characteristics could be a contributing factor. As developing nations, South Asian nations are more inclined to use unsustainable urbanization and tourism growth methods. As a result, these factors will cause CO2 emissions to be higher than in wealthy nations. According to the data presented in Tables 12, 13, and 14, FIN-based EKC does exist for Europe, Africa, the Middle East, and Asia but does not apply to the USA. Our findings imply a nonlinear connection between carbon pollution and overall economic growth where EKC is present. The hypothetical assumptions that ESG-linked principles and enticements for companies and people to support sustainable development vary across regions are consistent with the inconsistent behavior of FIN based on EKC. Therefore, there are better methods than a

one-size-fits-all policy to guarantee sustainable development (Chang et al. 2023).

Both the squared terms and coefficients of FIN strongly support our conclusions that EKC is present across both the full and subsamples. This further demonstrates the autonomy of the EKC founded on financial inclusion compared to the traditional EKC. Across Asia, Africa, the Middle East, and Europe (Chishti and Sinha 2022), FIN has a negative long-term effect on CO2 emissions and encourages environmental sustainability. These areas have put an emphasis on renewable energy and other forms of alternative power, enabling them to achieve the level of economic growth essential for cutting CO2 emissions. Previous findings support the nonlinear opposing outcome of squared financial expansion and the presence of the EKC inverted U-shaped hypothesis on CO2 emissions in various regions, such as Europe and Central Asia (Haldorai et al. 2022), South Africa (Cheng and Hu 2022), China, and the United Arab Emirates (Dai et al. 2022). On the other hand, 46 nations in Africa show that

Table 9 The nonlinear association between FIN and CO2 emission (emerging markets)

Variables	D-K		GLM			
Z_FIN	0.224***		0.224***			
	-0.0375		-0.0481			
Z_FIN2	-0.275***		-0.275***			
	-0.0268		-0.0403			
Soft_FIN		0.237***		0.237***		
		-0.0301		-0.0408		
Soft_FIN2		-0.199***		-0.199***		
		-0.0306		-0.0313		
mmx_FIN			0.278***		0.278***	
			-0.0462		-0.0451	
mmx_FIN2			-0.189***		-0.189***	
			-0.0319		-0.0342	
URB	0.0577***	0.0576***	0.0615***	0.0577***	0.0576***	0.0615***
	-0.00939	-0.0111	-0.0118	-0.0186	-0.0188	-0.019
GDP	0.0273	0.0205	0.530***	0.0273	0.0205	0.530***
	-0.0995	-0.0978	-0.16	-0.163	-0.164	-0.184
ER	0.0427***	0.0428***	0.0434***	0.0427***	0.0428***	0.0434***
	-0.0021	-0.00231	-0.00214	-0.00375	-0.00379	-0.00385
TO	0.000134	6.46E-05	0.000608	0.000134	6.46E-05	0.000608
	-0.00135	-0.00132	-0.00108	-0.00117	-0.00118	-0.00119
HC	0.767***	0.773***	0.805***	0.767***	0.773***	0.805***
	-0.165	-0.181	-0.162	-0.1	-0.101	-0.102
Constant	-2.381	-2.235	11.96**	-2.381	-2.235	11.96**
	-2.887	-2.877	-4.645	-4.32	-4.349	-4.899
R-squared	0.648	0.642	0.631			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	367	367	367	367	367	367
No of countries	22	22	22	22	22	22

*, **, and *** means level of significance at 1%, 5% and 10%

none of the financial expansion indicators had a significant nonlinear impact on carbon emissions. In OECD and Asian nations, carbon emissions were found to be linearly related to financial inclusion (Idrees and Majeed 2022). These studies suggest that the ease with which new businesses can obtain financing despite their high energy usage is a direct result of economic growth’s contribution to environmental degradation. As a corollary, financial development reduces transaction costs and makes private-sector lending much more reasonable. This leads to environmental pollution as new initiatives move forward without considering their impact on the planet.

Table 14’s coefficient indicators of RE components show similar outcomes to the earlier models summarized in Table 13, albeit at a higher degree of significance. (1) Carbon emissions in the certain countries rise as a result of energy use in nearby regions. For every percentage point that neighboring provinces raise their energy consumption, their CO2 emissions will rise by 0.217430. This lends credence to

claims made in the literature that increased energy consumption results in higher regional carbon emissions (Zhang and Song 2021). Because of this, spending money on energy is necessary to improve productivity. Therefore, we must take into account the critical significance of energy investment in reducing carbon emissions. Carbon emissions are lowered by tougher local environmental regulation. Environmental regulation has a negative direct effect coefficient.

This implies that carbon emissions in the same province may be lowered by 0.847501 depending on the stringency of environmental control at the provincial level. This is because interested parties seek for eco-friendly substitutes to avoid the repercussions of breaking environmental regulations, thereby improving environmental quality. Since the effects of environmental restrictions may be delayed in time, the coefficient for indirect effects is small. This would imply that stricter environmental restrictions in adjacent provinces have no effect on emissions in the region. This is because the environmental

Table 10 The nonlinear association between FIN and CO2 emission (frontier markets)

Variables	D-K			GLM		
Z_FIN	0.316***			0.316***		
	-0.0382			-0.0408		
Z_FIN2	-0.0334***			-0.0334**		
	-0.00709			-0.016		
Soft_FIN		0.289***			0.289***	
		-0.0343			-0.0379	
Soft_FIN2		-0.0251**			-0.0251***	
		-0.0112			-0.0103	
mmx_FIN			0.319***			0.319***
			-0.036			-0.04
mmx_FIN2			-0.0422***			-0.0422**
			-0.011			-0.021
URB	0.0165	0.0111	0.0188	0.0165	0.0111	0.0188
	-0.0423	-0.0416	-0.0425	-0.0335	-0.0336	-0.0336
GDP	0.00726	0.0347	0.356***	0.00726	0.0347	0.356**
	-0.0825	-0.0801	-0.0852	-0.161	-0.159	-0.169
ER	0.0388***	0.0394***	0.0414***	0.0388***	0.0394***	0.0414***
	-0.00998	-0.0106	-0.0109	-0.0109	-0.0111	-0.0109
TO	0.00859***	0.00844***	0.00830***	0.00859***	0.00844***	0.00830***
	-0.00119	-0.0012	-0.00128	-0.00189	-0.00191	-0.0019
HC	0.867***	0.888***	0.858***	0.867***	0.888***	0.858***
	-0.0676	-0.0666	-0.0756	-0.0927	-0.0933	-0.0927
Constant	-2.344	-1.706	6.750**	-2.344	-1.706	6.75
	-2.185	-2.093	-2.429	-4.245	-4.208	-4.512
Observations	224	224	224	224	224	224
R-squared	0.792	0.793	0.796			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	323	323	323	323	323	323
No of countries	19	19	19	19	19	19

*, **, and *** means level of significance at 1%, 5% and 10%

restrictions in one location may not be up to par with those in another, delaying the time it takes for the spillover effects to be felt in the other region.

Robustness check

Our inverted U-shaped link between CO2 emissions and FIN is tested for robustness. For both the complete and the split samples, we used the generalized linear model. In this scenario, the results are very comparable, according to this study. FIN is the key independent variable that has the most beneficial effect on CO2 emission. The findings in this study suggest that improvement in FIN contributes to these 70 countries and reduces the CO2 emission. Renewable energy consumption and TO are also found to have a notable positive effect on CO2 emission. However, the inflation rate has no bearing on economic development,

while the market interest rate has a substantial negative influence. The GLM regression result confirms the validity and reliability of the model employed in this investigation. Similar conclusions were reached by other empirical research (Abdur et al. 2022), which all backed up the nonlinear effect of FIN on carbon emissions.

Conclusion and policy implications

The economies of emerging nations are predicted to expand significantly over time; however, along with this economic expansion comes the prospect of unprecedented climate risks. This is because emerging nations frequently resolve to couple economic gains with environmental losses in their pursuit of faster economic growth. This trade-off between economic development and

Table 11 The nonlinear association between FIN and CO2 emission (standalone markets)

Variables	D-K			GLM		
Z_FIN	0.0703			0.0703		
	-0.0462			-0.0472		
Z_FIN2	-0.0434**			-0.0434*		
	-0.0151			-0.0256		
Soft_FIN		0.037			0.037	
		-0.0655			-0.0483	
Soft_FIN2		-0.0410*			-0.0410*	
		-0.0204			-0.0247	
mmx_FIN			0.0615*			0.0615
			-0.0352			-0.0409
mmx_FIN2			-0.0545***			-0.0545**
			-0.0148			-0.0241
URB	-0.111**	-0.113***	-0.123***	-0.111***	-0.113***	-0.123***
	-0.0399	-0.0377	-0.0354	-0.0386	-0.0384	-0.0387
GDP	0.340***	0.347***	0.454***	0.340**	0.347**	0.454***
	-0.0471	-0.045	-0.0726	-0.141	-0.143	-0.148
ER	0.00105	0.00162	0.00355	0.00105	0.00162	0.00355
	-0.00289	-0.0027	-0.00345	-0.00748	-0.00753	-0.00719
TO	0.00251***	0.00309**	0.00304***	0.00251**	0.00309**	0.00304***
	-0.000699	-0.00118	-0.000791	-0.00113	-0.00125	-0.00112
HC	0.694***	0.711***	0.598***	0.694***	0.711***	0.598**
	-0.106	-0.12	-0.122	-0.252	-0.254	-0.257
Constant	8.337***	8.402***	11.54***	8.337**	8.402**	11.54***
	-1.287	-1.228	-1.977	-3.816	-3.875	-4.055
Observations	106	106	106	106	106	106
R-squared	0.701	0.696	0.707			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	178	178	178	178	178	178
No of countries	10	10	10	10	10	10

*, **, and *** means level of significance at 1%, 5% and 10%

environmental stress is inevitable, given the widespread dependence on fossil fuels among the world’s emerging economies. When this happens, it is crucial to find ways to lessen the effects of climate change on developing countries. In light of this, the current research attempted to investigate the impacts of financial inclusion on CO2 emission in the context of 22 developing nations, while accounting for factors such as increases in energy efficiency, renewable energy use, GDP growth, trade, and urbanization. The estimation method was developed to eliminate the effects of endogeneity, endogeneity, and common-sample bias in the panel data used for analysis. In light of these crucial results, we propose a series of practical policies for reducing climate-related risks. First, developing countries should work toward making their financial sectors both more accessible and environmentally sustainable in order to mitigate the environmental risks connected

with financial inclusion. It is crucial that these countries take the necessary steps to green the related financial services by first identifying the sources of financial risks that are linked with climate risks. In addition, green financial schemes should be examined for implementation to further mitigate any unfavorable effects of financial inclusion on the environment. Second, developing countries should consider increasing funding for energy innovation projects to highlight the significance of improving energy use efficiency to both directly and indirectly hinder CO2 emission. Specifically, these countries should increase their expenditures in R&D to improve the technological stock related to increasing energy utilization efficiency. A more effective use of energy resources requires a number of measures, including promoting the replacement of energy-intensive electrical appliances with alternatives that use significantly less energy. Another possible method

Table 12 The Nonlinear association between FIN and CO2 emissions (Europe, Middle East, and Africa region)

Variables	D-K			GLM		
Z_FIN	0.305***			0.305***		
	-0.0144			-0.0173		
Z_FIN2	0.0729***			0.0729***		
	-0.00628			-0.0063		
Soft_FIN	0.278***			0.278***		
	-0.0123			-0.0155		
Soft_FIN2	0.0770***			0.0770***		
mmx_FIN	0.304***			0.304***		
	-0.0232			-0.0169		
mmx_FIN2	-0.0785***			-0.0785***		
	-0.00682			-0.00664		
URB	-0.0101	-0.0113	-0.0120	-0.0101	-0.0113	-0.0120
	-0.0153	-0.0148	-0.0152	-0.0112	-0.0111	-0.0111
GDP	0.230***	0.209**	0.0509	0.230***	0.209***	0.0509
	-0.0785	-0.0776	-0.0414	-0.0749	-0.0741	-0.0755
ER	0.0525***	0.0521***	0.0531***	0.0525***	0.0521***	0.0531***
	-0.00159	-0.0015	-0.00155	-0.00206	-0.00208	-0.00206
TO	0.00118***	0.00122***	0.00129***	0.00118**	0.00122***	0.00129***
	-0.000214	-0.000243	-0.000262	-0.00047	-0.000462	-0.000464
HC	0.590***	0.586***	0.581***	0.590***	0.586***	0.581***
	-0.0272	-0.03	-0.0267	-0.0433	-0.0428	-0.0432
Constant	-7.431***	-6.856***	-0.0883	-7.431***	-6.856***	-0.0883
	-2.016	-1.997	-1.048	-1.967	-1.947	-1.99
R-squared	0.748	0.754	0.751			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	790	790	790	790	790	790
No of countries	48	48	48	48	48	48

*, **, and *** means level of significance at 1%, 5% and 10%

of reducing energy consumption by consumers is to allow them to barter the energy they have saved as a result of efficiency gains. Furthermore, the end-user’s behavior can be nudged toward more energy efficiency through financial incentives and tax breaks, leading to a significant decrease in wasteful energy consumption.

Environmental regulation policies should take into account regional peculiarities and specifics. Strict regulations should be put in place to control the quantum emissions from high-emitting regions such as China, India, Russia, the United States of America, and other developed and developing countries. Enhanced energy conservation cooperation and continued low emissions could bring low-emitting regions full circle of goodwill if they adopt and implement stricter emission reduction and pollution control standards. In order to reduce carbon emissions, high-emission regions will need to be encouraged in the coming years to use clean coal and coal-to-gas conversion technology.

The empirical findings are used to suggest a number of policy implications for these 70 countries. First, reducing fossil fuel consumption and increasing environmental regulation (ER) are two proven strategies. Enhancing ER has the potential to lessen the impact of natural resource consumption on carbon emissions and boost environmentally friendly growth, as evidenced by the negative moderating effect of ER. Increases in efficiency in power plants, transitions to more sustainable industries, and the introduction of new technology all contribute to lower CO2 output. Second, increasing health and educational opportunities through productive energy use raises overall living standards. Clean energy portfolios must be implemented by certain country leaders in order to limit fossil fuels through the carbon tax and incentives to domestic enterprises and foreign sectors to boost investments in green technologies. Sustainable development, a carbon-neutral economy, and an improved living society

Table 13 The nonlinear link between FIN and CO2 emissions (Asia region)

Variables	D-K			GLM		
Z_FIN	0.483***			0.483***		
	-0.0345			-0.0337		
Z_FIN2	-0.0693***			-0.0693***		
	-0.0113			-0.0138		
Soft_FIN		0.443***			0.443***	
		-0.0325			-0.0296	
Soft_FIN2		-0.0428***			-0.0428***	
		-0.0114			-0.0151	
mmx_FIN			0.468***			0.468***
			-0.0268			-0.0344
mmx_FIN2			-0.0589***			-0.0589***
			-0.0112			-0.0123
URB	0.319***	0.325***	0.330***	0.319***	0.325***	0.330***
	-0.0631	-0.0621	-0.0619	-0.0427	-0.0416	-0.0439
GDP	0.0969	0.125*	0.625***	0.0969	0.125	0.625***
	-0.0626	-0.0641	-0.0797	-0.127	-0.126	-0.138
ER	0.0117**	0.0145***	0.0148***	0.0117***	0.0145***	0.0148***
	-0.00477	-0.0047	-0.00443	-0.00451	-0.00449	-0.00446
TO	0.000784**	0.000825*	0.000943**	0.000784**	0.000825**	0.000943**
	-0.000369	-0.000402	-0.000405	-0.000398	-0.000416	-0.000399
HC	0.517***	0.503***	0.558***	0.517***	0.503***	0.558***
	-0.0432	-0.0403	-0.0465	-0.0896	-0.087	-0.0888
Constant	1.44	2.038	14.98***	1.44	2.038	14.98***
	-1.601	-1.615	-2.21	-3.336	-3.301	-3.679
R-squared	0.918	0.92	0.912			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	212	212	212	212	212	212
Number of groups	12	12	12	12	12	12

*, **, and *** means level of significance at 1%, 5% and 10%

for humans are impossible to achieve without expanding and investing in nuclear energy in 70 countries. Policy and action to increase human capital and implement low-emission energy systems should include nuclear power. The government should support the development of novel nuclear technologies like the once-through fuel cycle and tiny modular reactors, as well as the renewal of licenses and the construction of new reactors. Research, pilot programs, and educational initiatives highlighting the benefits of nuclear energy, such as climate stability and human growth, should also receive support from these countries. To further address the issues of nonproliferation, security, human, and environmental safety associated with nuclear energy, these countries

should work together to create nuclear energy initiatives and share best practices through funding, technology transfer, and capacity development. The findings of this country-specific empirical study may or may not be generalizable to other countries with comparable human development indices (either high or low). Private and public debt, as well as other debt proxies, can be used in place of total external debt in environmental assessment effects. Researchers in the future will be able to look at the asymmetric effect of studied regressors on human development and carbon emission, but for now, this study focuses on the symmetric influence of nuclear energy, financial globalization, external debt, economic growth, and renewable energy. Table 15

Table 14 The nonlinear association between FIN and CO2 Emissions (Americas region)

Variables	D-K			GLM		
Z_FIN	0.0862***			0.0862***		
	-0.0166			-0.0328		
Z_FIN2	0.0482***			0.0482***		
	-0.0124			-0.0137		
Soft_FIN		0.0635***			0.0635*	
		-0.0152			-0.0348	
Soft_FIN2		0.0464***			0.0464***	
		-0.0121			-0.0155	
mmx_FIN			0.0628**			0.0628*
			-0.025			-0.0361
mmx_FIN2			0.0467***			0.0467***
			-0.0148			-0.0171
URB	-0.298**	-0.299**	-0.327***	-0.298***	-0.299***	-0.327***
	-0.109	-0.108	-0.0993	-0.102	-0.102	-0.104
GDP	0.162**	0.158**	0.0316	0.162	0.158	0.0316
	-0.0729	-0.0738	-0.0939	-0.121	-0.122	-0.13
ER	-0.0135**	-0.0133**	-0.0139**	-0.0135**	-0.0133**	-0.0139**
	-0.00469	-0.00487	-0.00501	-0.00549	-0.00557	-0.00574
TO	0.00984***	0.00987***	0.00980***	0.00984***	0.00987***	0.00980***
	-0.000465	-0.000445	-0.000326	-0.00149	-0.0015	-0.00153
HC	1.131***	1.134***	1.131***	1.131***	1.134***	1.131***
	-0.0892	-0.0895	-0.0981	-0.113	-0.116	-0.117
Constant	2.043	1.939	-1.270	2.043	1.939	-1.270
	-2.023	-2.045	-2.563	-3.197	-3.217	-3.431
Observations	117	117	117	117	117	117
R-squared	0.812	0.809	0.802			
F-stats (P value)	0	0	0			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	172	172	172	172	172	172
Number of groups	10	10	10	10	10	10

*, **, and *** means level of significance at 1%, 5% and 10%

Appendix

Table 15 Sample description

Developed market			
Australia	Ireland	Portugal	Netherlands
Austria	Israel	Singapore	New Zealand
Belgium	Italy	Spain	Norway
Canada	Japan	Sweden	Denmark
Finland	France	Switzerland	Germany
Emerging market			
Brazil	Czech Republic	Indonesia	Peru
Chile	Greece	Kuwait	Philippines
China	Hungary	Malaysia	Poland
Colombia	India	Mexico	Qatar
Russian Federation	Saudi Arabia	South Africa	Thailand
Turkey			
Frontier market			
Bahrain	Iceland	Lithuania	Oman
Bangladesh	Jordan	Mauritius	Pakistan
Croatia	Kazakhstan	Morocco	Romania
Estonia	Kenya	Nigeria	Serbia
Slovenia	Sri Lanka		
MSCI standalone markets			
Argentina	Lebanon	Botswana	Panama
Bosnia and Herzegovina	Malta	Bulgaria	Trinidad and Tobago
Jamaica	Ukraine		
Europe, Africa, and Middle East			
Austria	Czech Republic	Hungary	Lithuania
Bahrain	Denmark	Iceland	Malta
Belgium	Estonia	Ireland	Mauritius
Bosnia and Herzegovina	Finland	Israel	Morocco
Botswana	France	Italy	Netherlands
Bulgaria	Germany	Jordan	Nigeria
Croatia	Greece	Kazakhstan	Norway
Oman	Qatar	Saudi Arabia	South Africa
Poland	Romania	Serbia	Spain
Portugal	Russian Federation	Slovenia	Sweden
Switzerland	Turkey	United Arab Emirates	Zimbabwe
Tunisia	Ukraine	UK	Kenya
Asia			
Australia	India	Malaysia	Philippines
Bangladesh	Indonesia	New Zealand	Singapore
China	Japan	Pakistan	Sri Lanka
America			
Argentina	Chile	Mexico	Trinidad and Tobago
Brazil	Colombia	Panama	USA
Canada	Jamaica	Peru	

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Data availability The data can be available on request.

Declarations

Ethical approval and consent to participate We declare that we have no human participants, human data, or human tissues.

Consent for publication N/A

Competing interests The authors declare no competing interests.

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