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Does natural resource rent and financial inclusion curb carbon emissions? Empirical evidence from E7 and G7 economies

Shnehal Soni[1] & R. L. Manogna[1]✉

The study here analyzes the linkage between natural resource rent (NRR), financial inclusion, and carbon emissions taking foreign direct investment (FDI) and institutional quality as control variables in the emerging (E7) and developed (G7) economies during 2004–2021. Fully modified ordinary least squares (FMOLS) techniques and dynamic ordinary least squares (DOLS) are applied for estimating the model and the method of moments quantile regression (MMQR) is used for checking the robustness of the results. Findings indicated that NRR depicted a positive impact on carbon emissions in both emerging and developed economies and financial inclusion showed a negative impact on carbon emissions in emerging economies but lacked statistical significance with respect to developed economies. FDI inflows depicted a positive impact on carbon emissions with respect to all the economies taken together and with respect to institutional quality there was a varied impact of institutional factors on carbon emissions in both E7 and G7 nations. In order to lower carbon emissions, the policymakers should prioritize the establishment of regulatory frameworks that promote the delivery of sustainable financial services. They should focus on the enhancement of institutional quality and reduce the dependence on resource rents derived from fossil fuels.

[1] Birla Institute of Technology and Science Pilani—Goa Campus, Sancoale, India. ✉email: manognar@goa.bits-pilani.ac.in

Introduction

The notion of a green environment is associated with sustainable development which addresses a number of issues, such as encouraging the adoption of sustainable production and consumption practices, lowering environmental pollutants, and minimizing waste (Li et al. 2022). Globalization has boosted the competitiveness of both developed and emerging economies but it has also led to an increased consumption of energy as well as carbon emissions (Yasmeen et al. 2023). The depletion of non-renewable natural resources has resulted in environmental degradation, including contamination of air, water, and soil. Protecting the environment and preserving natural resources has emerged as a top priority not only in the developing economies but also in the developed economies, as the natural capital has a vital role in economic development. The usage of natural resources is vital for the development of nations, leading to a continuous increase in the rents obtained from natural gas, oil, and forests (Unceta 2021). Jia et al. (2024) stated that in the long run, a substantial dependence on natural resources, including mineral and forest resources leads to increased carbon emissions and worsens environmental issues.

Finance also plays a vital role in managing a nation's socio-economic and environmental development (Manogna 2021a; Manogna and Anand 2023; Soni and Manogna 2024a; Soni and Manogna 2024b). Financial inclusion being a very crucial component of financial development, significantly impacts the carbon emissions. It can exert both negative and positive effects on carbon emissions. Financial inclusion provides enhanced access for companies and individuals to affordable financial products that facilitate investments in green technology (Le et al. 2020). Promoting financial inclusion is essential in impoverished societies where farmers do not have sufficient funds to invest in clean technology (Manogna and Mishra 2020; Manogna and Mishra 2022; Manogna and Kulkarni 2024; Manogna et al. 2024). If financial services are accessible as well as affordable, farmers may purchase cost-effective solar energy microgrids, which are more environmentally friendly than coal-burning plants (IPA 2017; Zaidi et al. 2021). Conversely, enhanced access to financial services and a rise in manufacturing and industrial activities contribute to increased carbon emissions, subsequently exacerbating global warming. An increase in activities may lead to energy poverty, which could also contribute to carbon emissions (Zhao et al. 2021). Furthermore, increased financial inclusion enables consumers to purchase high-energy goods which significantly contribute to environmental degradation through elevated emissions. Economic activities are enhanced through the incorporation of financial systems, leading to increased energy demand. This demand, particularly for non-renewable energy sources contributes to higher carbon emissions (Frankel and Romer 1999).

In this context, the study here analyzes the linkage between natural resource rent (NRR), financial inclusion, and carbon emissions in emerging (E7) and developed (G7) economies during 2004–2021. The emerging economies include Brazil, Turkey, China, Mexico, Indonesia, Russia, and India and developed economies include the United States, France, Italy, Germany, Canada, Japan, and the United Kingdom. Foreign direct investment (FDI) and institutional quality are the control variables taken. The relationship between FDI inflows and carbon emissions has been extensively documented in the literature. In this regard, two contrasting perspectives have emerged. The first perspective is articulated as the pollution haven hypothesis. The pollution haven hypothesis posits that weak environmental regulations in host nations lead to the relocation of highly polluting and resource-intensive firms from other countries via FDI inflows resulting in a significant rise in carbon emissions. Studies (Liu et al. 2017; Nasir et al. 2019; Shahbaz et al. 2019) have investigated this and validated that FDI inflows exacerbate environmental degradation. The alternative perspective is defined as the pollution halo hypothesis. This suggests that FDI inflows bring with them superior, modern, and energy-efficient technologies to host nations, thereby aiding in the reduction of carbon emissions. Studies (Pao and Tsai 2011; Zhang and Zhou 2016; Liu et al. 2017; Sung et al. 2018) have stated that FDI inflows contribute positively to the reduction of carbon emissions. There is presently no consensus on whether the effect of FDI inflows on carbon emissions aligns with the pollution haven hypothesis or the pollution halo theory. Therefore, understanding this association between FDI inflows and carbon emissions is significant. The other control variable taken is institutional quality. The concept of "institutional quality" encompasses a nation's governance framework and the effectiveness of its institutions. Empirical evidence in the literature (Hakimi and Hamdi 2019; Wawrzyniak and Doryn 2020; Boussaidi and Hakimi 2024) indicates that higher institutional quality enhances environmental quality. Enhanced corruption control, stringent rule of law, and increased political stability are associated with the implementation of rigorous environmental policies which contribute toward lowering carbon emissions.

The study adds to the existing literature in the following ways: Firstly, many previous studies (Tufail et al. 2021; Qin et al. 2021; Hodžić et al. 2023; Shang et al. 2024) have investigated the impact of financial inclusion and natural resources rent separately on carbon emissions but there is a lack of comprehensive analysis on the synergistic effects of natural resource rents and financial inclusion on carbon emissions in both E7 and G7 economies. Therefore, the primary objective of the paper is to examine the impact natural resource rent and financial inclusion have on carbon emissions in the context of both emerging and developed economies. The emerging economies, according to IEA (2022), are anticipated to raise their demand for energy by 2030 which will increase carbon emissions. So analyzing these factors in the context of emerging economies becomes imperative. The developed economies taken for the study are considered to be the most advanced and industrialized nations which historically have been the largest contributors to carbon emissions. Thus, it becomes very vital to examine the factors that could support them in lowering their carbon emissions.

Secondly, the study has also taken FDI and institutional quality as control variables impacting carbon emissions. Institutional quality is significant for the improvement of the quality of the environment in a nation. By establishing rules that support environmentally conscious and sustainable lending and investing practices, high-quality institutions can reduce the risk of funding activities that harm the environment. Thirdly, robust estimation methods which include fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and method of moments quantile regression (MMQR) were applied and all these three estimation techniques handle the issue of endogeneity in the data and help in providing consistent estimates.

The remaining paper is organized as follows: Literature review is provided in the second section. Data and methodology are described in the third section. Results and their interpretation have been presented in the fourth section and the final section concludes the study with a few policy recommendations.

Literature review

Natural resource rent and carbon emissions. Various studies examined the linkage between these two variables but provided varied results. Lei et al. (2022) found that G-20 nations struggled

to meet carbon control targets due to their dependency on natural resources. Wang et al. (2020) analyzed the effect of financial development, natural resource rent, and agricultural value added on carbon emissions with respect to G7 countries. The study found that NRR led to higher carbon emissions in these nations.

Bekun et al. (2019) found that NRR raised carbon emissions in EU countries. Luo et al. (2023) also found that in the countries belonging to the lower income category, the association was positive between NRR and carbon emissions. Daboussi (2023) also stated that NRR led to increased carbon emissions, which negatively impacted the environment. However, the impact varied between oil-exporting MENA nations and the non-MENA exporting nations. Shi et al. (2023) in their study with respect to Saudi Arabia stated that positive shocks to economic growth and natural resources led to higher carbon emissions. Jia et al. (2024) stated that in the long run, a substantial dependence on natural resources, including mineral and forest resources leads to increased carbon emissions.

There are also few studies that have provided contradictory results with respect to NRR impacting carbon emissions. Danish et al. (2019) stated that natural resources available in BRICS nations helped in lowering pollution, except for India. Combining the renewal of natural resources and its conservation would assist in reducing carbon emissions and outdated technologies should be replaced with ecologically friendly alternatives (Manogna and Mishra 2021).

Kongbuamai et al. (2020) stated that natural resources improved the quality of the environment in ASEAN economies. Tufail et al. (2021) also revealed that natural resource rent contributed to lowering carbon emissions in the OECD nations, hence helped in improving the environment. Udemba and Yalçıntaş (2021) in their study stated that positive and negative shocks to FDI and natural resources reduced carbon emissions in Algeria. Liu et al. (2023) also stated that efficient resource management could help in preserving the environment even in countries which have abundant natural resources. Udemba et al. (2024) investigated Norway's sustainable environmental development by utilizing natural resources, FDI, and economic growth and it was found that natural resources and carbon emissions were negatively associated with each other indicating that Norway's atmosphere improved with natural resource policies.

Financial inclusion and carbon emissions. Increased access to financial services can boost carbon emissions, contributing to global warming. Increased activities may lead to energy poverty as well as carbon emissions (Zhao et al. 2021). Higher financial inclusion assists individuals in purchasing goods like cars, and air conditioners which are highly energy-consuming goods and lead to increased emissions. Fareed et al. (2022) looked at the linkage between environmental quality and financial inclusion as well as the moderating effect of innovative activity in twenty-seven European nations during 1995–2018. Financial inclusion was found to increase carbon emissions and accelerate ecological imprint. Musah (2022) investigated the influence financial inclusion depicts on the sustainability of the environment in Ghana through ARDL approach. It was discovered that the sustainability of the environment was negatively impacted by financial inclusion through increased carbon emissions. Liu et al. (2022a) also noted that financial inclusion raised the carbon emissions with respect to OBOR economies.

Ben Jebli and Hakimi (2023) analyzed how economic growth, financial inclusion, technological innovation, and other factors affect environmental quality across the top 10 nations in terms of advancement of technology during 2004–2019. They emphasized that in the long run, non-renewable energy and financial inclusion increased carbon emissions while the other variables lowered it.

Hussain et al. (2023) investigated the linkage between financial inclusion and carbon emissions across 74 countries, encompassing emerging, developed, and frontier economies spanning the years 2004–2020. They observed an inverse U-shaped association between the variables throughout the whole sample and in several geographical areas, including the Middle East, Asia, Africa, and Europe.

Dogan and Seker (2016) in their study stated that financial development boosted the usage of renewable energy which helped in lowering GHGs. Usman et al. (2021) observed in their study that in the top 15 emitting countries carbon emissions was lowered due to financial development. Liu et al. (2022b) suggested that improving financial inclusion might assist in increasing green economic competency, which could be done by imposing credit limitations on carbon-emitting firms in China. Boussaidi and Hakimi (2024) observed that financial inclusion caused a considerable increase in carbon emissions in MENA nations. Furthermore, the interaction between the quality of the institutions and financial inclusion increased growth and improved environmental quality.

Thus, based on the review of existing literature, it can be observed that many studies have examined the effects of financial inclusion and natural resource rents on carbon emissions independently. However, there is a notable absence of comprehensive analysis regarding the combined effects of these factors on carbon emissions in both E7 and G7 economies. Hence, the study here analyzes the effect of natural resource rent and financial inclusion on carbon emissions in both emerging and developed economies.

Data and methodology

Data and variables selection. The study analyzes the linkage between natural resource rent, financial inclusion, and carbon emissions in emerging (E7) and developed (G7) economies during 2004–2021. FDI and institutional quality are the control variables taken. The variables are defined in Table 1.

Theoretical underpinning and empirical model. Natural resource rents are an important factor that influences carbon emissions. According to the World Bank (2022), natural resource rents encompass the total of oil rents, natural gas rents, and coal rents. Natural resources rent refers to the total revenue generated from the extraction of natural resources. Classical theory posits that nations rich in natural resources tend to exhibit superior performance compared to those with fewer resources. Some studies contend that nations rich in natural resources may experience greater income inequality and poverty compared to

Table 1 Variables definition.

Variables	Definition
CEM	CO_2 emissions (kg per PPP $ of GDP)
NRR	Total natural resources rents (% of GDP)
FI	Financial inclusion index
FDI	Net inflows (% of GDP)
VA	Voice and accountability
PS	Political stability and absence of violence/terrorism
GE	Government effectiveness
RQ	Regulatory quality
RL	Rule of law
CC	Control of corruption

World Bank and International Monetary Fund.

those with fewer resources (Ben-Salha et al. 2021). The impact of natural resources on economic growth has garnered significant interest from researchers and policymakers but there is a lack of consensus regarding the significant positive or negative effects of natural resource rents on carbon emissions. The relationship between natural resources and carbon emissions is significant, as rising commodity prices, particularly for oil and gas, may lead to decreased energy consumption and, in turn, lower carbon emissions. A decrease in oil prices results in heightened economic activity, thereby fostering economic growth and elevating carbon emissions. Addressing global climate change necessitates comprehensive systemic reforms regarding the types and quantities of resources utilized for energy (Hodžić et al. 2023).

Another important factor that can influence carbon emissions is financial inclusion. The implications of financial inclusion are multifaceted and constitute a new discourse within the framework of sustainable development goals. Consequently, it is essential to incorporate theoretical perspectives on carbon emissions while forecasting the policy directions that would influence financial inclusion initiatives. Innovations in the financial sector expand the scope of cross-border investment and provide enhanced opportunities for access to new energy-efficient products and advanced technologies. The technologies optimize energy appliance usage and decrease pollution levels in nations (Zaidi et al. 2021). Financial inclusion may adversely affect the environment through various mechanisms. It encourages consumers to borrow money for the acquisition of luxury items such as air conditioning units, refrigerators and automobiles, leading to increased emissions in the environment. It also contributes in decreasing the cost of financial resources for companies, enabling them to establish more factories, construct new sites, and acquire additional equipment and machinery, which subsequently increases emission levels (Sadorsky 2010). It is crucial to assess the effect of financial inclusion on carbon emissions in the emerging and developed nations which are characterized by advanced technology and elevated emission levels (Manogna 2021b).

Therefore, based on the above theoretical understanding, the empirical model for the study is developed. The dependent variable is carbon emissions and natural resource rent and financial inclusion are the main independent variables. The model is stated as follows:

$$CEM_{it} = \alpha + \beta_1 NRR_{it} + \beta_2 FI_{it} + \beta_3 FDI_{it} + \beta_4 IQ_{it} + \in_{it} \quad (1)$$

where, CEM denotes carbon emissions, NRR is natural resource rent, FI is financial inclusion, FDI is foreign direct investment and IQ represents institutional quality. IQ is the matrix of institutional variables which includes voice and accountability, rule of law, control of corruption, regulatory quality, government effectiveness, and political stability. α is a constant parameter and $\in_{it}$ is the error term. Equation (1) is estimated for the emerging economies and developed economies using data from 2004–2021.

Financial inclusion is measured by constructing an index by taking into consideration six aspects based on the approach followed by Boussaidi and Hakimi (2024) and Said and Acheampong (2023). The six aspects are: (i) number of commercial bank branches per 1000 km^2, (ii) number of ATMs per 1000 km^2, (iii) number of commercial bank branches per 100,000 adults, (iv) number of ATMs per 100,000 adults, (v) outstanding deposits with commercial banks (% of GDP), (vi) outstanding loans from commercial banks (% of GDP). The six variables are normalized before constructing the index. Using the z-score approach the variables are normalized and the method is described below:

$$Z - score = \frac{X_i - \bar{X}}{\alpha}$$

whereX_i is the raw score, $\bar{X}$ is the group mean and α is the standard deviation. Once the variables are normalized, principal component analysis (PCA) is conducted on normalized variables. This method helps in capturing most of the information from the data and helps in eliminating the risk of multicollinearity that might arise when in a given equation more than one proxy is taken. For all the institutional variables taken, the value of the estimate lies between −2.5 and 2.5. Data for this has been taken from the Worldwide Governance Indicators 2023 database.

Estimation techniques. The empirical analysis is conducted in four distinct steps. In the first step, we conducted the cross-sectional dependence test given by Pesaran (2004). This test is performed before looking into whether the data series is stationary or not. Then in the second step, we employed the Covariate Augmented Dickey-Fuller (CADF) test by Pesaran (2007) to examine the stationarity of the variables. This test takes care of cross-sectional dependence in the dataset (Said and Acheampong 2023). In the third step, we performed the cointegration test proposed by Kao (1999) to check for cointegration among the variables. This test assumes that across all the panels the cointegrating vector is the same and it does not allow time trend and estimates panel-specific means and then in the final step, we apply FMOLS techniques and DOLS are applied to estimate Equation (1). DOLS solves the problem of endogeneity as well as removes serial correlation present in OLS (Yahyaoui and Bouchoucha 2019). FMOLS provides efficient results for cointegrated variables and is a residual-based test. Then, to ensure the robustness of the results obtained, we applied the MMQR given by Machado and Silva (2019). If there is multicollinearity or issues of endogeneity present in the data then this approach is helpful in providing consistent and efficient estimates (Leng et al. 2024).

Results and discussion

Summary statistics. Summary statistics are presented in Table 2. Results are reported for all the economies, the emerging economies and the developed economies. It is seen that the mean value of CO_2 emissions in emerging countries is 0.32 while in developed countries it is 0.23. This implies that the carbon emissions are higher in emerging economies compared to developing economies. The mean value of natural resource rent is 5.12 in emerging economies while in developed economies it is 0.64. With respect to financial inclusion, in emerging economies, the mean value is only 0.01 whereas in developed economies it is 0.19. In the case of FDI inflows, the mean value is 2.35 in emerging economies while it is 2 in developed economies. Regarding all the institutional variables taken into consideration, the mean values are higher in developed economies than in emerging economies. It was also seen that with respect to emerging economies, half of the variables were positively skewed and majority of them depicted platykurtic properties as the values were less than 3. In the case of developed economies, most of them were negatively skewed and depicted leptokurtic properties as the values were greater than 3 and with respect to all the economies taken together majority of the variables were positively skewed and depicted platykurtic properties as values were less than 3.

Cross-sectional dependence test. With growing economic and financial integration across countries, policy shocks in one nation could also impact other nations. Therefore, performing the

Table 2 Summary statistics.

Categories	Mean	Standard deviation	Skewness	Kurtosis	No. of observations
Emerging economies					
CO_2	0.32	0.20	1.58	5.07	126
NRR	5.12	4.50	1.39	4.31	126
FI	0.01	1.11	−0.42	1.86	115
FDI	2.35	0.97	0.31	2.47	126
VA	−0.28	0.72	−0.75	2.18	126
PS	−0.76	0.39	−0.55	3.57	126
GE	−0.04	0.29	0.24	2.66	126
RQ	−0.11	0.28	0.29	2.11	126
RL	−0.39	0.31	−0.09	1.98	126
CC	−0.48	0.33	−0.15	2.26	126
Developed economies					
CO_2	0.23	0.10	0.59	2.75	126
NRR	0.64	1.07	2.81	11.27	126
FI	0.19	1.19	−0.93	3.59	120
FDI	2.00	2.01	2.26	9.97	126
VA	1.22	0.19	0.01	1.89	126
PS	0.62	0.33	−0.13	2.27	126
GE	1.40	0.42	−1.58	4.35	126
RQ	1.38	0.33	−0.65	2.70	126
RL	1.40	0.44	−1.62	4.37	126
CC	1.40	0.53	−1.31	3.79	126
All economies					
CO_2	0.28	0.16	1.99	7.84	252
NRR	2.88	3.96	2.07	7.23	252
FI	0.10	1.15	−0.69	2.78	235
FDI	2.18	1.58	2.12	12.06	252
VA	0.47	0.92	−0.89	2.79	252
PS	−0.07	0.78	−0.13	1.87	252
GE	0.68	0.81	0.09	1.36	252
RQ	0.64	0.81	0.04	1.42	252
RL	0.51	0.97	0.07	1.33	252
CC	0.46	1.04	0.13	1.39	252

Table 3 Pesaran's (2004) cross-sectional dependence test.

Categories	Test statistic	*p* value
Emerging economies		
CO_2	15.58	0.00
NRR	11.43	0.00
FI	14.25	0.00
FDI	0.50	0.62
VA	2.41	0.02
PS	−2.26	0.02
GE	−1.37	0.17
RQ	−1.25	0.21
RL	−1.66	0.09
CC	−2.45	0.01
Developed economies		
CO_2	19.16	0.00
NRR	6.23	0.00
FI	5.03	0.00
FDI	2.54	0.01
VA	7.87	0.00
PS	3.59	0.00
GE	7.09	0.00
RQ	0.69	0.49
RL	7.44	0.00
CC	−1.07	0.28
All economies		
CO_2	36.23	0.00
NRR	19.30	0.00
FI	14.79	0.00
FDI	3.77	0.00
VA	19.17	0.00
PS	−0.12	0.90
GE	0.27	0.78
RQ	−0.93	0.35
RL	4.06	0.00
CC	−1.13	0.26

cross-sectional dependence test is vital. The test results are given in Table 3. With respect to all the economies, emerging and developed, majority of the variables are significant. So, this implies cross-sectional dependence exists in the data.

Unit root test. The CADF test was performed in order to analyze the stationarity properties of the given variables. The unit root test results given in Table 4 showed that with respect to the emerging economies, developed economies, and all the economies, all the variables were stationary at first difference.

Cointegration test. The Kao test was applied to check for cointegration among the variables. It can be seen in Table 5 that with respect to emerging economies, all the test statistics are statistically significant and in the case of developed economies and all economies, most of the test statistics are significant which implies that long-run cointegration exists among the variables.

Panel regression results. Table 6 presents the regression results. NRR depicted a positive impact on carbon emissions in both emerging and developed economies as well as with respect to all the economies taken together. This result aligns with the findings of past studies (Bekun et al. 2019; Wang et al. 2020; He et al. 2022; Lei et al. 2022; Shang et al. 2024) which have confirmed the positive association between the two variables. The overuse of natural resources in the form of increased fossil fuel consumption can be a possible explanation for the positive relationship between NRR and carbon emissions in both developed and emerging economies. The emerging economies are considered to be the newly evolving industrialized economies that support their economic activities with the use of NRR and the use of fossil fuels is favorably associated with this economic development. Consequently, this leads to a rise in carbon emissions thereby declining the quality of the environment. However, this is in contrast to the findings of studies (Tufail et al. 2021; Wang et al. 2024). Tufail et al. (2021) offered empirical insights into the role of natural resources and fiscal decentralization in addressing carbon emissions in OECD economies from 1990 to 2018. Their findings indicated that natural resource rent contributed toward decreasing carbon emissions. Wang et al. (2024) in their study stated that low economic and financial risks may result in a decrease in carbon emissions when natural resource rents increased. Thus, these variations in results highlight the complex link between natural resource rent and carbon emissions and emphasize on the differing effects contingent upon regional and economic contexts.

Financial inclusion showed a negative impact on carbon emissions in emerging economies as well as with respect to all the economies taken together but lacked statistical significance with respect to developed economies. Studies (Renzhi and Baek 2020; Usman et al. 2021; Shahbaz et al. 2022) have confirmed this negative association between the two variables. Financial inclusion enables firms in adopting energy-efficient technologies with lower carbon emissions. It facilitates access to cost-effective financial instruments, enabling green technology investments (Le et al. 2020). This is in contrast to the findings of studies (Pata 2018; Gokmenoglu and Sadeghieh 2019; Amin et al. 2022; Le and Pham 2024) who have highlighted the positive impact of financial inclusion on carbon emissions in both high-income and low and

Table 4 CADF test.

Categories	Test statistic
Emerging economies	
CO_2	−0.276
ΔCO_2	−2.762***
NRR	0.167
ΔNRR	−2.270***
FI	−0.319
ΔFI	−2.898***
FDI	−0.869
ΔFDI	−4.817***
VA	−0.143
ΔVA	−1.279*
PS	0.478
ΔPS	−1.174*
GE	3.279
ΔGE	−0.964*
RQ	0.059
ΔRQ	−3.107***
RL	2.956
ΔRL	−1.799**
CC	1.467
ΔCC	−3.669***
Developed economies	
CO_2	−2.263
ΔCO_2	−5.886***
NRR	1.855
ΔNRR	−3.848***
FI	−1.263
ΔFI	−5.144***
FDI	−2.639
ΔFDI	−5.246***
VA	1.176
ΔVA	−2.793***
PS	0.695
ΔPS	−3.469***
GE	−2.848
ΔGE	−7.183***
RQ	0.023
ΔRQ	−2.642***
RL	−0.954
ΔRL	−6.331***
CC	−1.049
ΔCC	−2.800***
All economies	
CO_2	−0.938
ΔCO_2	−6.194***
NRR	−0.295
ΔNRR	−3.122***
FI	−1.192
ΔFI	−5.041***
FDI	−2.756
ΔFDI	−6.694***
VA	1.203
ΔVA	−1.564**
PS	−1.339
ΔPS	−3.847***
GE	2.453
ΔGE	−4.658***
RQ	0.703
ΔRQ	−2.084**
RL	2.010
ΔRL	−3.805***
CC	0.335
ΔCC	−4.921***

***,**,* denote significance at 1%, 5%, and 10% respectively.

Table 5 Kao cointegration test.

Test statistic	Value
Emerging economies	
Modified Dickey-Fuller *t*	−1.82**
Dickey-Fuller *t*	−3.91***
Augmented Dickey-Fuller *t*	−2.81***
Unadjusted modified Dickey-Fuller *t*	−2.54***
Unadjusted Dickey-Fuller *t*	−4.18***
Developed economies	
Modified Dickey-Fuller *t*	1.48*
Dickey-Fuller *t*	1.22*
Augmented Dickey-Fuller *t*	2.42***
Unadjusted modified Dickey-Fuller *t*	−0.34
Unadjusted Dickey-Fuller *t*	−0.63
All economies	
Modified Dickey-Fuller *t*	0.37
Dickey-Fuller *t*	−0.95*
Augmented Dickey-Fuller *t*	0.96*
Unadjusted modified Dickey-Fuller *t*	−0.68
Unadjusted Dickey-Fuller *t*	−1.70**

***,**,* denote significance at 1%, 5%, and 10% respectively.

Table 6 FMOLS and DOLS estimation.

Categories	FMOLS	DOLS
Emerging economies		
NRR	0.003***	0.001
FI	−0.018	−0.024**
FDI	0.016	0.010
VA	0.208***	0.217***
PS	−0.075	−0.095***
GE	−0.151	−0.111**
RQ	0.239	0.202***
RL	−0.129*	−0.129*
CC	−0.016	−0.001
Developed economies		
NRR	0.035***	0.025**
FI	−0.007	−0.007
FDI	0.001	0.001
VA	0.206***	0.219**
PS	0.036	0.034
GE	0.033	0.078
RQ	0.020	0.004
RL	0.129*	0.084
CC	−0.009	0.018
All economies		
NRR	0.015***	0.012***
FI	−0.007	−0.011*
FDI	0.006*	0.003
VA	0.210***	0.230***
PS	−0.026	−0.048**
GE	−0.044	−0.057
RQ	0.069*	0.077*
RL	0.005	−0.015
CC	−0.012	0.001

***,**,* denote significance at 1%, 5%, and 10% respectively.

middle-income nations. These studies stated that increased access to financial services resulted in heightened economic activity, which in turn elevated energy consumption and carbon emissions. Moreover, restricted access to sustainable finance options may lead to dependence on fossil fuels, thereby increasing carbon emissions. The variation in results highlights the intricate nature of the relationship between financial inclusion and carbon

Table 7 MMQR estimation.

Categories	Location	Scale	Quantiles		
			0.25	0.50	0.75
Emerging economies					
NRR	0.018***	0.005	0.013*	0.017***	0.023**
FI	−0.049***	−0.007	−0.042**	−0.048**	−0.056**
FDI	0.020	−0.001	0.021	0.020	0.019
VA	−0.162***	0.008	−0.169***	−0.163***	−0.154***
PS	0.011	−0.053	0.038	−0.004	−0.062
GE	0.057	0.001	0.056	0.057	0.059
RQ	−0.029	−0.048	0.015	−0.023	−0.076
RL	0.194*	−0.044	0.234*	0.200*	0.152
CC	−0.087	0.057	−0.139*	−0.094	−0.031
Developed economies					
NRR	0.054***	0.013	0.043***	0.051***	0.067***
FI	−0.007	−0.005	−0.002	−0.006	−0.012
FDI	−0.003	−0.005	0.001	−0.002	−0.008
VA	0.157	−0.040	−0.022	−0.047	−0.098
PS	0.074**	−0.036	0.106***	0.084***	0.038
GE	0.157**	0.021	0.139***	0.152***	0.178**
RQ	0.084*	0.034	0.054	0.075**	0.119*
RL	−0.052	−0.045	−0.012	−0.040	−0.097
CC	−0.098**	0.018	−0.115***	−0.103**	−0.080
All economies					
NRR	0.02***	0.01	0.013***	0.02***	0.028***
FI	−0.030**	−0.01	−0.02**	−0.03**	−0.042*
FDI	0.00	−0.01	0.01*	0.00	−0.005
VA	−0.15***	−0.01	−0.14***	−0.15***	−0.153**
PS	0.03	−0.02	0.05***	0.04	0.014
GE	0.03	−0.02	0.05	0.03	0.018
RQ	0.00	−0.01	0.01	0.00	−0.007
RL	0.16*	0.03	0.13***	0.16*	0.190
CC	−0.07	0.02	−0.10***	−0.08	−0.052

***,**,* denote significance at 1%, 5%, and 10% respectively.

emissions and illustrates the necessity for specific policy strategies that account for regional and economic variations to optimize the sustainability benefits of financial inclusion.

With respect to FDI inflows, a positive impact was depicted on carbon emissions both with respect to emerging and developed economies but it lacked statistical significance. But with respect to all the economies taken together, there was a positive and significant impact on carbon emissions. Past studies have highlighted this positive impact of FDI on carbon emissions (Shahbaz et al. 2019; Xiaowei et al. 2021; Khan et al. 2023; Wang et al. 2023). In developing nations, this positive impact can be attributed to FDI stimulating economic activity which depletes natural resources and deteriorates the quality of the environment (Antweiler et al. 2001). While few studies (Liu et al. 2017; Nasir et al. 2019) state that because of liberal environmental policies in the developing nations there is a transfer of enterprises which are highly polluting to these nations through FDI which ultimately increases carbon emissions. He et al. (2022) in their study stated that nations with advanced economic development and superior regulatory quality are more capable of reducing these emissions while Wang and Huang (2022) found that in the context of East Asian nations, during 2011–2020, in the short run, an increase in FDI was associated with elevated carbon emissions but in the long run, the effect of FDI on emissions was insignificant.

With respect to institutional quality, it was observed that in emerging economies most of the institutional variables depicted a significant impact on carbon emissions. Political stability, government effectiveness, and rule of law depicted a negative impact on carbon emissions while voice, accountability, and regulatory quality depicted a positive impact. Lower carbon emissions are associated with stronger law and order, stronger anti-corruption measures, and better political stability. Tighter environmental regulations are linked to lower levels of corruption. In addition, regulations and standards in place guard against the improper use of substances causing pollution. Furthermore, environmental goals are more likely to be achieved when there is better political stability and clearer environmental plans (Hakimi and Hamdi 2019; Wawrzyniak and Doryn 2020; Boussaidi and Hakimi 2024). In the case of developed nations, only voice and accountability and rule of law depicted a positive impact and for all the economies voice and accountability and regulatory quality showed a positive impact while the rest of the institutional factors did not play any significant role. Here, the varied impact of institutional factors on carbon emissions can be attributed to the specific characteristics of the country such as its level of development, the existing environmental laws as well as the effectiveness of its enforcement of regulations. Based on the findings of E7 and G7 countries, the policymakers can frame policies specific to the challenges and opportunities faced by these particular groups of countries, and with respect to the combined panel data findings, the policymakers can formulate integrated strategies and policies suitable for global implementation.

After applying FMOLS and DOLS estimation, MMQR was also applied for checking the robustness of the results. Table 7 shows the estimation results. It can be seen that with respect to NRR, financial inclusion, and FDI the findings are similar as in FMOLS and DOLS. However, voice and accountability depicted a negative impact in contrast to the findings of the previous estimation. Political stability, government effectiveness, and regulatory quality also showed a positive and significant impact on carbon

emissions in the case of developed economies but in the previous estimation, these positive coefficients had lacked statistical significance. Rule of law also depicted a positive impact in emerging economies unlike in the previous estimation. Control of corruption also depicted a negative and significant impact unlike in previous estimations where the negative coefficients had lacked statistical significance. These variations in the findings using MMQR, as opposed to FMOLS and DOLS, can be explained by their respective methodological differences. MMQR may indicate that particular institutional variables significantly influence carbon emissions at specific quantiles. Therefore, utilizing these insights from MMQR findings can enable the policymakers to formulate more effective, targeted, and equitable interventions aimed at reducing carbon emissions.

Conclusion and policy implications

The study here examined the relationship between NRR, financial inclusion, and carbon emissions in emerging (E7) as well as developed (G7) economies during 2004–2021. Results indicated that both NRR and financial inclusion had a significant impact on carbon emissions. However, the impact of these variables differed across both the emerging and developed economies. With respect to natural resource rent, it was observed that it depicted a positive impact on carbon emissions in both emerging and developed economies as well as with respect to all the economies taken together. The overuse of natural resources in the form of increased fossil fuel consumption is one of the possible explanations for the positive relationship between NRR and carbon emissions in both developed and emerging economies. Financial inclusion showed a negative impact on carbon emissions in emerging economies as well as with respect to all the economies taken together but lacked statistical significance with respect to developed economies. Financial inclusion facilitates access to cost-effective financial instruments, enabling green technology investments and enabling firms to adopt energy-efficient technologies with lower carbon emissions.

The control variables also depicted a significant effect on carbon emissions but their effect also differed with respect to the emerging and developed economies.FDI inflows depicted a positive impact on carbon emissions both with respect to emerging and developed economies but it lacked statistical significance. But with respect to all the economies taken together, there was a positive and significant impact on carbon emissions. With respect to institutional quality, there was a varied impact of institutional factors on carbon emissions with respect to both emerging and developing economies and this varied effect can be attributed to the specific characteristics of the country such as its level of development, the existing environmental laws as well as the effectiveness of its enforcement of regulations.

The findings of the study offer some significant policy recommendations: firstly, in both emerging and developed economies, it is essential to establish limits on natural resource extraction to safeguard the environment. Reducing reliance on non-renewable resources can help policymakers allocate funds toward renewable energy development. Advocating for the adoption of environmentally sustainable practices like biofuels and similar other fuels will not only help in contributing toward resource conservation but also reduce carbon emissions. Secondly, in emerging economies, policymakers should prioritize the establishment of regulatory frameworks that promote the delivery of sustainable financial services which may involve providing incentives for banks to invest in environmentally sustainable projects. Furthermore, sustainability ideas can be included in financial literacy programs. People can be informed about the advantages that their financial decisions such as purchasing green bonds or endorsing eco-friendly companies can have on the environment. Thirdly, given the positive impact of FDI inflows on carbon emissions, developed countries must ensure that FDI inflows to developing nations adhere to environmental standards and do not involve the transfer of production technologies and industrial practices that fail to meet the environmental regulations established in developed nations. Fourthly, developing and strengthening institutions that promote political stability and effective governance should be prioritized in both emerging and developed economies. Lower carbon emissions are always found to be associated with stronger law and order, stronger anti-corruption measures and better political stability. Collaboration among financial institutions, government agencies, and environmental organizations can play a pivotal role in facilitating the design and implementation of initiatives aimed at lowering carbon emissions.

However, the study has a few limitations that could be addressed in future research. Firstly, future studies could focus on individual countries which would help the policymakers to take into consideration a particular country's characteristics while framing the policies. Secondly, the data related to financial inclusion was not available before 2004 so we had to take the time period starting from 2004 to 2021. Future research may broaden the time frame and also use the updated data of the variables to examine the long-term effects of natural resource rent and financial inclusion on carbon emissions. Thirdly, to quantify financial inclusion, we constructed an index. Nonetheless, disaggregating this index into separate dimensions which include penetration of financial services, access to financial services and usage of financial services may help in identifying which aspect of financial inclusion is more effective in lowering carbon emissions.

Data availability

Data for the study are available from the International Monetary Fund (IMF) and World Bank databases. Data for constructing the financial inclusion index were taken from the International Monetary Fund (IMF) Financial Access Survey database. It is freely accessible at https://data.imf.org/?sk=e5dcab7e-a5ca-4892-a6ea-598b5463a34c. The dataset can be downloaded in both Excel and Stata format. Data for the independent variables were taken from the World Bank database. The data is freely accessible at https://data.worldbank.org/. Data for institutional variables were taken from the Worldwide Governance Indicators database provided by the World Bank. The data is freely accessible at https://www.worldbank.org/en/publication/worldwide-governance-indicators. It can be downloaded in both Excel and Stata format.

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Author contributions

Shnehal Soni and RL Manogna have contributed to the conception and design of the study. Shnehal Soni has contributed toward the literature review, data collection, data analysis, and writing of the initial draft. RL Manogna has reviewed and edited the final draft of the manuscript.

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Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

Informed consent was not required as this study did not involve human participants.

Additional information

Correspondence and requests for materials should be addressed to R. L. Manogna.