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RESEARCH ARTICLE

Technological innovation, financialization, and ecological footprint: evidence from BEM economies

Mehmet Akif Destek[1] · Muge Manga[2]

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Abstract
Despite the growing interest in researches on the impact of technological development on carbon emissions, the effect of technological innovation on the other indicators of environmental degradation is of little interest. In order to close this gap, the aim of this study is to determine the effects of technological innovation on both carbon emission and ecological footprint for big emerging markets (BEM) countries. In doing so, the environmental impacts of the financialization process are also explored, in line with the fact that these countries face constraints in financing technological developments. In this context, the effects of technological development, financialization, renewable energy consumption, and non-renewable energy consumption on environmental degradation are examined through the second-generation panel data methods for the period 1995–2016. The findings indicate that technological innovation is effective in reducing carbon emissions, but does not have a significant impact on the ecological footprint, namely a 1% increase in technological innovations reduces carbon emission by 0.082–0.088%. Moreover, it is found that financialization harms environmental quality for both indicators of the environment because a 1% increase in financialization increases carbon emissions by 0.203–0.222% and increases ecological footprint by 0.069–0.071%.

Keywords Technological innovation · Financialization · Environmental degradation · Carbon emission · Ecological footprint · Panel data

Introduction

In recent years, due to the serious effects of the economic policies on the environment, there are intensive discussions on the concepts pointing to environmental destruction such as global warming and climate change. Accordingly, the environmental Kuznets curve (hereafter, EKC) hypothesis that deals with the effects of economic growth on environmental destruction has become a popular research subject. The hypothesis is basically derived from the inverted U-shaped relationship between economic growth and income inequality expressed in the study of Kuznets (1955), but Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992) pioneered the adaptation of this hypothesis to environmental destruction. EKC hypothesis briefly states that in the first phase of economic growth, environmental degradation increases due to the increase in income level, and environmental destruction decreases after exceeding a certain threshold in income level (Dinda 2004). According to Grossman and Krueger (1991), it is possible to divide the impact of the economic activities on environmental destruction into three groups as scale effect, composition effect, and technology effect. The scale effect is an effect explaining the increase in the environmental degradation caused by the economic activities carried out by using fossil fuels depending on the increase in commercial activities in the period when the national economies started to grow. However, in the later stages, environmental destruction decreases due to the changes in the commercial policies of the countries in which the economic growth process continues, especially due to the specialization in certain areas where the level of pollution is less (composition effect) and due to the improvement in technology and increasing competitive advantage (technological effect).

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✉ Mehmet Akif Destek
adestek@gantep.edu.tr

Muge Manga
mboga@erzincan.edu.tr

[1] Department of Economics, Gaziantep University, Gaziantep, Turkey

[2] Department of Economics, Erzincan Binali Yıldırım University, Erzincan, Turkey

Despite the only cause of environmental destruction or environmental quality has been hypothesized as economic growth, it has been determined by country experiences that just economic enrichment is not enough to reach the final stage of the hypothesis. Therefore, the researchers strived to explain the difference in the effects of enrichment on the environment by focusing on the indicators triggered by economic growth and the indicators triggering economic growth. In this context, some recent studies explained mentioned differences by financialization (Shahbaz et al. 2018a, 2020; Ahmad et al. 2018; Khan et al. 2019; Destek and Sarkodie 2019; Nasir et al. 2019; Zafar et al. 2019; Destek 2019a; Liu and Song 2020), globalization (Rafindadi and Usman 2019; Ahmed et al. 2019; Destek 2019b; Balsalobre-Lorente et al. 2020; Bilgili et al. 2020; Destek and Sinha 2020), urbanization (Salahuddin et al. 2019; Wang and Su 2019; Ulucak and Khan 2020), industrialization (Asumadu-Sarkodie and Owusu 2017; Liu and Bae 2018; Dong et al. 2019; Wang et al. 2020), energy portfolio (Destek et al. 2018; Bekun et al. 2019; Alola et al. 2019; Sharif et al. 2020; Destek and Aslan 2020; Erdogan et al. 2020), human capital (Ahmed and Wang 2019; Chen et al. 2019; Sarkodie et al. 2020; Zafar et al. 2020), and technological innovation (Yu and Du 2019; Hashmi and Alam 2019; Sinha et al. 2020; Khan and Ulucak 2020) levels of the countries.

In spite of the fact that all the mentioned factors have direct or indirect effects on the environment, environmental regulations and technological progress are accepted as the most important prerequisite for reaching the final stage of the EKC hypothesis (Yin et al. 2015). In addition to its direct effects, it is stated that technological innovation manages the relations among the determinants of environmental quality and also that innovation-supported commercial activities also serve environmental quality (Torras and Boyce 1998). In particular, the effective support of innovative activities specific to the energy sector decreases environmental damage by increasing renewable energy use and energy efficiency (Vukina et al. 1999). However, access to high-cost environmental technologies is not possible especially in developing countries due to the fund constraint. In this context, low-income developing countries are still obliged to have a production structure based on fossil energy sources, while high-income developing countries (emerging economies) can obtain the necessary funds for environmental technologies through the financial system. Therefore, although the financialization process appears to indirectly contribute to environmental quality, there are also debates that it increases environmental degradation.

Many scenarios with opposite views regarding the environmental effects of the financialization process come to the fore. In the optimistic scenario, it is stated that the technologies that provide savings in energy use and help reduce environmental pollution will be easier and lower cost. In addition, according to this view, the environmental dominance of firms, which are managed with a more effective financial system, leads to a reduction in the environmental destruction of these firms (Claessens and Feijen 2007; Tamazian et al. 2009). According to the opposite view, the impact of financial development on environmental destruction arises for various reasons. The first of these is to attract foreign direct investments to the country at the expense of environmental destruction to support financial development and economic growth. Secondly, the widespread use of financial instruments increases the power of consumers to purchase products such as automobiles, refrigerators, and air conditioners. It causes more environmental degradation by purchasing such products. Finally, it is an increase in energy consumption and therefore environmental damage due to frequent use of new projects and new investment channels in order to reduce financing costs, diversify financing channels, and distribute business risk (Zhang 2011). Apart from all these arguments, some empirical studies suggest that there is no relationship between financial development and carbon emissions (Shahbaz et al. 2018b). Therefore, the following research questions need to be answered: (i) Is technological progress an environmental blessing or a curse? (ii) Does the expansion and deepening of the financial system fund long-term profitable environmental projects or pursue short-term profit?

Based on the above debates, this study aims to examine the impact of technological innovation and financialization on environmental degradation in big emerging markets (BEM) countries: Argentina, Brazil, China, India, Indonesia, Mexico, Poland, S. Africa, S. Korea, and Turkey. For this purpose, the impact of technological development, financial development, renewable energy consumption, and nonrenewable energy consumption on environmental degradation is analyzed with second-generation panel data methodologies for the period from 1995 to 2016. In doing so, to compare the atmospheric and total environmental effect of explanatory variables, both carbon emissions and ecological footprint are used as environmental degradation indicators. The reason for using the ecological footprint of Wackernagel and Rees (1996) is that the ecological footprint is seen as a more appropriate measure representing environmental degradation than other environmental indicators (Wackernagel and Rees 1996) because it simultaneously measures grazing land, fishing grounds, forest land, settled land, and carbon footprint (Lin et al. 2016). Moreover, the reason why this country group is preferred in the study is that BEM countries have a more developed financial system and higher technology investments than other developing countries. In addition, according to the recent report of Muntean et al. (2018), BEM 10 countries are responsible for 45.71% of global carbon emissions in 2017. Therefore, identifying the triggers of the carbon emissions of these countries and finding solutions to this will also play an important role in reducing global carbon emissions.

The contributions of the study to existing literature are fourfold: (i) this is the first study to examine the determinants of environmental degradation in BEM countries. (ii) The study uses environment-related technologies as an indicator of technological innovation to clearly observe the environmental efficiency of technological development. (iii) The study also uses the Financial Development Index as an indicator of financial development instead of private credits that are widely used in the literature because the Financial Development Index includes many sub-indices about the financial system. (iv) The study compares the effects of explanatory variables on carbon emissions and ecological footprint instead of focusing only on atmospheric pollution. (v) Unlike previous studies, the study uses second-generation panel data methodologies to take into account the possible cross-sectional dependence among observed countries.

The paper is organized as follows: the "Literature review" section reviews and summarizes the previous studies. The "Data and methodology" section describes the empirical models, data, and methodology. The "Empirical results" section presents and discusses the empirical results. Finally, the "Conclusions and policy implications" section concludes the study with policy implications.

Literature review

Since the main purpose of this study is to observe the impact of technological innovation and financialization on environmental degradation, we categorize the section into two parts as financialization and environment nexus and technological innovation and environment nexus. In the first part, we focus on the environmental impact of financialization and the second part includes the previous studies on the environmental impact of technological innovation.

Financialization and environment

It is seen that studies investigating the effect of financialization on environmental quality have obtained different findings. In general, the main view that financialization increases environmental quality is stated that in parallel with the improvement in economic growth with financialization, energy will be used efficiently and the possibility of accessing new technologies that increase environmental quality will increase; thus, environmental pollution will decrease (Islam et al. 2013). On the other hand, the opposite view argues that the economic growth provided by the increase in financialization may cause more industrial pollution and environmental degradation (Jensen 1996). As one of the pioneering studies on financialization and environmental degradation nexus, Tamazian et al. (2009) analyzed the relationship between financial development, economic growth, and carbon emissions in BRIC countries between 1992 and 2004 with the standard reduced-form modeling approach. In the study, the ratio of deposit money bank assets to GDP, the capital account convertibility, and financial liberalization are used as indicators of financial development. In conclusion, it is stated that especially the developments in the capital market and the banking sector and the FDI inflows in these sectors are effective in reducing environmental degradation. Similar to the findings of this study, Jalil and Feridun (2011) also found that financial development reduces carbon emissions and stated that the reduction of carbon emissions in China is the possible result of the establishment of new environmental facilities that are realized with the capital accumulation provided by financial development and provide waste disposal. In addition, the study also argued that the financialization process required for reducing environmental pollution should be continued by supporting the problematic loans with various privatization reforms. Shahbaz et al. (2013a) reach a similar result for Malaysia and attributed this finding to that financial development in Malaysia providing the financing required for environmental development projects at a lower cost and the environmental projects carried out with financial development to achieve significant efficiency in fossil fuel consumption throughout the country. Shahbaz et al. (2013b) also validated the environmental pollution reducing effect of financial development in South Africa.

Opposite to the above studies, some studies found the environmental degradation increasing effect of financial development. For instance, Zhang (2011) analyzed the impact of financial development on carbon emission for China between 1980 and 2009 by using the variance decomposition method and reached the finding that financial development, especially the effect of financial intermediation transactions, increases carbon emissions. This is mainly attributed to the deficiencies in adapting the direction of the use of FDI movements entering China to encourage low-carbon development and the development of financial intermediation activities in China, which lead to a significant increase in carbon emissions. Shahbaz et al. (2015) also concluded that financial development increases environmental destruction and explained the reason of this finding that the lack of obstacles and sanctions in promoting and increasing energy use to ensure unsustainable high economic growth, as in many developing countries such as India. Similarly, Shahbaz et al. (2016) for Pakistan and Baloch et al. (2019) obtained for 59 Belt and Road countries. The findings obtained in these studies are attributed to the financial developments in the banking sector; the fact that the financial resource distribution mechanism of the banking sector in selected countries is not monitored after the resource allocation, the companies that use their funds in practices lacking environmental control are punished by various methods such as interest rate increases or tax increases.

There are also some studies that found an indirect effect of financialization instead of the direct effect such as Al-Mulali and Sab (2012) observed the relationship between financial development, energy consumption, carbon emission, and economic growth in Sub-Saharan African countries for the period of 1980–2008, and concluded that increased energy use due to economic growth and financial development significantly increases carbon emissions. Boutabba (2014) discussed the relationship between carbon emissions, financial development, economic growth, energy consumption, and openness in India between 1971 and 2008 using with ARDL bound test. According to the findings, the increase in financial development increases the environmental degradation by increasing the energy use.

Based on the parabolic function of the EKC hypothesis, Moghadam and Lotfalipour (2014) examined the possible parabolic impact of financial development on environmental pollution between 1970 and 2011 using the ARDL method and found that there is a positive relationship between financial development and carbon emissions, but this relationship evolved negatively after achieving a certain level of financial development; therefore, the study argued that there is an inverted U-shaped relationship between these twin variables. According to the study, this situation is a result of the investments supported by financial development that only focus on the size of industrial activities in Iran and the developments that will increase environmental protection in the sector are ignored. Furthermore, some studies argue that there is no statistical relationship between financialization and environmental degradation. Ozturk and Acaravci (2013) examined the nexus between financial development, trade openness, energy consumption, and carbon emissions in Turkey for the years of 1960–2007 and the findings show that financial development has no effect on carbon emissions.

Similar to our study, there are also some studies that employ the second-generation panel data methodologies to check the financialization-environment nexus. For instance, Wang et al. (2019) utilized methods that allow cross-section dependency while examining the relationship between financialization and environment for OECD countries. According to this study, financial development plays an important role in reducing CO2 emissions by funding companies to acquire environmentally friendly technologies in the production process. Similar findings were obtained from the studies of Dogan and Seker (2016) for the top renewable energy generator countries and Awan et al. (2020) for the Middle East and North African countries. On the contrary, Bayar and Maxim (2020) predicted that for post-transition European economies, funds other than energy-saving technological developments or financial developments that are directed towards production channels only increase environmental degradation.

Technological innovation and environment

Similar to the studies on the relationship between financialization and environment, it is seen that mixed results are obtained from the studies examining the effects of technological innovation on the environment, depending on the used methodology, observed country/country group, or considered period. But still, as hypothesized, empirical findings often appear to be that technological innovation contributes to environmental quality. For instance, Ali et al. (2016) examined the relationship between technological innovation and carbon emission in Malaysia and the finding about pollution reducing effect of technology was attributed to the fact that technological developments in Malaysia were based on green and environmentally friendly technology. Ibrahiem (2020) investigated the nexus for the Egyptian economy which emphasized that low- and zero-carbon energy supply is important in the application of technologies, especially in energy-intensive sectors such as the cement sector. Ahmed et al. (2016) also found the evidence that technological progress reduces carbon emission. Moreover, Hang and Yuan-Sheng (2011) considered the possible parabolic relationship between the mentioned variables and found that the effect of technological development on carbon emission is positive in the first stage and negative in the later stages in China. In other words, it is found that there is an inverted U-shaped relationship between both variables. This situation is attributed to the increase in investment and higher emissions due to the emergence of more technological innovations in the first phase of industrialization in the country's economy. In the later stages of industrialization, the positive impact of technology has been explained by the change in consumption patterns from the energy-intensive manufacturing sector to the more environmentally friendly service sector and the emergence of alternative energy sources.

It is surprisingly seen that most of the studies focusing on only the causal nexus between technological innovation and the environment found that there is no significant relationship between the variables. For instance, Fei et al. (2014) examined the relationship between renewable energy, economic growth, carbon emissions, and technological innovation in Norway and New Zealand for the period 1971–2010 with the Granger causality test. According to the results, while it is concluded that there is a bidirectional causality between carbon emission and technological innovation for Norway, it is estimated that there is no causal relationship between these variables in New Zealand. Irandoust (2016) searched the relationship between technological innovation, renewable energy, and carbon emissions in Denmark, Finland, Norway, and Sweden for the period from 1975 to 2012. The study used the R&D expenditures in the energy sector as an indicator of technological innovation with employing the causality test of Toda and Yamamoto (1995) and concluded that there is a unidirectional causality from technological innovation to renewable energy, but there is no significant causal relationship between carbon emission and technological innovation. Fan and Hossain (2018) analyzed the relationship between trade openness, technological innovation, and carbon emissions for the period of 1974–2016 in China and India with the Toda-Yamamoto causality test. According to the findings, while there is a bidirectional causal relationship between twin variables in China, there is a unidirectional causality from technological development to carbon emission in India. The difference of the findings between China and India is attributed to India's being far behind the world standards in terms of preparation for technological development. Yii and Geetha (2017) investigated the relationship between technological innovation and carbon emissions in Malaysia for the period of 1971–2013 with the VECM Granger causality test. The findings have revealed that there is no relationship between technological innovation and carbon emissions. Samargandi (2017) tested the relationship between sectoral value added, technological development, and carbon emissions between 1970 and 2014 in Saudi Arabia with the ARDL bound test and concluded that technological development does not have a significant effect on carbon emissions. This situation is attributed to the fact that 100% fossil fuel is still used as the primary energy source in the country; the petroleum supply with low prices is abundant and therefore innovative activities that enable the use of clean energy resources are ignored.

Moreover, there are also studies analyzing the relationship between technological development and the environment by considering cross-sectional dependency. For some recent studies, Khattak et al. (2020) analyzed the impact of technological innovation, economic growth, and renewable energy use on carbon emissions in the BRICS countries for the period of 1980–2016. Findings have shown that innovation activities have failed to reduce carbon emission for BRICS countries except Brazil. Similarly, Ali et al. (2020) concluded that innovation activities in 33 selected European Union countries reduced carbon emissions. This finding is attributed to the diffusion of technological developments that provide energy efficiency.

Data and methodology

Data

Following the above debate, the annual data from 1995 to 2016 is observed to examine the impact of technological innovation and financialization on environmental degradation based on the IPAT environmental model of Ehrlich and Holdren (1971) which is a widely used theoretical model by environmental economists. The IPAT environmental model can be summarized as follows:

$$I = P \times A \times T \tag{1}$$

where I shows the environmental impact, P means population, A indicates economic activities, and T implies technological level. In the following years, Dietz and Rosa (1994, 1997) transformed this basic model into a stochastic model and obtained the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model. While creating the empirical model, we follow the STIRPAT model, but we excluded the population variable from the model by using countable variables in the per capita form. In this direction, our empirical model is as follows;

$$\begin{aligned} \text{lnED}_{it} = a_0 + a_1\text{lnR}_{it} + a_2\text{lnNR}_{it} + a_3\text{lnTEC}_{it} \\ + a_4\text{lnFIN}_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

where ED is environmental degradation and proxied by two different indicators such as carbon dioxide emission (CO) and ecological footprint (EF), R is renewable energy consumption, NR is non-renewable energy consumption, TEC is technological innovation, and FIN indicates financialization. In the empirical procedure, CO is measured in per capita carbon emissions in metric tons, EF is used as per capita ecological footprint in gha, R (NR) is used as per capita renewable (non-renewable) energy consumption in kwh, TEC is measured as a patent number in environmental-related technologies, and FIN is used as the Financial Development Index.

In regard to the source of the dataset, CO data is obtained from Gilfillan et al. (2019), UNFCCC (2019), and BP (2019), and EF data is obtained from Global Footprint Network. R and NR data are obtained from Energy Information Administration, TEC data is retrieved from OECD statistics, and FIN data is obtained from the Financial Development Index of the International Monetary Fund. In empirical analysis, to avoid scaling differences and to normalize the series, all variables are used in natural logarithmic form.

Methodology

Preliminary tests

In the panel data procedure, it is necessary to choose the right estimator to obtain consistent and reliable results for policy recommendations. Based on the fact that the effects of the 2008 global financial crisis spread across almost all countries, it is anticipated that estimators (called as first-generation estimators), which do not take into account inter-country dependency, are not expected to yield reliable results. Accordingly, when using panel data techniques, it is most likely necessary to test the interdependence between countries, in other words, the cross-sectional dependence (hereafter, CSD). In this study, the CSD issue is investigated by the CD test developed by Pesaran (2004). Then, it is also necessary to observe the stationarity process, which is important in all econometric predictions. Therefore, the CIPS unit root test developed by Pesaran (2007) is used in the study since the unit root test to be used should be a test that also allows CSD. At the end of the preliminary tests, the test of whether the long-term relationship between the variables is valid affects the choice of the estimator to be used. Accordingly, the validity of the mentioned relationship is investigated through the ECM-based cointegration test developed by Westerlund (2007).

Panel long-run estimators

After validating the cross-sectional dependent cointegration among variables, the coefficient of cointegrated regressor should be searched with an estimation technique that allows cross-sectional dependence. Thus, we conduct CUP-FM (continuously updated and fully modified) and CUP-BC (continuously updated and bias-corrected) estimators developed by Bai et al. (2009). These estimators augment the basic panel regression model and assume cross-sectional dependence and error term (ε_{it}) (e.g., Bai and Kao 2006) as follows:

$$y_{it} = a_i + \beta x_{it} + \varepsilon_{it} \tag{3}$$

$$\varepsilon_{it} = \lambda_i^{'} F_t + \mu_{it} \tag{4}$$

where F_t, $\lambda_i^{'}$ and μ_{it} indicate the vector of common factors, corresponding factor loadings, and the idiosyncratic component of the error term, respectively. The computation process of CUP-FM is based on repeatedly estimating coefficients and long-run co-variance matrix until reaching the convergence as follows:

$$\widehat{\beta}_{Cup} = \left[\sum_{i=1}^{n}\left(\sum_{t=1}^{T}\widehat{y}_{it}^{+}\left(\widehat{\beta}_{Cup}\right)\left(x_{it}-\overline{x}_i\right)^{'}-T\left(\left(\lambda_i^{'}\left(\widehat{\beta}_{Cup}\right)\widehat{\Delta}_{F\varepsilon i}^{+}\left(\widehat{\beta}_{Cup}\right)+\widehat{\Delta}_{\mu\varepsilon i}^{+}\left(\widehat{\beta}_{Cup}\right)\right)\right)\right] \times \left[\sum_{i=1}^{n}\sum_{t=1}^{T}\left(x_{i,t}-\overline{x}_i\right)\left(x_{i,t}-\overline{x}_i\right)^{'}\right]^{-1} \tag{5}$$

where $\widehat{y}_{it}^{+} = y_{it}-\left(\widehat{\lambda}_i^{'}\widehat{\Omega}_{F\varepsilon i}+\widehat{\Omega}_{\mu\varepsilon i}\right)\widehat{\Omega}_{\varepsilon i}^{-1}\Delta x_{it}$, $\widehat{\Omega}_{F\varepsilon i}$, and $\widehat{\Omega}_{\mu\varepsilon i}$ are estimated long-run co-variance matrices and $\widehat{\Delta}_{F\varepsilon i}^{+}$ and $\widehat{\Omega}_{\mu\varepsilon i}$ are estimated one-sided long-run co-variance.

There are also some reasons for using the CUP-FM and CUP-BC estimators in this study. First, similar to our preferred cointegration test, these estimators are also consistent tests in the case of exogenous explanatory variables. In addition, these estimators can be used for the variables that are integrated from different orders. Moreover, since the CUP-FM estimator is a test developed based on the fully modified OLS estimator which uses the Bartlett-Kernel procedure, it can also be used especially in possible autocorrelation and heteroskedasticity situations (Kiefer and Vogelsang 2002). Finally, both estimators are robust in case of endogeneity (Bai et al. 2009).

Empirical results

The results of preliminary tests

In the first step of empirical analysis, we employ some preliminary tests (i.e., CSD, unit root, and cointegration) to prefer the most suitable estimator for our empirical models. In doing so, first, the possible CSD among BEM countries are examined with CD test and the findings are presented in Table 1. Based on the results, the null hypothesis if there is no CSD is clearly rejected; therefore, the importance of considering the impact of globalization on our indicators is validated.

Based on the confirmation of CSD, since the stationarity process of variables should be searched with a unit root test that allows CSD, we employ the CIPS unit root test of Pesaran (2007). The results from Table 1 show that the unit root process can not be rejected in the level form of variables. However, all variables have become stationary in the first differenced form thence the evidence that all variables are integrated of order one is confirmed.

In the final step of preliminary analysis, the existence of a long-run relationship between variables for both models is investigated with the ECM-based panel cointegration test of Westerlund (2007) and the findings are shown in Table 2. In the first model, the null of no cointegration is rejected by $G\tau$, $P\tau$, and $P\alpha$ statistics. In case of the second model, the null is also rejected by $G\tau$ and $P\tau$ statistics. Therefore, we confirm the validity of the cointegration relationship between variables for both models and this result allows us to search the cointegrating coefficients of explanatory variables on environmental degradation.

Determinants of environmental degradation

As financialization, technological innovation, renewable energy consumption, and non-renewable energy consumption are cointegrated with the environmental degradation indicators, the long-run impact of these variables on different degradation proxies is observed with CUP-FM and CUP-BC estimation techniques that allow CSD. First, we examine the determinants of carbon emissions (CO) and present the findings in Table 3. At a first glance, both estimation results show that increasing renewable energy consumption reduces carbon emissions while non-renewable energy consumption increases it. In addition, the hypothesis that technological development is efficient on carbon mitigation is confirmed. However, it is surprisingly found that financialization harms the atmospheric quality in BEM countries.

In the case of ecological footprint, the findings from Table 4 reveal that renewable energy consumption also reduces the ecological footprint as it reduces the carbon emissions. However, unlike carbon emission function, the ecological footprint increasing role of non-renewable energy use is

Table 1 The results of CSD and unit root tests

	CO	EF	R	NR	TEC	FIN
CD test	− 3.016 (0.001)	− 1.530 (0.063)	− 2.710 (0.003)	− 2.192 (0.014)	− 2.389 (0.008)	− 3.074 (0.001)
Unit root						
CIPS (level)	− 2.227	− 1.383	− 1.429	− 1.581	− 2.290	− 2.274
CIPS (first differences)	− 2.679**	− 2.616**	− 3.468***	− 2.810**	− 2.895**	− 3.268***

*, **, and *** indicate statistical significance at 10, 5, and 1% level, respectively

not observed. Similarly, it is also found that technological innovation does not significantly affect ecological footprint. However, the hypothesis that financialization harms environmental quality is also supported because financial development increases ecological footprint.

Overall, our findings reveal that renewable energy consumption reduces environmental degradation for both environmental indicators and the finding is consistent with the findings of Alola et al. (2019) and Sharif et al. (2020). The environmental degradation reducing the effect of renewable energy consumption means that the renewable energy consumption level of selected countries has reached to an adequate level to combat with environmental destruction. In addition, we found that non-renewable energy consumption increases carbon emissions but does not affect ecological footprint. The degradation increasing effect of non-renewable energy use is also validated by the studies of Bekun et al. (2019), Destek and Aslan (2020), and Erdogan et al. (2020). This finding is an expected situation because fossil energy sources are accepted as the most pollutant energy sources. When the environmental effects of technological innovation are evaluated in line with the main purpose of the study, it is seen that technological progress reduces carbon emission in line with the studies of Ahmed et al. (2016) and Ibrahiem (2020). However, it has been observed that technological progress does not have a significant impact on the ecological footprint. This indicates that technological research focuses only on targets that increase atmospheric quality in selected countries. Finally, it is found that financialization accelerates deterioration in all environmental indicators. The environmental degradation increasing effect of financial development is also confirmed by Ali et al. (2019). This finding emphasizes that the countries observed have failed in terms of regulation policies that will encourage the financial system to provide funding for environmentally friendly technologies.

We also use the two-way fixed-effect model for robustness check and present the findings in Table 5. As seen, the findings from the two-way fixed-effect model are consistent with the continuously updated estimators. Namely, the results validated the evidence that increasing renewable energy consumption and technological innovation reduces the carbon emissions while non-renewable energy consumption and financialization increase it. In addition, for the ecological footprint model, increasing renewable energy reduces ecological footprint while financialization increases the degradation level of countries. Similar to the findings from CUP estimators, these findings also confirmed that non-renewable energy use and technological innovation do not have any significant impact on ecological footprint.

Conclusions and policy implications

This study explores the impact of technological innovation on environmental degradation by controlling the financialization, renewable energy consumption, and non-renewable energy consumption in big emerging markets (BEM) countries. In addition, to compare how the atmospheric pollution and total

Table 2 The results of panel cointegration test

	Model I		Model II	
	Statistic	Boot *p* value	Statistic	Boot *p* value
G_τ	− 22.967**	0.041	− 28.263**	0.025
G_α	− 5.836	0.719	0.995	0.783
P_τ	− 22.318***	0.005	− 13.566*	0.052
P_α	− 9.822*	0.085	− 0.870	0.437

*, **, and *** indicate statistical significance at 10, 5, and 1% level, respectively

Table 3 The results of panel long-run estimations for model: CO

	CUP-FM Coefficient	*t*-statistics	CUP-BC Coefficient	*t*-statistics
lnR	− 0.161***	− 3.038	− 0.160***	− 3.072
lnNR	0.052*	1.664	0.052*	1.753
lnTEC	− 0.088**	− 2.201	− 0.082**	− 2.193
lnFIN	0.203***	4.661	0.222***	5.336

*, **, and *** indicate statistical significance at 10, 5, and 1% level, respectively

Table 4 The results of panel long-run estimations for model: EF

	CUP-FM Coefficient	*t*-statistics	CUP-BC Coefficient	*t*-statistics
lnR	− 0.241***	− 5.892	− 0.236***	− 6.085
lnNR	0.013	0.056	0.016	0.615
lnTEC	− 0.025	− 0.729	− 0.021	− 0.629
lnFIN	0.071*	1.875	0.069*	1.912

*, **, and *** indicate statistical significance at 10, 5, and 1% level, respectively

environmental degradation are affected by technological innovation, both carbon emissions and ecological footprint are used as an indicator of environment. In doing so, the period from 1995 to 2016 is analyzed with second-generation panel data methodologies. In detail, the stationary properties of variables are examined with CIPS unit root test, the existence of a long-run relationship between variables is searched with ECM-based panel cointegration test, and the long-run impacts of the regressors are probed with Cup-FM and Cup-BC estimation techniques.

The results of the empirical analysis can be summarized as follows: (i) increasing renewable energy consumption reduces both carbon emissions and ecological footprint. (ii) Increasing non-renewable energy consumption increases carbon emissions while it does not significantly affect the ecological footprint. (iii) Technological innovation reduces carbon emissions while it does not significantly affect ecological footprint. (iv) Financialization increases both carbon emissions and ecological footprint. Based on these findings, the first one indicates that renewable energy share in the total energy portfolio of these countries has reached the level that reduces environmental degradation. Therefore, it can be said that continuing green energy policies to increase the mentioned rate plays a key role in success for combating environmental destruction. In addition, the second finding implies that non-renewable energy consumption is a factor that mainly increases atmospheric pollution but has an almost insignificant effect on total environmental degradation. In this context, the conversion to renewable energy should be accelerated in order to reduce atmospheric pollution. Thirdly, it is surprisingly seen that technological innovations act mainly with the focus of reducing atmospheric pollution. On the other hand, it seems there is no technological progress to reduce damage on cropland, grazing land, fishing grounds, build-up lands, and forest land. Therefore, the innovative researches should also be directed to create improvements in ecological footprint indicators. The fourth and most negative picture clearly reveals the fact that the financial system accelerates environmental degradation. This is largely due to the fact that emerging economies are in need of funds provided by the financial system in their development strategies and that they are limited in terms of environmentally friendly regulation policies. However, it is observed that the development policy, which is pursued solely based on economic enrichment, is an important obstacle to reaching other sustainable development targets. Moreover, the problems that will arise as a result of environmental degradation eliminate the economic gains in the long term. Accordingly, it will be a more rational policy to regulate the financialization process to provide funding projects especially for environmentally friendly technological progress. When the findings are evaluated on financialization, technological innovation, and environmental transfer mechanism, it is concluded that technological innovation activities that reduce environmental pollution do not benefit the financial sector, contrary to expectations. That is to say, technological development in these countries reduces environmental degradation, but the financing opportunities provided by the financialization process to environmental technologies are insufficient. In fact, the financial sector provides more funds for areas that increase environmental pollution in big emerging economies.

Table 5 The results of two-way fixed effect model

	CO model		EF model	
	Coefficient	*t*-statistics	Coefficient	*t*-statistics
lnR	− 0.245***	− 8.742	− 0.168**	− 2.306
lnNR	0.335***	3.110	0.092	0.608
lnTEC	− 0.114***	− 5.417	− 0.030	− 0.340
lnFIN	0.122**	2.436	0.042**	2.368

*, **, and *** indicate statistical significance at 10, 5, and 1% level, respectively

Considering the rapidly increasing production levels and emissions of BEM countries, it is of great importance that developed countries with higher technology levels compared to BEM countries share environment-friendly technologies with BEM countries in terms of global emission reduction. In addition, considering the rapid industrialization and innovation processes, other countries should take measures to restrict the import of high-emission industrial products rather than low-cost goods imports in their trade with BEM countries.

Finally, we should note about the limitations of this study to create a roadmap for future studies. Although this study provides information about the effects of technological development and financialization on overall environmental degradation, identifying the impact on disaggregated environmental indicators will allow more detailed policy recommendations, namely, determining the effects of technological innovation and financialization on cropland, grazing land, fishing grounds, forest land, built-up land along with carbon footprint can be compared by using subcomponents of the ecological footprint as dependent variables instead of total ecological footprint.

Author contributions MAD initiated and designed the study. MM reviewed the literature and collected the dataset. MAD carried out the empirical analysis. MAD and MM have jointly interpreted the empirical findings, and revised and completed the manuscript. All authors read and approved the final manuscript.

Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethical approval and consent to participate Not applicable

Consent to publish Not applicable

Competing interests The authors declare that they have no competing interests.

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