Received: 14 June 2020 | Revised: 14 July 2020 | Accepted: 28 July 2020
DOI: 10.1002/bse.2615

RESEARCH ARTICLE

Business Strategy and the Environment
WILEY

Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter?

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Abstract

In the modern era of the wave of globalization, financial development is leading toward a higher rate of economic expansion and promoting energy innovation around the globe. Nevertheless, environmental impact of financial development has preoccupied government officials to circumvent adverse impact on environmental quality. Thus, this paper examines the nexus between financial development, economic growth, energy innovation, and environmental pollution for the period of 1990–2017 for the panel of Organization for Economic Cooperation and Development (OECD) countries. To obtain robust and unbiased results, this study utilizes Pooled Mean Group Autoregressive Distributed Lag (PMG/ARDL) estimator that counters the issue of heterogeneity and cross-sectional dependence. Empirical evidence suggests that financial development promotes energy innovation and improves environmental quality. Globalization also has a long-term relationship with energy innovation and reduces greenhouse gas (GHG) emissions. Moreover, findings validate the environmental Kuznets curve for OECD countries in the significance of financial development, globalization, and energy innovation.

KEYWORDS

energy innovation, financial development, globalization, greenhouse gases, OECD countries

1 | INTRODUCTION

Globalization boosts economic growth and integrates economies through trade, investment opportunities, capital flows, and cultural ties worldwide. It also facilities countries to accelerate the innovation process by highlighting common problems and priorities, collaborate to fill innovation gaps, sharing good practice, and make possible to deploy clean energy technologies (Shahbaz, Nasir, & Roubaud, 2018). Globalization brings institutional reforms, which leads to financial development and economic growth. Undoubtedly, financial development helps countries to exploit their scarce resources efficiently, promote investment, and boost economic growth (Li & Ramanathan, 2020; Mishkin, 2009).

Meanwhile, globalization facilitates financial sector reforms in both developing and developed countries, through which it can stimulate financial development and economic growth (Xu, Baloch, Meng, Zhang, & Mahmood, 2018). In the same way, financial development provides customers greater access to easy loans. It encourages customers to buy big items such as air conditioners, houses, and cars that raise level of energy consumption and greenhouse gas (GHG) emissions (Baloch, Meng, Zhang, & Xu, 2018).

Financial development is key to promote the innovation process that improves energy efficiency and thus to reduce emissions (Alvarez-Herranz, Balsalobre-Lorente, Shahbaz, & Cantos, 2017). Financial development may stimulate the innovation process in the energy sector by expanding public budget on energy research, development, and demonstration (RD & D; Álvarez-Herránz, Balsalobre, Cantos, & Shahbaz, 2017). Financial development is a backbone of the innovation process that helps to manage risk, minimize cost, and improve efficiency in energy sector. Moreover, financial development makes it possible to acquire clean energy by giving support to investment, innovation, and energy efficiency (al Mamun, Sohag, Shahbaz, & Hammoudeh, 2018). Financial development promotes energy innovation by allocating more funds to innovative firms that help to reduce energy intensity and increase energy efficiency (Aguilera-Caracuel, Guerrero-Villegas, & Garcia-Sanchez, 2020; Chang, 2015).

Financial development promotes research and development (R&D) activities that leads to technology improvement and thereby less emissions (Abbasi & Riaz, 2016). Financial development encourages the adoption of new products or process that leads to stimulate the energy innovation process (Law, Lee, & Singh, 2018). Appropriate allocation of financial resources is crucial for energy innovation (Inglesi-Lotz, 2019; Murad, Alam, Noman, & Ozturk, 2019). Nevertheless, addressing these issues demand public budget on RD & D; in other words, there is need to increase energy efficiency and maximize the share of clean energy sources in the energy mix (Alvarez-Herranz et al., 2017). Energy innovation can play important role in limiting global warming by bringing transformational changes in energy sector. However, it is hard for any single country to address energy and environmental challenges alone (International Energy Agency, 2019). Nevertheless, globalization also affects environmental quality through various channels (Xu et al., 2018).

From the above evidence, it is clarified that financial development is the answer to promoting energy innovation. In addition, prior studies have reported energy innovation as a source to increase energy efficiency and reduce environmental pollution. However, the role financial development plays in stimulating energy innovation in the era of globalization has been overlooked, especially for the prestigious panel of countries such as Organization for Economic Cooperation and Development (OECD) countries. Therefore, this study aims to extend the current literature by investigating the dynamic linkage between financial development, energy innovation, and environmental degradation controlling the model for globalization into a single multivariate framework for OECD countries (Álvarez-Herránz et al., 2017).

The panel of OECD countries is an important setting to investigate the dynamic linkage between financial development, energy innovation, and environmental pollution. Because the governmental political will is an essential factor in transforming any country's energy system, International Energy Agency (IEA) and OECD countries have jointly agreed to intensely increase public budget on energy RD & D aiming to reduce GHG emissions. In this regards, the several new agreements such as Clean Energy Ministerial (CEM) and Mission Innovation (MI) have been signed aiming to promote clean energy technologies and pledged to double the expenditure on clean energy R&D and related activities under major innovation areas (International Energy Agency, 2019). In addition, OECD countries are agreed to compliance with Kyoto Protocol, aiming to reduce GHG emissions and counter the global environmental challenges. Therefore, OECD countries have high intentions to maximize public budget on RD & D in energy sector to promote clean energy sources and reduce their dependence on fossil fuel. It is because the GHG emissions from fossil fuel combustion have been increased 6% in 2015 and considered to be the main culprit behind environmental degradation in OECD countries (Zhang, Hassan, & Iqbal, 2019). In the current scenario, the role of financial sector in promoting energy innovation is very crucial in OECD countries. It is because the financial sectors of OECD countries cover 80% of the world's financial sector and well developed as compared with the other countries in the world (al Mamun et al., 2018). Therefore, this group of countries has great potential to lead the rest of the world, especially the role of financial development in stimulating energy innovation (Baloch & Meng, 2019).

This study is different from previous studies in the following ways: (i) To the best of authors' knowledge, no study so far has empirically analyzed the dynamic linkage between financial development, energy innovation, and environmental degradation through globalization channels in OECD countries, and (ii) previous studies have overlooked an important environmental-related factor such as globalization in nexus of financial development and energy innovation. By incorporating globalization factor, we can counter the problem of specification bias and can produce reliable and consistent empirical results. It may play an important role in mitigating GHG emissions and serve as blueprint for government officials and stakeholders in energy-environment issues for adequate policy framework construction to engender sustainable economic growth in the blocs investigated. (iii) Furthermore, the present study contributes to the extant literature on methodological front by utilizing advanced econometric technique, namely, Pooled Mean Group Autoregressive Distributed Lag (PMG/ARDL) method for long-term estimation (Pesaran, Shin, & Smith, 1999). PMG/ARDL estimator counters the issues of cross-sectional dependence (CSD) and country-specific heterogeneity in the panel data. The adaptation of this method enables us to obtain unbiased and accurate results.

The remainder of this study is structured as follows: Section 2 presents a stylized review of related literature on the explored theme. Subsequently, Section 3 focuses on materials and econometrics methodology. Section 4 renders the empirical findings and interpretations. Finally, the concluding remarks and policy direction are reported in Section 5.

2 | LITERATURE REVIEW

Ample research has sought to discuss GHGs with various factors including urbanization, governance, energy, economic growth, and information and communication technology. In line with the renowned environmental Kuznets curve (EKC) stating the increasing income after the optimum level diminishes pollution (Destek & Sarkodie, 2019; Rauf et al., 2018; Sarkodie & Ozturk, 2020; Sarkodie & Strezov, 2018). The mantra of EKC "grow now clean later" demands huge resources and environmental costs to make it practical that may not be possible for this planet to sustain in future (Gill, Viswanathan, & Hassan, 2018). There is an ongoing debate on EKC, and scholars present different views on the role of income in mitigating pollution due to various pollution reduction patterns across regions and countries. Some studies support the existence of EKC (Baloch, Mahmood, & Zhang, 2019; Dong, Sun, & Hochman, 2017; Halkos & Polemis, 2017; Jebli, Youssef, & Ozturk, 2016), whereas others do not confirm EKC (Ozturk, 2015; Sohag, Kalugina, & Samargandi, 2019; Tedino, 2017). At the initial stage, economic development increases environmental pollution due scale effect because economic growth exploits natural resources, promotes industrialization, and intensifies agriculture (Baloch et al., 2019). In the next phase, the adverse effect of economic growth on environment started declining due to the structural changes in the economy and referred as composition effect. After crossing the threshold level, environmental quality starts improving due to the emergence of advanced environmentally friendly technologies and exercising environmental laws associated with technique effect (Destek & Sarkodie, 2019). The inverted U-shaped relationship between real income per capita and pollution takes place when composition effect combined with technique effect dominates the scale effect. The graphical representation of EKC is as below in Figure 1.

Nevertheless, when income crosses the optimum level, the marginal disutility of pollution goes beyond the marginal utility of consumption, more resources leads to utility maximization and thereby pollution reduction, that creates a dichotomy between income growth and pollution reduction (Lorente & Álvarez-Herranz, 2016). The reduction in environmental pollution will not occur automatically with income growth; it requires advanced technologies particularly in energy sector because energy is the main source of environmental degradation. Public expenditure on R&D is imperative for pollution mitigation, and it draws particular attention in the literature. Balsalobre, Álvarez, and Cantos (2015) investigated the EKC curve by incorporating not just income but also energy-oriented RD & D and energy intensity for 28 OECD countries. The empirical findings suggest that energy innovation helps to reduce energy intensity and thus GHG emissions. Dauda, Long, Mensah, and Salman (2019) utilized holistic approach to different regions (i.e., G6, MENA, and BRICS countries) and estimated how energy innovation reduces GHG emissions. The empirical evidence reveals that energy innovation improves environmental quality in G6 countries but contributes to GHG emissions in MENA and BRICS countries. Koçak and Ulucak (2019) performed disaggregated analysis for energy (R&D) expenditures on environmental quality in 19 high-income OECD countries. The empirical results show that energy-oriented R&D spending on energy efficiency and fossil energy, renewable energy, and power and storage have adverse effect, no effect, and reducing effect on the environmental quality, respectively.

Shahbaz, Nasir, and Roubaud (2018) estimated the role of energy innovation in reducing environmental pollution by employing bootstrapping ARDL bounds testing approach for France. The empirical evidence suggests that energy innovation has a negative and statistically significant effect on CO_2 emissions. In addition, EKC holds in case of France. Mensah, Long, Dauda, Boamah, and Salman (2019) investigated the role of technology innovation in mitigating emissions by using the proxy of patents and trademarks for technology innovation in OECD countries. The findings suggest that technology innovation is helpful in reducing environmental pollution. Moreover, Fethi and Rahuma (2019) analyzed the extend version of EKC curve by analyzing the role eco-innovation in reducing emissions for 20 refined oil-exporting countries. The empirical evidence suggests that rise in income and emissions encourages eco-innovation. Pan, Uddin, Han, and Pan (2019) investigate the contemporaneous causal linkage between financial development technological innovation by employing yearly data for the period 1975 to 2014 in case of Bangladesh. The results drawn from directed acyclic graphs (DAG) technique and structural vector autoregression (SVAR) model suggest that financial development influences technological innovation.

The pattern of financial development affecting energy innovation and hence environmental pollution is complex and remained unsolved. There is a scarcity of research for panel of countries like OECD that examines how financial development helps to promote energy innovation and can reduce greenhouse gas (GHG) emissions. A sound

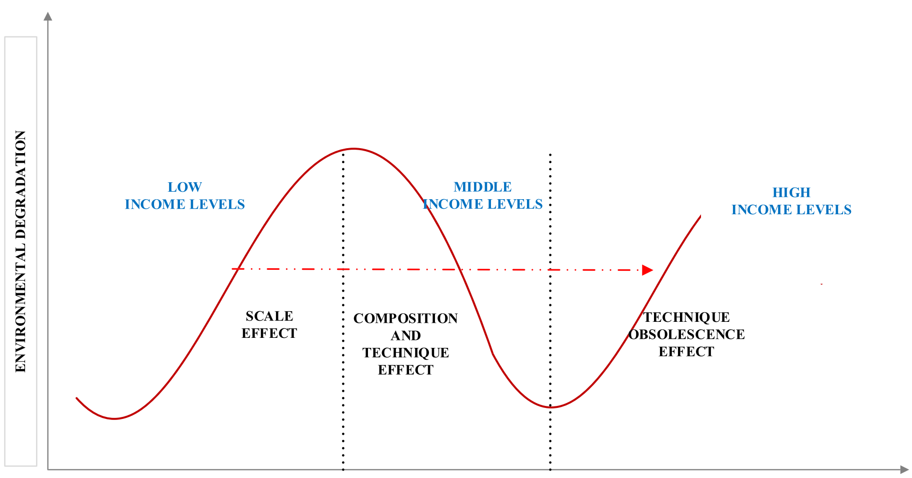

FIGURE 1 Income–pollution nexus (Sarkodie & Strezov, 2019) [Colour figure can be viewed at wileyonlinelibrary.com]

financial sector is crucial to support public expenditure on energy (RD & D). Due to various proxies and overlooked some potential factors, it is much needed to undertake the study by incorporating potential factors in the context of OECD countries. This study, therefore, takes an advantage to investigate the dynamic relationship between financial development, energy innovation, and environmental degradation by controlling the role of globalization as additional variable to conventional carbon-income function in OECD countries to circumvent for omitted variable bias issues in modeling. The study has utilized a larger dataset and adopted the advanced econometric approach PMG/ARDL in order to accommodate for CSD and heterogeneity issues.

3 | MATERIAL AND METHODS

3.1 | Data source

The sample data comprise balanced panel data from 1990 to 2017, covering 27 OECD countries.[1] The choice is subjected to the availability of data. The dataset covers the variables of financial development, economic growth, globalization, energy innovation, and GHG emissions. To measure financial development, we rely on the financial development index developed in the context of the International Monetary Fund (IMF) staff discussion note (Svirydzenka, 2016). An advantage of using financial development index is that it is a comprehensive index that covers financial institutions (i.e., banks, mutual funds, insurance firms, and pension funds) and financial markets (i.e., bond and stock markets). Financial development index is derived by combining depth (magnitude and liquidity of markets), access (individuals' ability and firms to access financial services), and efficiency (institutions' ability to offer financial services at minimum cost along with sustainable revenues, and activity level of capital markets). Economic growth is a gross domestic product (GDP) per capita calculated in constant U.S. dollar keeping 2010 as base year. The Konjunkturforschungsstelle (KOF) index of globalization proposed by Dreher (2006) is utilized to estimate globalization. Energy innovation is derived from the public budget on energy RD & D per capita (constant 2011 PPP, US$). Finally, GHG emissions are used as proxy of environmental pollution and measured as (million tons of CO_2 equivalent). Data for financial development index are borrowed from IMF. The data for GDP per capita and GHG emissions per capita are collected from the World Development Indicator (WDI-CD, 2018). The data for the index of globalization are extracted from KOF Swiss Economic Institute.[2] The data on public budget on energy RD & D per capita have been collected from (OECD, 2018).[3]

[1]List of OECD countries used in the final analysis: Australia, Austria, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungry, Iceland, Ireland, Israel, Italy, Japan, Korea Republic, Mexico, Netherland, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Turkey, United Kingdom, and United States. Twenty-seven OECD countries are selected for final analysis, and the rest of the countries are eliminated due to insufficient data of those countries.

[2]For more details, see http://globalization.kof.ethz.ch/.

[3]OECD (2018). http://www.oecd.org/statistics.

3.2 | Model specification

The present study seek to operationalize the nexus between the financial development, economic expansion, energy innovation, and pollutant emissions while accommodating for globalization as additional variable in model setting for the case of OECD countries. In doing so, two separate models were fitted with energy innovation and GHG emissions considered, respectively, as explained variable on separate models. This empirical setting draws support from the study (Álvarez-Herránz et al., 2017) which is consistent with existing literature. The model for linkage between financial development and energy innovation is proposed as

$$\ln EIN_{it} = \beta_0 + \beta_1(\ln FD_{it}) + \beta_2(\ln GDP_{it}) + \beta_3\left(\ln GDP^2\right)_{it} + \beta_4(\ln G)_{it} + w0, \quad (1)$$

where *EIN* represents energy innovation, *FD* shows financial development, *GDP* stands for economic growth per capita, and *G* indicates index of globalization. *I* represents the cross-sectional dimension whereas *t* means time dimension. As earlier mentioned, the second model that operationalizes the impact of financial development on pollutant emissions has been analyzed. The econometric form is as below:

$$\ln GHG_{it} = \beta_0 + \beta_1(\ln FD_{it}) + \beta_2(\ln GDP_{it}) + \beta_3\left(\ln GDP^2\right)_{it} + \beta_4(\ln G)_{it} + w0, \quad (2)$$

where *GHG* is the greenhouse gas emissions (million tons of CO_2 equivalent) per capita, *FD* reflects financial development, *GDP* indicates economic growth, and *G* shows the index of globalization. Globalization is incorporated in the model because globalization facilitates international transactions by reducing cost and helps correspondence between financial and real sectors of at a global level. It supports free flow of exchanges in the real economy of a global magnitude. In this way, globalization may have positive and adverse effects on environment. As globalization facilitates economic development by reducing cross-border barriers between trading partners, if foreign firms incorporate modern technologies, energy efficiency may improve and thereby reduces environmental pollution. These practices further effect the operations of local firms in host countries, and they also tend to utilize the modern methods of production. Oppose to this, globalization may pollute the environment because the prime objective of overseas firms is to maximize their wealth and not to conserve energy in the host country (Shahbaz, Shahzad, Alam, & Apergis, 2018).

3.3 | Econometric approach

In panel econometrics, given the amalgamation of both time series and cross-sectional dimension Baltagi, Bratberg, and Holmås (2005), panel dataset is usually plagued with presence of CSD and heterogeneity issues. Thus, it is imperative to select appropriate econometric tests for analysis, such as unit roots and cointegration tests. Therefore, this study uses Pesaran (2004) CSD test that deals with both CSD and heterogeneity. Afterward, the level of integration has been determined by employing cross-sectionally augmented Im, Pesaran and Shin (CIPS) unit roots test that counters the issue of CSD. This study than utilizes Westerlund (2007) cointegration test to investigate the long-run relationship among financial development, economic growth, energy innovation, and environmental pollution, due to its ability to address the potential problem of heterogeneity and CSD in panel data. As for long-term and short-term estimates, this study takes advantage of using PMG/ARDL estimator by (Pesaran et al., 1999). The choice of PMG/ARDL estimator is because it allows controlling the long-run parameters to be constant across individual country groups however permitting the short-term estimates, error variances, and imposes heterogeneity in intercepts. It is considered as a dominant model in terms of reliability and efficiency if the long-term prerequisites are valid. PMG/ARDL model provides an advantage of obtaining long-term and short-term estimates simultaneously, regardless the series is $I(1)$ or $I(0)$. Finally, Dumitrescu–Hurlin panel causality test is used to detect the direction of causality flow among the outlined indicators under review.

4 | EMPIRICAL RESULTS AND DISCUSSION

This section depicts the empirical findings derived from CSD, panel unit roots test, cointegration test, long-term panel estimator, and causality test. In advanced econometrics, it is necessary to detect the cross-section dependence (CD). In case CD exists in panel data series, the conventional unit root test would not be appropriated. This study utilizes Pesaran (2004) CD test, and results shown in Table 1 confirm that null hypothesis of CD is strongly rejected at the 1% level of significance. The existence of CD in panel data does not recommend using first-generation panel unit root tests because results obtained from these tests would not be considered reliable. Therefore, this study employs a second-generation CIPS unit root test that is robust against CD and heterogeneity. The results of CIPS unit root test in Table 1 suggest that the variables are not stationary at level; nevertheless, after taking the first difference, all variables become stationary at 1% level of significance. Therefore, the null hypothesis of nonstationarity is rejected.

This study moves forward and estimates the possible cointegration among variables of interest. For this purpose, this study takes an advantage of using Westerlund panel cointegration test proposed by (Westerlund, 2007). Westerlund cointegration test is suitable for this study because it circumvent for issue of CSD. The process of estimating Westerlund panel cointegration test depends on panel of four (4) statistics, namely, (Ps, Pa) and group statistics (Gs, Ga). The panel estimator is unique as it is based on error correction mechanisms and cross-sectional units: group statistics do not require information from the error correction term. Findings derived from Westerlund panel cointegration test in Table 2 provide strong evidence of rejecting the null hypothesis of no cointegration. In other words, the cointegrating relationship is significant. Thus, financial development, economic growth, globalization, energy innovation, globalization, and GHG emissions are cointegrated and can move together in the long term over the investigated period.

After confirming the statistical and economic viability of independent variables for dependent variables through the cointegration test, this study utilizes PMG/ARDL method to analyze the long-term elasticities of financial development, economic growth, energy innovation, globalization, and GHG emissions, as shown in Table 3. This study takes the natural logarithm values of panel data series to avoid any abnormal size effect in long-run elasticities. The empirical analysis offers several useful insights. First, financial development has but positive impact on energy innovation, as financial development leads to increasing the rate of energy innovation. In other words, financial development stimulates public spending on energy RD & D. A 1% increase in financial development enhances energy innovation by 0.437% in OECD countries. On the other hand, energy innovation has statistically negative significant effect on GHG emissions. A 1% increase in the coefficient of energy innovation leads to decrease GHG emissions by 0.159%. This could be attributed that OECD countries have pledged to double public budget on energy RD & D and co-lead activities (International Energy Agency, 2019). Therefore, it is possible that OECD countries have induced financial sector to play imperative role in expanding public budget on energy RD & D in order to stimulate energy innovation and promote clean energy sources. Also, there are major financial sector reforms that have been noted over the years in OECD countries (Baloch et al., 2019). These reforms may have reduced the financial challenges by financial deepening, thus allocating more resources for energy research and promote innovative projects in energy sector. Our results coincide with findings of Hsu, Tian, and Xu (2014), al Mamun et al. (2018), and Baloch et al. (2019).

In addition, the environmental impact of financial development is also recorded in Table 3. A 1% increase in financial development leads

TABLE 1 CD test results

	Ln(EI)	Ln(GDP)	Ln(GDP^2)	Ln(GHG)	Ln(FD_{IX})	Ln(G)
CD test	38.57* [0.000]	86.34* [0.000]	86.34* [0.000]	6.38* [0.000]	78.52 [0.000]	84.83 [0.000]
Panel unit root test						
CIPS (at level)	−2.619	−1.765	−1.707	−0.865	−3.126	−3.141
CIPS (at first difference)	−4.610*	−3.658*	−3.601*	−1.853*	−5.169*	−4.963*

*Significance level at 1%.

TABLE 2 Westerlund panel cointegration test

	Dependent variable = energy innovation			Dependent variable = GHG emissions		
Test	Value	*Z* value	*P* value	Value	*Z* value	*P* value
Gt	−3.008**	−1.815	0.035	−2.426	0.105	0.542
Ga	−11.082	2.874	0.998	−20.223*	−4.928	0.000
Pt	−21.115*	−8.836	0.000	−10.898	0.245	0.597
Pa	−18.343*	−4.214	0.000	−16.471*	−4.911	0.000

Abbreviation: GHG, greenhouse gas.
*Significance level at 1%.
**Significance level at 5%.

TABLE 3 Result of Pooled Mean Group Autoregressive Distributed Lag (PMG/ARDL) estimator

	Dependent variable = energy innovation	Dependent variable = greenhouse gas emissions
Regressor	Coefficient (Prob.)	Coefficient (Prob.)
Long-run estimates		
Ln(GDP)	0.425* (0.000)	4.542* (0.000)
Ln(GDP^2)	–	−0.210* (0.000)
Ln(FD)	0.438* (0.000)	−0.246* (0.000)
Ln(GLOB)	1.416* (0.000)	−0.309* (0.000)
Ln(EI)	–	−0.159* (0.000)
Short-run estimates		
Ln(GDP)	−0.059 (0.000)	3.396 (0.000)
Ln(GDP^2)	–	−0.150 (0.000)
Ln(FD)	−0.059 (0.109)	−0.013 (0.330)
Ln(GLOB)	0.389 (0.391)	−0.064 (0.440)
Ln(EI)	–	−0.008 (0.711)

*Significance level at 1%.

to a decline GHG emissions by 0.245%. In other words, financial development improves environmental quality in OECD countries. These findings are not surprising for OECD countries because these countries have well-established financial sector. It is possible that financial sectors in OECD countries promote environmentally friendly projects by making capital cheaper for firms that bring innovative methods of production. In addition, a sound financial sector allocates more resources to R&D in energy sector that promotes modern technologies in the firms and economies which increases energy efficiency and thereby enhances environmental quality. Energy innovation is a complex phenomenon that demands regular modifications with respect to new development, particularly at the time of change (Inglesi-Lotz, 2019). In order to maintain and raise research spending, financial sector can utilize existing funds to fill the research gaps, which leads to improve energy efficiency and thus reduces environmental pollution. As energy sector is a heavily finance-dependent sector, financial development can support energy sector by providing lower cost finance that promote innovation in energy sector and hence improve environmental quality. Our results reciprocate the findings of Park, Meng, and Baloch (2018), Saidi and Mbarek (2017), and Khan, Saleem, and Fatima (2018).

Regarding GDP per capita, it is noted that GDP per capita has a positive and significant impact on energy innovation in OECD countries, whereas the coefficient of GDP is also elastic to GHG emissions. The impact of GDP per capita on GHG emissions is positive and statistically significant; on the other side, the effect of the square of GDP per capita is negative and statistically significant. This outcome is consistent with the EKC phenomenon where real income grows until a certain threshold level whereas GHG emissions start to decline. In the initial stage of economic growth, the environmental quality decreases, whereas after reaching the optimum level, environmental quality starts improving in OECD countries. This supports the inverted U-shaped relationship between economic growth and environmental quality. The findings are justifiable for the well-developed OECD economies and associated with structural change and technological advancement in the economy. Environmental awareness rises among the people as income grows, so environmental regulations are enforced to use energy-efficient technologies to mitigate pollution. Our results are consistent with findings of Ganda (2019) and Lorente and Álvarez-Herranz (2016) for OECD countries. However, the findings contradict with Mensah et al. (2018) for OECD countries.

The impact of the index of globalization exerts a statistical positive effect on energy innovation and reduces the level of pollutant emissions (GHG). A 1% rise in coefficient of globalization stimulates energy innovation by 1.416%. It means that globalization is helpful in bringing energy innovation in OECD countries. In addition, globalization improves environmental quality in OECD countries by reducing GHG emissions. A 1% increase in globalization mitigates the GHG emission by 0.309%. This empirical evidence suggests that globalization promotes energy innovation and reduces environmental pollution in OECD countries. The findings seem logical for OECD countries because it is a common view that globalization promotes economic growth by eliminating cross-border barriers and promoting trade and investment. It is possible that OECD countries restrict overseas firms from utilizing innovative technology to set up new businesses or expand the existing one. Meanwhile, these innovative practices also affect the existing firms in the host country that overall improves the energy efficiency that leads to reduce environmental pollution. Another reason could be that OECD countries adopt energy-efficient technology and promote innovative methods of production during their exposure to the rest of the world. It could also be attributed that globalization backed up by domestic financial reforms in OECD may have attracted investment and latest technology in energy sector that reduces environmental stress.

Results of PMG/ARDL estimators are shown in Table 3. Our empirical findings suggest that financial development is insignificant in both energy innovation and GHG emissions model. As for economic growth, the findings are similar to those in the long term for GHG emissions model, whereas in energy innovation model, economic growth decreases energy innovation in the short run. Finally, unlike with the long run, the results of globalization in short term are insignificant for both energy innovation and GHG emissions models.

Finally, Dumitrescu–Hurlin panel causality test that is robust against CSD is utilized to determine the causal relationship between financial development, GDP per capita, energy innovation, and GHG emissions. The findings of Dumitrescu–Hurlin panel causality test shown in Table 4 suggest that bidirectional causality exists between GDP and GHG emissions, energy innovation and GHG emissions, energy innovation and GDP, energy innovation and globalization, and energy innovation and financial development, whereas unidirectional causality is detected from GHG emissions to globalization, GDP to globalization, and globalization to energy innovation. Moreover, no causality is found between financial development and globalization and financial development and GDP. All mentioned causality results have policy implication as globalization is seen to induce economic growth and energy innovation in one way. Although these outcomes have environmental implications, as caution is suggested for the OECD government officials, there is need to drift from fossil fuel based energy mix to renewables that are reputed to be cleaner and ecosystem friendly.

TABLE 4 Pairwise Dumitrescu–Hurlin panel causality tests

Null hypothesis	W-Stat.	Zbar-Stat.	Prob.
$Ln(GDP) \nLeftrightarrow Ln(GHG_S)$	299.63*	629.046	0.0000
$Ln(GHG_S) \nLeftrightarrow Ln(GDP)$	4.6368*	5.13152	0.0000
$Ln(G) \nLeftrightarrow Ln(GHG_S)$	1.7768	−0.91713	0.3591
$Ln(GHG_S) \nLeftrightarrow Ln(G)$	3.6711*	3.08906	0.0020
$Ln(FD_{IX}) \nLeftrightarrow Ln(GHG_S)$	2.0152	−0.41311	0.6795
$Ln(GHG_S) \nLeftrightarrow Ln(FD_{IX})$	2.1723	−0.08073	0.9357
$Ln(EI) \nLeftrightarrow Ln(GHG_S)$	3.2385**	2.17412	0.0297
$Ln(GHG_S) \nLeftrightarrow Ln(EI)$	4.7910*	5.45769	0.0000
$Ln(G) \nLeftrightarrow Ln(GDP)$	2.5240	0.66302	0.5073
$Ln(GDP) \nLeftrightarrow Ln(G)$	107.56*	222.826	0.0000
$Ln(FD_{IX}) \nLeftrightarrow Ln(GDP)$	1.6687	−1.14588	0.2518
$Ln(GDP) \nLeftrightarrow Ln(FD_{IX})$	1.9689	−0.51100	0.6093
$Ln(EI) \nLeftrightarrow Ln(GDP)$	4.0874*	3.96953	0.0000
$Ln(GDP) \nLeftrightarrow Ln(EI)$	6.6293*	9.34553	0.0000
$Ln(FD_{IX}) \nLeftrightarrow Ln(G)$	1.8205	−0.82484	0.4095
$Ln(G) \nLeftrightarrow Ln(EI)$	3.8625*	3.49398	0.0005
$Ln(EI) \nLeftrightarrow Ln(G)$	3.5002*	2.72762	0.0064
$Ln(G) \nLeftrightarrow Ln(EI)$	4.8715*	5.62800	0.0000
$Ln(EI) \nLeftrightarrow Ln(FD_{IX})$	3.6545*	3.05411	0.0023
$Ln(FD_{IX}) \nLeftrightarrow Ln(EI)$	5.4153*	6.77811	0.0000

*Significance level at 1%.
**Significance level at 5%.

5 | CONCLUSION AND POLICY IMPLICATIONS

This study aims to find the dynamic relationship between financial development, economic growth, energy innovation, and pollutant emissions. There been neglect in the related literature the role of globalization for the theme under consideration. Thus, the present study accounts the role of globalization for the case OECD countries where little documentation exists. The study data span from 1990 to 2017 utilizing the PMG/ARDL technique that ameliorates for CSD and heterogeneity problems. Empirical results from PMG/ARDL method suggest interesting outcomes. Financial development encourages energy innovation and reduces the level of GHG emissions. In the initial stages, GDP per capita increase environmental degradation. Thus, it indicates the scale stage of the bloc growth trajectory (Shahbaz & Sinha, 2019). While after reaching the threshold level, it starts declining. Globalization promotes energy innovation and helps to reduce GHG emissions in OECD countries.

The empirical findings suggest some important policy implications. Environmental pollution will not be disappeared automatically with economic growth, but it requires some reasonable initiatives taken by the government, more precisely to encourage energy-oriented (RD &D). In this regard, financial development can play an important role in encouraging energy innovation that leads to increase in energy efficiency and thus reduces GHG emissions. Moreover, it becomes hard for OECD countries to meet GHG emissions targets if the comprehensive policies would solely in the context of role of economic growth on pollution reduction without taking account the effects of financial development and energy innovation. Therefore, the financial sectors in OECD countries are encouraged to expand their share for energy-oriented (RD &D) without compromising the economic objectives. In this regard, financial institutions can offer incentives to the firms that bring innovation in their products and processes. Moreover, the financial sector should make a comprehensive energy innovation policy that includes funds and tax relaxations for RD & D projects.

As for the policy implication regarding the role of globalization in stimulating energy innovation and reducing environmental degradation, globalization encourages international collaboration and market integration among trading partners by eliminating trade constraints. OECD countries should collaborate and accelerate the process of energy innovation by highlighting common threats and preferences, sharing best practices, bridging innovation gaps, minimizing cost, and making it possible to adopt clean energy technologies. In addition, globalization promotes trade openness and fosters foreign direct investment (FDI); therefore, it is recommended that OECD countries should control the transfer of outdated technologies and adopts modern technologies. It would help countries to promote environmentally friendly technologies that lead to reduce environmental pollution.

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How to cite this article: Baloch MA, Ozturk I, Bekun FV, Khan D. Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter? *Bus Strat Env*. 2020;1–9. https://doi.org/10.1002/bse.2615