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Research article

Linking clean energy consumption, globalization, and financial development to the ecological footprint in a developing country: Insights from the novel dynamic ARDL simulation techniques

Solomon Prince Nathaniel [a,b], Zahoor Ahmed [c,d,e], Zilola Shamansurova [f], Hossein Ali Fakher [g,*]

[a] *Department of Economics, University of Lagos, Akoka, Nigeria*
[b] *Lagos State University School of Basic and Advanced Studies (LASUSBAS), Topo, Badagry, Nigeria*
[c] *Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon*
[d] *Department of Economic & Data Sciences, New Uzbekistan University, 54 Mustaqillik Ave., Tashkent, 100007, Uzbekistan*
[e] *UNEC Research Methods Application Center, Azerbaijan State University of Economics (UNEC), Istiqlaliyyat Str. 6, Baku 1001, Azerbaijan*
[f] *Department of Finance, Tashkent State University of Economics, Tashkent City, Uzbekistan*
[g] *Department of Business Management, Ayandegan Institute of Higher Education, Tonekabon, Iran*

A R T I C L E I N F O

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A B S T R A C T

Developing countries have been facing economic difficulties for over three and a half decades due to numerous factors, including fossil fuel consumption and dwindling biocapacity. It is necessary to pinpoint the factors that may be culpable for poor environmental quality leading to a rising ecological footprint (EFP). This study explores the effect of clean energy, financial development (FDV), and globalization on the EFP in a developing country using the novel dynamic ARDL simulation techniques and the bootstrap causality test. The findings suggest that green energy has no meaningful impact on the EFP. Globalization and FDV significantly reduce the EFP by 0.25% and 0.08%, respectively. Besides, the findings confirm the existence of the EKC hypothesis. Furthermore, the causality results affirm a unidirectional causality from globalization and FDV to EFP, while economic growth drives globalization. Also, a one-way causality flows from globalization to FDV, just as FDV Granger causes green energy. In line with the findings, the study recommends that public policies focus on funding environmental-friendly technologies and green innovations. The funding must be on recently developed energy-saving technologies that can ensure complementarity between increased economic growth and environmental deterioration.

1. Introduction

In recent times, climate change has been among the severe challenges faced by humanity [1]. Some of the unprecedented threats created by climate change include soil degradation, food shortage, species extinction, extreme weather, biodiversity loss, drought, and ecological distortions. Now, sustainable development is an important policy target in all countries with the objective of declining GHGs. Extensive cooperation among economies is required to tackle climate change and all its anomalies. As such, one hundred and

* Corresponding author. Department of Business Management, Ayandegan Institute of Higher Education, Tonekabon, Iran.
E-mail addresses: nathaniel_solomon21@yahoo.com (S.P. Nathaniel), Zahoorahmed83@Yahoo.Com (Z. Ahmed), Z.Shamansurova@Tsue.Uz (Z. Shamansurova), imanfakher@yahoo.com, ha_fakher@aihe.ac.ir (H.A. Fakher).

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ninety-six (196) countries that assembled at the Conference of the Parties (COP21) in France, Paris to be precise, in 2005, intended to consolidate various efforts aimed at addressing climate change and ensuring environmental sustainability.

The primary aim of COP21 was to ensure that temperature stays below 2 °C above pre-industrial levels, and if possible 1.5 °C in the near future [2]. Bangladesh, one of the fastest developing countries, is still unable to economic growth and environmental issues. More economic growth appears to increase EFP figures in Bangladesh. As such, the dangers related to ecological changes must be considered and the reasons for ecological distortions must be unveiled to enhance environmental wellbeing in Bangladesh.

Achieving economic growth is a necessity for all countries. However, there is a need to consider the causal interaction between economic expansion and environmental quality indicators, since the latter often leads to environmental deterioration. The EKC hypothesis clearly describes the link between environmental performance and economic growth [3]. Many researchers in the early 1990s have explored the authenticity of the EKC hypothesis in various countries, regions, and blocs. The EKC suggests that countries should focus more on attaining economic growth because environmental quality will automatically improve after a particular threshold of growth. Some researchers have argued that the EKC cannot be applied in countries with a low level of development since there is an uncertainty of them attaining the level where the relationship between pollution and income becomes negative. Developing countries, including Bangladesh, often disregard environmental laws for international competitiveness and to attract the inflow of investment so as to achieve economic expansion. As such, the much-needed economic growth often results in environmental degradation in developing countries [4]. However, this idea has been refuted recently by studies that have affirmed the existence of the EKC for all income groups, as well as emerging economies [5,6].

Bangladesh ranks among the fastest-growing countries in South Asia [7]. In 2015, Bangladesh attained the status of a lower-middle-income country. For more than three decades now, Bangladesh has maintained a 6.7% annual GDP growth rate. Globalization and financial development are key contributors to this growth. The target of the country was to achieve, and if possible, maintain US$1046 GDP per capita [8]. To achieve this feat, a seven to eight percent annual GDP growth rate must be maintained in the next decade. However, there are fears that this may not be achieved due to the economic downturn associated with the COVID-19 pandemic [9]. Vulnerability to climate change, environmental health risks, pollution, and dwindling biocapacity are core environmental issues in Bangladesh [7]. For instance, since 1971, the EFP figures in Bangladesh have exceeded the biocapacity figures. This portrays Bangladesh as an ecological deficit country. Hence, the need to examine the drivers of ecological deterioration in Bangladesh.

Globalization affects the economy via the use of technology, energy consumption, economic growth, and environmental alterations. From the listed factors, economic growth and environmental changes are more challenging [10]. Whether a developing country like Bangladesh can enhance its economic growth rate through globalization without worsening environmental quality is a vital question. The outcomes of researchers on the effect of globalization on the EFP are mixed, especially for Bangladesh. Globalization supporters are of the opinion that globalization increases FDI and the transfer of innovation, green technologies, and shared knowledge from advanced economies to developing countries.

The opponents of globalization argue that it encourages global warming [11,12]. Globalization can promote the usage of energy intensive technologies thereby aggravating environmental problems. The carbon emissions emanating from globalization are caused by the extensive exhaustion of natural resources, energy consumption, and transportation [13,14]. In globalization, forests, land, water, and the air are all harmed by careless human consumption, leading to environmental deterioration [15].

There is no consensus on how financial development impacts the EFP. Financial development is an important driver of EFP [16]. A functional financial system promotes access to credit, empowering people to buy expensive energy-intensive items that are high in emissions. Also, stock market development declines financial costs and enhances firms' liquidity, helping them to improve productivity, and thus accelerating energy consumption and environmental degradation. Besides, some researchers favor the positive effect of financial development on EFP by arguing that it increases investment in technology that could curb pollution [17,18].

Likewise, the desire for economic advancement has exacerbated environmental degradation, which is usually a resultant effect of industrialization and development in both developed and developing countries. The economy of any country largely depends on the country's level of resource endowment, human capital development, technical know-how, the strength of institutions, and energy consumption, among others [19–21]. While clean energy sources are expected to promote environmental sustainability, non-renewable energy sources perform the opposite [22].

The objective of this study is to examine the effect of clean energy consumption on the ecological footprint in Bangladesh considering the influence of globalization and financial development. This study is of great importance to Bangladesh considering that the country has a biocapacity deficit (that is, the percentage that ecological footprint exceeds biocapacity) of about −180% [23]. Besides, the country's exposure to lots of environmental tragedies and climate-related natural disasters as a result of the meager consumption of renewable energy, deforestation, and overdependence on fossil fuels serve as a rationale for this study.

This study enhances the literature in the following areas: (i) past studies predominantly use CO_2 emissions to capture environmental deterioration, we used EFP instead holding to the fact that Bangladesh is not among the highest emitters of noxious gases but harbors an ecological deficit territory. The EFP tracks the use of biologically productive surface areas like forest areas, carbon demand on land, fishing grounds, built-up land, cropland, and grazing land. (ii) we applied the dynamic ARDL simulation techniques and the bootstrap causality test while accounting for structural breaks. These are advanced time-series estimation techniques. This study is the first to apply the novel dynamic ARDL simulation techniques to scrutinize the effects of clean energy, FDV, and globalization on the EFP in Bangladesh.

The subsequent sections of this paper are structured in the following order. Section 2 shows the literature review, especially on studies that link the selected variables. Section 3 presents the methodology. Section 4 shows the results. The conclusion, as well as possible direction, are outlined in Section 5.

2. Literature review

Here, the study is divided into three subsections. The first subsection reviews previous studies on the EKC hypothesis, especially for Bangladesh. The second subsection is on clean energy and EF, while the third subsection focuses on the link between globalization, FD, and EF.

2.1. Studies on EKC hypothesis and energy-growth-environment nexus

After the seminar work of Kuznets [24], and subsequently, Grossman & Krueger [25], studies on the growth-environment nexus have proliferated. This sudden increase was informed by the perceived relationship between economic growth and environmental deterioration. In recent times, many researchers have channeled their studies toward assessing the impact of economic on the environment; using various proxies, including EFP [26,27] and CO_2 emissions [28] to capture environmental degradation.

Now, there are a plethora of studies that seek to estimate the interaction between growth and the quality of the environment [8,29,30] while others discovered no relationship between both variables [31]. Sultana et al. [8] explored the relationship between human capital, trade openness, energy consumption, economic growth, and EFP in Bangladesh from 1972 to 2018. The ARDL technique was used for parameter estimation while the FMOLS estimator served as a robustness check. The results affirmed the EKC for Bangladesh. The causality test suggests that economic growth drives the EFP in Bangladesh.

Murshed et al. [32] investigated the EKC hypothesis for Bangladesh while accounting for different energy sources including hydropower, refined petroleum oil, natural gas, and coal. Akin to the study of Sultana et al. [8], they confirmed the validity of the EKC hypothesis. Besides, the results also suggest that petroleum oils and coal consumption increase environmental degradation while higher consumption of hydropower and natural gas are seen to enhance environmental quality.

Rahman et al. [33] explored the effect of energy consumption and economic growth on environmental quality in Bangladesh via the FMOLS technique. Apart from confirming the EKC hypothesis, they also discovered that energy consumption, specifically non-renewable energy drives environmental degradation in Bangladesh. They recommended the increased consumption of renewables to stimulate sustainable development in Bangladesh. Similar to the study of Khan et al. [34] controlled for FDI while investigating the energy-growth-environment nexus for Bangladesh via the VECM.

Analogous to other studies in Bangladesh, they confirmed the EKC hypothesis and the deteriorating impact of energy consumption on EFP. Besides, a two-way causality also existed between FDI and economic growth. Selcuk et al. [35] also examined the effect of FDI, energy consumption, and trade on environmental quality in N11 countries, which also includes Bangladesh. The results from the CCEMG estimator confirmed that economic growth increases environmental degradation in Turkey, Nigeria, Mexico, Bangladesh, Mexico, and the panel. Akter et al. [36] examined the existence of the N-shaped EKC in Bangladesh. Their findings showed an N-shaped EKC for Bangladesh; suggesting that economic expansion initially mitigates environmental deterioration. This finding contradicts those of Sultana et al. [8], Rahman et al. [33], and Selcuk et al. [35].

2.2. Renewable energy, globalization, and EFP

Earlier studies linked renewable energy to emissions, but in recent times, renewable energy has been linked to EFP. For instance, Nathaniel et al. [27] examined the effect of natural resources, renewable energy, urbanization, and economic growth on the EFP in MENA. The findings revealed that growth increases the EFP. Urbanization and renewable energy decline the EF. Specifically, renewable energy reduces the EF in Bahrain, Algeria, UAE, Israel, Egypt, Lebanon, Jordan, Oman, Morocco, Tunisia, Sudan, and Yemen. Pata and Caglar [31] examined the impact of human capital, renewable energy, income, and trade contributing to the ecological deficit in China. Surprisingly, the EKC hypothesis was not validated for China, and renewable energy has no effect on both EF and CO_2 emissions. Also, while income and trade openness amplify the EF, human capital ensures environmental sustainability.

Usman and Hammar [37] analyzed the effect of FDV, technological innovations, renewable energy consumption, population, and growth on the EFP in APEC countries. The outcomes showed that renewable energy and financial development increased the EFP by 0.4274% and 0.0927%, respectively. However, population size, economic growth, and technological innovation exact a detrimental effect by increasing the EFP by 0.458%, 0.517%, and 0.099% respectively. Besides, a feedback causality exists between renewable energy consumption, FDV, and EFP. Sharma et al. [38] also investigated the influence of life expectancy, population density, and growth on EFP in eight emerging economies of Southeast and South Asia. Unlike previous studies, they applied techniques that address the issues of endogeneity including the CS-ARDL approach. They discovered the presence of the N-shaped EKC, and how renewable energy declines the EFP in Southeast and South Asia.

Similarly, Usman and Makhdum [39] further confirmed that renewable energy reduces the EFP in BRICS and Turkey. Ansari et al. [40] discovered that urbanization, globalization, and renewable energy reduce the EFP, while economic growth and non-renewable energy increase the EFP in top renewable energy-consuming countries. Pata [41] performed Fourier causality and cointegration tests to examine the effect of globalization, agricultural activities, and renewable energy generation on EFP in BRIC countries from 1971 to 2016. The findings suggest that globalization and renewable energy generation increase and reduce the EFP in China respectively. Also, renewable energy generation reduces the EFP in Brazil.

Sahoo and Sethi [42] discovered no harmful effect of globalization and renewable energy on the EFP in developing countries. Also, globalization and EFP have a feedback causality. Naqvi et al. [43] measured the effect of financial development, renewable energy, and income on the EFP across 155 countries from 1990 to 2017. From their findings, financial development increases the EFP in low-income countries. However, renewable energy reduces the EF across all income groups. This finding further reiterates the benefits of consuming renewables both for a healthy environment and human health. Other studies in support of the abating role of renewable energy include [34,44–51].

Kirikkaleli et al. [52] examined the effect of globalization on EFP in Turkey. Their findings clearly reveal that globalization impacts EFP positively, while economic growth impacts EFP negatively. Trade openness reduces EFP in the short run. Salari et al. [53] explored the effect of renewable energy and globalization on EFP in emerging economies by applying fixed-effect panel quantile regression. The results confirmed that renewable energy reduced the EF across all quantiles, except the 25th quantile. Also, globalization negatively impacts the EF in all quantiles.

In summary, empirical studies on EKC indicate different findings including inverted U-shaped, positive U-shaped, and even no such relationship in previous studies. It is believed that the validity of the EKC can be affected by the regressors used in the models, the methodology adopted, and the selected period for the analysis. A majority of the studies confirmed that renewable energy amplifies the EFP. However, its impact depends upon the level of renewable energy usage in the energy mix [54,55]. The role of globalization and FDV in ensuring a sustainable environment is still murky as previous studies have illustrated both the positive and negative roles of these variables in environmental deterioration.

Additionally, most of the single-country studies adopted either the ARDL estimation technique or the FMOLS estimator. Moreover, we could not find any study in Bangladesh that focused on analyzing the relationship between clean energy, globalization, and EFP. Now, this study contributes empirically being a maiden attempt to estimate the effect of clean energy, FDV, and globalization on EFP in Bangladesh in the EKC framework via the novel dynamic simulation ARDL approach advanced by Jordan and Philips [56].

3. Methodology

3.1. Data and model

This study examined the association between EFP, FDV, globalization, economic growth, and clean energy in Bangladesh using the model as shown in Eq. (1):

$$lnefp_{i,t} = \gamma_0 + \gamma_1 lnegr_{it} + \gamma_2 lnegr_{it}^2 + \gamma_3 lnglob_{it} + \gamma_4 lngen_{it} + \gamma_5 lnfdv_{it} + \varepsilon_{it} \quad (1)$$

where ***efp*** represents the ecological footprint of consumption, ***egr*** stands for economic growth, ***egr***^{2} is the non-linear term of economic growth, ***glob*** refers to globalization, ***gen*** indicates green energy, and ***fdv*** represents financial development. ε_{it} is the error term. γ_0 is the parameter that represents the constant term. $\gamma_1 - \gamma_5$ are parameters of the explanatory variables to be estimated. If γ_1 turns out positive, and γ_2 turns out negative, then we can safely claim the existence of the EKC hypothesis. Economic expansion imposes environmental pressure by raising the demand for food, energy, water, and infrastructure, which in turn drives the EFP [57].

In line with previous studies, ***egr***^{2} was included because economic prosperity may alleviate ecological distortions [17]. FDV and globalization can either amplify or decline the EFP. Globalization encourages the importation of products that could enhance human well-being and/or aggravate the already existing environmental problems [58,59]. Besides, it is possible that globalization could add to environmental degradation in Bangladesh because of the country's heavy dependence on imported products and weak environmental regulations [8,33]. Table 1 provides information on the selected variables.

3.2. Econometric procedure

Firstly, we considered the unit root of the variables being a prerequisite for cointegration analysis and choice of the long-run estimation, and causality technique. We applied the Phillips-Perron (PP) and ADF tests initially. However, the aforementioned tests (PP and ADF) are not efficient amidst structural breaks; therefore, the Zivot-Andrews test is employed in this case. The Zivot and Andrews (ZA) [60] test is capable of revealing structural breaks that might have arisen from global, or maybe local economic shocks. The three tests all have the H_0 of non-stationarity, and the H_1 of stationarity of time series.

Now, once the integration level(s) of the series is revealed, appropriate econometric methods are applied to derive results. In terms of parameter estimation, the study applies the ARDL bounds test of Pesaran et al. [61] alongside the dynamic simulation ARDL (DARDL). The FMOLS and DOLS were applied to ascertain the robustness of the findings. The ARDL technique is useful for the following reasons: (i) It can be used amidst a mixed order of integration, let's say, $I(0)$ and $I(1)$, or strictly $I(1)$ but not $I(2)$. (ii) It addresses the problem of serial correlation and endogeneity. (iii) Robust for small sample size. Besides, to adopt the ARDL, it is necessary to choose the optimum lags, this study follows AIC for optimum lag selection. The ARDL model is specified in Eq. (2) as follows:

$$\Delta lnefp = \xi_0 + \xi_{dum} dum + \xi_1 lnefp + \xi_2 lnegr_{t-1} + \xi_3 \ ln\ egr_{t-1}^2 + \xi_4 lnglob_{t-1} + \xi_5 \ ln\ gen_{t-1} + \xi_6 lnfdv_{t-1} + \sum_{i=1}^{p} \psi_i \Delta lnefp_{t-i}$$
$$+ \sum_{j=0}^{q} \psi_j \Delta ln\ egr_{t-j} + \sum_{k=0}^{r} \psi_k \Delta lnegr_{t-k}^2 + \sum_{l=0}^{s} \psi_l \Delta lnglob_{t-l} + \sum_{m=0}^{t} \psi_m \Delta lngen_{t-m} + \sum_{n=0}^{u} \psi_n \Delta lnfdv_{t-n} + \mu_t \quad (2)$$

All the variable retained their early definition. Δ is the difference term. Also, ψ_i, ψ_j, ψ_k, ψ_l, ψ_m, and ψ_n are the short-run coefficients, ***m*** represents the optimum lags, t-Statistics and F-statistics are the determinants of the significance level of the ARDL long-run outputs.

The short-run connection existing between EFP and its covariates are evaluated via an error correction model. In Eq. (3), the

Table 1
Data sources and variables.

Variables		Proxy	Sources
Ecological Footprint	LnEFP	EF of Consumption expressed in global hectors per capita.	GFN [69]
Economic Growth	LnEGR	GDP per capita	WDI [70]
	$LnEGR^2$	Square of GDP to investigate EKC	
Globalization	LnGLOB	KOF index	KOF index [71]
Green Energy	LnGEN	Green energy consists of renewable energy sources including wind, solar, hydro, geothermal, and others	BP Statistical Review [72]
Financial Development	LnFDV	Domestic credit to the private sector	WDI [70]

Table 2
Descriptive statistics.

	LnEFP	LnEGR	LnGLOB	LnGEN	LnFDV
Mean	−0.57189	6.227304	3.504020	−5.567103	2.782105
Median	−0.656868	6.130386	3.552793	−6.556175	2.939797
Maximum	−0.130819	6.967947	3.955756	−6.076762	3.812855
Minimum	−0.779246	5.807806	2.907421	−7.271611	0.650824
Std. Dev.	0.179013	0.335839	0.323255	0.245348	0.823490

Table 3
Unit root results.

Variables	Augmented Dickey-Fuller (ADF)				Phillips-Peron (PP)			
	At Level		First Difference		At Level		First Difference	
	T-Stat.	Prob.	T-Stat.	Prob.	T-Stat.	Prob.	T-Stat.	Prob.
Ln EFP	−1.2191	0.997	−6.8742*	0.0000	−1.6752	0.9995	−6.8698*	0.000
Ln EGR	−2.9188	1.000	−5.8601*	0.0000	−2.3912	1.0000	−5.9218*	0.000
Ln GLOB	−1.2479	0.644	−7.6528*	0.0000	−1.3168	0.6130	−7.6528*	0.000
Ln GEN	−0.3302	0.560	−10.076*	0.0000	−1.0433	0.2629	−6.0597*	0.000
Ln FDV	−2.2547	0.191	−7.1203*	0.0000	−2.0181	0.5747	−7.0240*	0.000

Note: * refers to significance at 1, 5, and 10%, respectively.

adjustment speed parameter and the short-run coefficients are given.

$$lnefp_{,t} = \xi_0 + \sum_{i=1}^{k} \psi_i \Delta lnefp_{t-i} + \sum_{j=0}^{k} \psi_j \Delta ln\ egr_{t-i} + \sum_{k=0}^{k} \psi_k \Delta ln\ egr_{t-i}^2 + \sum_{l=0}^{k} \psi_l \Delta lnglob_{t-i} + \sum_{m=0}^{k} \psi_m \Delta ln\ gen_{t-i} + \sum_{n=0}^{k} \psi_n \Delta lnfdv_{t-i} + \gamma ecm_{t-1} + \varepsilon_t \tag{3}$$

where the adjustment coefficient (γ) reveals how much time is required for the government policy to absorb and affect EFP. Also, the F-statistic has the following null and alternative hypotheses, $H_0 : \xi_1 = \xi_2 = \xi_3 = \xi_4 = \xi_5 = \xi_6 = 0$ against $H_1 : \xi_1 \neq \xi_2 \neq \xi_3 \neq \xi_4 \neq \xi_5 \neq \xi_6 \neq 0$. Both hypotheses give information on the existence of cointegration which we examined via the Bayer and Hanck (BH) [62] combined cointegration test. The BH test is derived from combining Johansen [63], Boswijk [64], Banerjee et al. [65], and Engle and Granger [66] cointegration tests. The Fisher BH tests are presented in Eq. (4) and Eq. (5) as follows:

$$EG - JOH = -2[\ln(\rho_{EG}) + (\rho_{JOH}) \tag{4}$$

$$EG - JOH - BO - BDM = -2[\ln((\rho_{EG}) + (\rho_{JOH}) + (\rho_{BO}) + (\rho_{BDM}) \tag{5}$$

where ρ_{EG} , ρ_{JOH}, ρ_{BO}, and ρ_{BDM} represent the probability values of Boswijk [64], Johansen [63], Banerjee et al. [65], and Engle and Granger [66]. As a result of the complications in the long-run and short-run evaluation of the ARDL model, Jordan and Philips [56] developed the DARDL approach. The DARDL captures and predicts the counterfactual responses of one dependent variable on the other explanatory variables in the model. The DARDL requires the dependent variable to be I(1) which is in tandem with *efp*, our dependent variable. The current study applied the DARDL algorithms for five covariates. The DARDL model for this study, based on the choice of selected variables, is given in Eq. (6).

$$\Delta lnEFP_i = \gamma_0 + \delta_0\ ln\ EFP_{t-1} + \xi_1 \Delta ln\ EGR_t + \delta_1\ ln\ EGR_{t-1} + \xi_2 \Delta lnEGR_{t-1}^2 + \delta_2 lnEGR_{t-1}^2 + \xi_3 \Delta ln\ GLOB_t + \delta_3 lnGLOB_{t-1} + \xi_4 \Delta lnGEN_t + \delta_4 lnGEN_{t-1} + \xi_5 \Delta ln\ FDV_t + \delta_5 lnFDV_{t-1} + \varepsilon_t \tag{6}$$

Table 4
Zivot and Andrews Structrual Break test.

Variables	t-Stat	B.Year
LnEFP	−2.1590	1986
LnEGR	−0.6345	2005
LnGLOB	−3.6508	1988
LnGEN	−3.4383	2010
LnFDV	−3.1494	1983
ΔLnEFP	−9.5471*	1995
ΔLnEGR	−5.9577*	2005
ΔLnGLOB	−6.5353*	1986
ΔLnGEN	−6.6708*	1986
ΔLnFDV	−9.5422*	1985

Note: * shows 1 percent significance. Critical values are: 4.58 (10%), −4.93 (5%), and −5.34 (1%), respectively.

Table 5
Bayer-Hanck cointegration results.

Model	Fisher Statistics		
	EG-JOH	EG-JOH-BO-BDM	Cointegration
(LnEFP/LnEGR, LnEGR2, LnGLOB, LnGEN, LnFDV)	55.5608*	58.9826*	✓
Critical Values at 1%	15.701	29.85	
5%	10.419	19.888	
10%	8.242	15.804	

Note: * rejection of null at 1 percent significance.

Table 6
Bounds test results.

Model estimated		F-stat.	AIC Lags	Coint.
(LnEFP/LnEGR, LnEGR2, LnGLOB, LnGEN, LnFDV)		4.3506**	[0–2,2,2,2]	✓
Critical Values	LCB 1 (0)	UCB 1 (1)		
1% level	3.657	5.256		
5% level	2.734	3.92		
10% level	2.306	3.353		

Note: ** shows a 5 percent level of significance. Optimal lags 2 under the AIC criterion are used. Critical of Narayan (2005) for 40 observations are reported.

Table 7
Dynamic ARDL simulations and ARDL outputs.

Estimated Model= (LnEFP/LnEGR, LnEGR^2,LnGLOB, LnGEN, LnFDV)						
ARDL				DARDL		
Variables	**Coefficient**	**t-stat.**	**Prob.**	**Coefficient**	**t-stat.**	**Prob.**
LnEGR	9.1989*	3.5591	0.0014	4.9132**	2.73	0.011
ΔLnEGR	−0.2533	−0.8535	0.4008	−7.9001	−0.81	0.426
LnEGR^2	−0.6132*	−3.2015	0.0035	−0.3315**	−2.44	0.021
ΔLnEGR^2	−0.0045	−1.4336	0.1631	0.5997	0.74	0.467
LnGLOB	−0.4295**	−2.6471	0.0134	−0.256***	−1.87	0.072
ΔLnGLOB	0.0468	1.3947	0.1745	−0.2365	−1.52	0.140
LnGEN	−0.0817	−1.3153	0.1994	−0.0292	−1.32	0.196
ΔLnGEN	0.0018	0.1258	0.9008	0.0050	0.32	0.748
LnFDV	−0.1392*	−3.5067	0.0016	−0.0844*	−3.47	0.002
ΔLnFDV	−0.1085*	−3.0766	0.0048			
Dummy	−0.0777**	−2.4317	0.0219	–	–	–
ΔDummy	−0.1032*	−3.7855	0.0008	–	–	–
ECT (-1)	−0.6289*	−6.5389	0.0000	−0.5864*	−4.09	0.000
R-Square	0.9857			0.5865		
AdjustedR^2	0.9777			0.4297		
F-statistics Prob.	0.0000			0.0000		

Note: ***, **, and *denotes significance at 10%, 5%, and 1% levels, respectively. P values are provided in brackets for diagnostic tests. ARDL estimation allows including dummy variables, while DARDL does not allow it.

Table 8
Robustness analysis (DOLS and FMOLS).

DOLS				FMOLS			
Variables	Coefficient	t-stat.	Prob.	Variables	Coefficient	t-stat.	Prob.
LnEGR	9.9307*	3.6378	0.0019	LnEGR	3.5623**	2.2964	0.0278
$LnEGR^2$	−0.6791*	−3.1441	0.0056	$LnEGR^2$	−0.201***	−1.7369	0.0912
LnGLOB	−0.5137**	−2.6061	0.0179	LnGLOB	−0.3167*	−2.8924	0.0065
LnGEN	0.0497	0.7880	0.4409	LnGEN	0.0283	1.3151	0.1970
LnFDV	−0.1411**	−2.8254	0.0112	LnDEV	−0.0872*	−3.8026	0.0006
Dummy	−0.0373	−1.1945	0.2478	Dummy	−0.0191	−0.8746	0.3877
C	−33.4142*	−3.9215	0.0010	C	−13.379*	−2.7268	0.0099
R-Square	0.9897			R-Square	0.9620		
AdjustedR^2	0.9776			AdjustedR^2	0.9555		

Note: ***, **, and * show significance levels of 10, 5, and 1 percent, respectively.

To ease policy directions, the causal association among the variables are estimated using the Hacker-Hatemi-J (HH) causality procedure. The HH is a modified version of the bootstrapped causality test suggested by Hacker and Hatemi-J [67]. Bootstrapping distributions ameliorate the problems associated with small samples endemic in the Wald test proposed by Toda and Yamamoto [68]. The HH technique applies a VAR model to estimate the modified Wald test statistics (see Table 1).

4. Results and discussion

We proceed by investigating the descriptive statistics as shown in Table 2. The table revealed statistics relating to the standard deviation, median, minimum, mean, and the maximum values of the data.

Table 2 indicates that GDP has the largest average of 6.227304 while financial development is the most volatile of the variables in the model. The ADF, PP, and Zivot and Andrews (ZA) tests, in Tables 3 and 4, respectively, have all confirmed that the varibales are trended, but stationary at I (1). These findings show that the null hypotheses of all the unit root tests cannot be rejected at 0.05% except at the first difference; confirming that all the variables have a stable mean at the first difference. Meanwhile, the ZA test in Table 4 revealed different break dates (1983, 1985, 1986, 1988, 1995, 2005, and 2010) which were considered while estimating the models.

Bayer-Hanck cointegration results in Table 5, confirmed the values of EG-JOH and EG-JOH-BO-BDM to be 55.5608 and 58.9826, respectively. These values are significant at the 0.01%, 0.05%, and 0.10% levels. Therefore, it is safe to conclude that the variables are cointegrated. The bounds test in Table 6 also confirmed the existence of a long-run relationship. It showed that the T- and F-statistics of the variables are more than the upper bound since the probability values are positive and significant. As such, the H_0 is rejected. Table 7 presents the ARDL estimates alongside the DARDL simulations results.

From results, economic growth increases the EFP in Bangladesh. Also, the square of economic growth is negative and statistically significant in the long run. The positive and negative coefficients of both variables confirm the existence of the EKC hypotheses for Bangladesh. This shows that economic growth initially declines environmental progress in Bangladesh, but promotes environmental quality over the long run period. Furthermore, globalization increases the EFP in the long run. Precisely, a 1% increase in globalization will trigger a 0.256% decrease in EFP. The implication here is that, globalization does not hurt the environment in Bangladesh but rather contributes to environmental betterment in the long run.

Analogous to the effect of globalization, the coefficient of green energy is negative, but not significant. This suggests that green energy can impede the EFP if consumed at a desirable level. On the flipside, the coefficient of FDV is negative and significant. A 1% increase in FDV will lead to a 0.0844% decrease in EFP, holding the effects of other variables constant. The result implies that FDV is not detrimental to environmental sustainability in Bangladesh. However, the coefficient of globalization is way larger than that of financial FDV, implying that globalization has more effect on the EFP in Bangladesh compared to FDV.

4.1. Discussion of findings

Interestingly, we discovered that green energy reduces the EFP in Bangladesh, although the effect is not significant. This finding confirms our thoughts. Over the years, Bangladesh has been overwhelmingly dependent on fossil fuels. Thus, it is germane for the country to reduce its consumption of non-renewable energy sources like coal, oil, natural gas, etc. The studies of Qing et al. [73], Opoku-Mensah et al. [74], Yadou [75], and Samour et al. [76] discovered a negative relationship between clean energy and EFP. Murshed et al. [32] acknowledged the importance of replacing fossil fuels with green energy sources in order to reduce emissions in Bangladesh. The transition to green energy can be achieved if the country reduces the employment of its imported oils for electricity generation purposes. The inability to reduce the oil import dependency can cause serious environmental problems, thus jeopardizing the country's prospects of achieving environmental betterment. The importance of reducing imported oil dependence in Bangladesh was emphasized by Mohazzem Hossain et al. [77].

To restore environmental harmony, transiting to modern and cleaner alternatives is required in Bangladesh. Renewable energy consumption in Bangladesh has always lagged behind those of its neighbors; including Sri Lanka, Myanmar, Pakistan, Bhutan, and India; which goes to show the meagre investment in the clean energy sector. Between 1971 and 2019, the share of hydropower fell from 16.95% to 0.96%, while the share of natural gas increased from 39% to 80% (32). Hence, the declining trend in the consumption

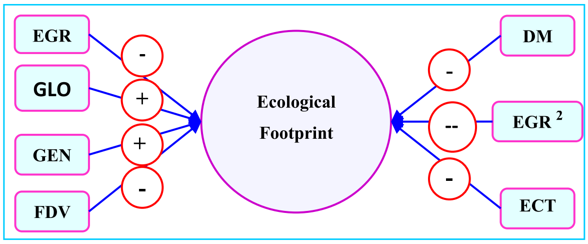

Fig. 1. Graphical results of ARDL long-run coefficients.

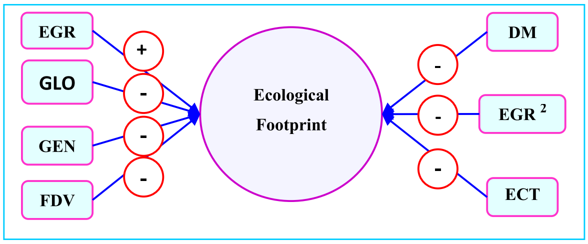

Fig. 2. Graphical results of ARDL short-run coefficients.

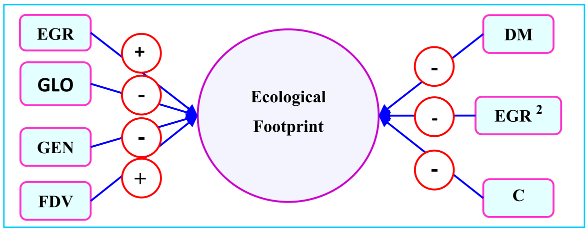

Fig. 3. Graphical long-run results of DOLS and FMOLS long-run.

of renewables reveals the inability of the country to increase its renewable energy output which is mainly due to infrastructural and technological constraints.

Unlike economic growth, financial development (LnFDV) reduces the EFP, as revealed in Tables 7 and 8. The negative coefficient indicates that an increase in FDV alleviates the EFP. This shows that FDV is consistent with environmental sustainability in Bangladesh. This outcome is parallel to the results obtained by Ramzan et al. [78] for Pakistan, Arogundade et al. [79] for Africa, and Ozturk et al. [80] for South Asia, but contradicts the findings of Wang et al. [81] for developing European countries. In practice, strengthening the financial system will help alleviate environmental challenges in Bangladesh.

A well-developed financial system provides funds for environmentally-friendly and energy-saving projects. Besides, firms that utilize energy-efficient technologies also obtain financial incentives from financial institutions which reduces business costs and reduces environmental deterioration [78]. Also, FDV attracts FDI inflows that accelerate investment in green technologies, R&D activities, and productivity [82]. As such, a functional financial institution, with the cooperation of banks and capital markets, can provide a pathway for environmental sustainability.

Also from the DARDL results, economic growth increases environmental degradation. Growth can actually deteriorate the environment by reducing the biocapacty especially when the components of growth are capable of deteriorating the environment. For instance, excessive exploration of natural resources, which is the case in Bangladesh, is capable of increasing the EFP [32]. This result is expected considering the fact that Bangladesh is ranked among the fastest-rising economies by the World Bank. Developing economies always concentrate on achieving more growth at their early stage of development while giving little or no attention to environmental wellbeing [30,83]. This finding complements the earlier studies of [26,27].

The World Bank [7] estimated the per capita real income of Bangladesh to be U$1288 in 2019 (in constant 2020 prices). From the estimated figure, it can be deduced that the country's current per capita real GDP is below the anticipated threshold beyond which the trade-off between environmental pollution and economic growth can be expected to be phased out [32]. In practice, the policymakers should execute expansionary monetary and fiscal policies to attain the envisaged growth thresholds. However, growth-enhancing policies should be aligned with environmental welfare policies.

On the flip side, when globalization promotes the importation and use of energy-intensive technologies, environmental degradation will worsen. For instance, Murshed et al. [32], Sabir and Gorus [84] and Kirikkaleli et al. [52] reported that globalization increased the

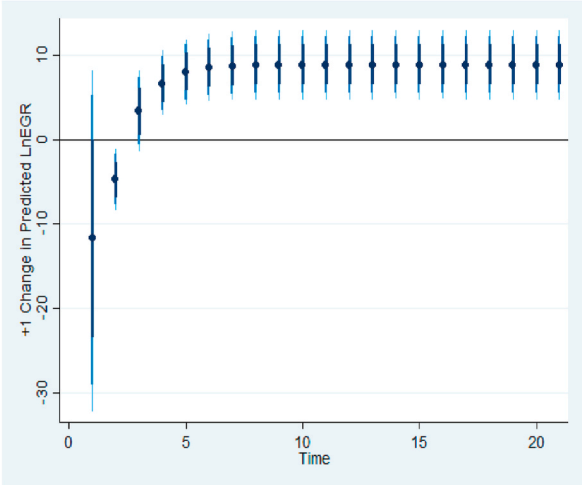

Fig. 4. +1 shock to LnEGR.

Table 9
Hatemi J (2012) causality test.

Direction of Causality	MWALD Stat.	Critical Values 1% 5% 10%
LnEGR to LnEFP	3.270	13.337 7.957 5.915
LnEFP to LnEGR	3.404	11.106 6.656 5.008
LnGLOB to LNEFP	3.841***	7.291 4.084 2.871
LnEFP to LnGLOB	0.394	7.323 4.138 2.837
LnGEN to LnEFP	0.038	7.440 4.100 2.892
LnEFP to LnGEN	0.076	7.564 4.175 2.839
LnFDV to LnEFP	4.566**	7.329 4.094 2.942
LnEFP to LnFDV	0.195	7.265 4.214 2.932
LnGLOB to LnEGR	2.289	10.535 6.609 5.031
LnEGR to LnGLOB	5.937***	10.752 6.520 4.886
LnGEN to LnEGR	0.140	7.879 4.260 2.898
LnFDV to LnEGR	0.042	7.686 4.237 2.958
LnEGR to LnFDV	0.003	8.199 4.250 2.935
LnGEN to LnGLOB	1.569	7.297 4.135 2.848
LnGLOB to LnGEN	2.426	7.362 4.294 2.920
LnFDV to LnGLOB	1.012	10.371 6.479 4.832
LnGLOB to LnFDV	7.338**	11.142 6.817 5.148
lnFDV to LnGEN	6.242***	11.163 6.619 5.014
LnGEN to LnFDV	0.056	11.327 6.736 4.997

Note: ** and *** refer to 5 and 10 percent significance, respectively.

EFP in Bangladesh, South Asia, the USA, and Turkey respectively, while Nathaniel [57] discovered the opposite for Bangladesh.

The results in Table 8 (DOLS and FMOLS) complement the findings in Table 7, especially the DARDL results. For instance, The EKC exists because LnEGR and $LnEGR^2$ turned out positive and negative respectively. Again, globalization reduces the EFP, whereas the effect of FDV remains negative in both models. Besides, the influence of green energy on the EFP in both estimators (DOLS and FMOLS) remains the same as those obtained in Table 7. The results of ARDL long-run and short-run estimations are presented in Figs. 1 and 2, respectively. Furthermore, the DOLS and FMOLS results are provided in Fig. 3. The graphical results of the DARDL analysis are presented through Figs. 4–13.

Table 9 shows the direction of causality among the variables. Financial development and globalization cause EFP, while economic growth drives globalization. Also, a one-way causality flows from globalization to FDV, just as FDV Granger causes green energy. These outcomes further exposed the strong link existing between globalization, FDV, and EFP in Bangladesh. Table 1A provided in the appendix confirms the consistency of our findings with the OLS assumptions. There is no direction of causality between economic growth and FDV. Globalization and clean energy have no direction of causality. Also, there is no direction of causality between economic growth and EFP, clean energy and EFP, and clean energy and economic growth. The causality results further confirmed the arguments in the literature that impact is different from causation [85,86].

Figs. 4 and 5 show a 10% downward and upward movement of economic growth and its influence on the EFP. The dots represent the mean prediction value, while the lines indicate the various confidence intervals.

Figs. 6 and 7 show a 10% downward and upward movement of the square of economic growth and its influence on the EFP. The dots

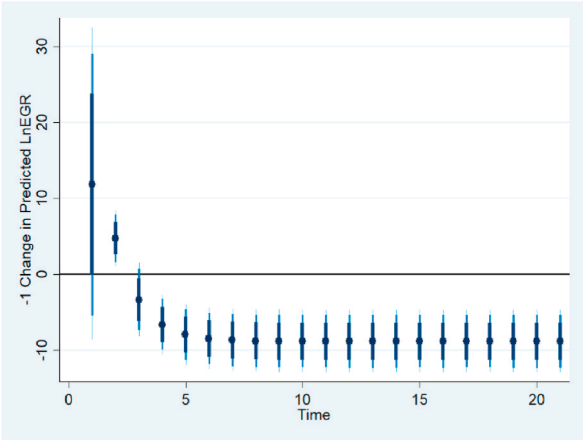

Fig. 5. −1 shock to Ln EGR.

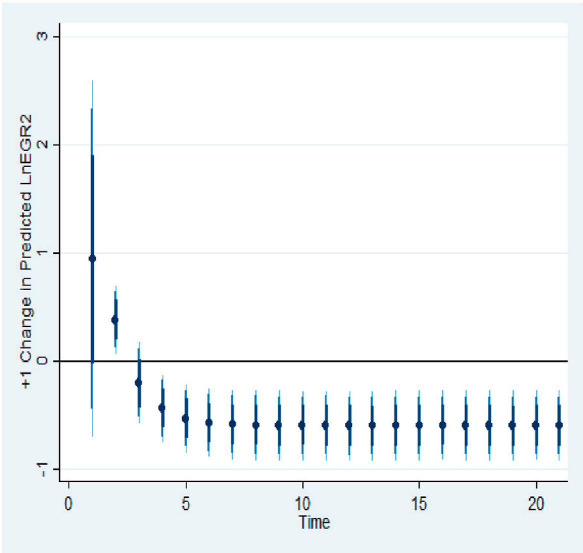

Fig. 6. +1 shock to LnEGR.[2].

represent the mean prediction value, while the lines indicate the various confidence intervals.

Figs. 8 and 9 show a 10% downward and upward movement in globalization and its influence on the ecological footprint. The dots represent the mean prediction value, while the lines indicate the various confidence intervals.

Figs. 10 and 11 show a 10% downward and upward movement in green energy and its influence on the ecological footprint. The dots represent the mean prediction value, while the lines indicate the various confidence intervals.

Figs. 12 and 13 show a 10% downward and upward movement in financial development and its influence on the EFP. The dots represent the mean prediction value, while the lines indicate the various confidence intervals.

5. Conclusion, policy recommendation, and limitations of the study

5.1. Conclusion

In recent times, attaining environmental sustainability has become a critical global issue. Developing countries, including Bangladesh, have rectified the Paris Agreement and also show commitments to achieving a green environment by consuming renewables and reducing fossil fuel consumption. Now, it is still not clear if the country's consumption of renewables over the years has contributed to mitigating environmental deterioration. As such, this study estimated the effect of green energy, economic growth, FDV, and globalization on the EFP in Bangladesh from 1975 to 2018, using some advanced time series econometric techniques including the Maki cointegration and the DARDL estimator.

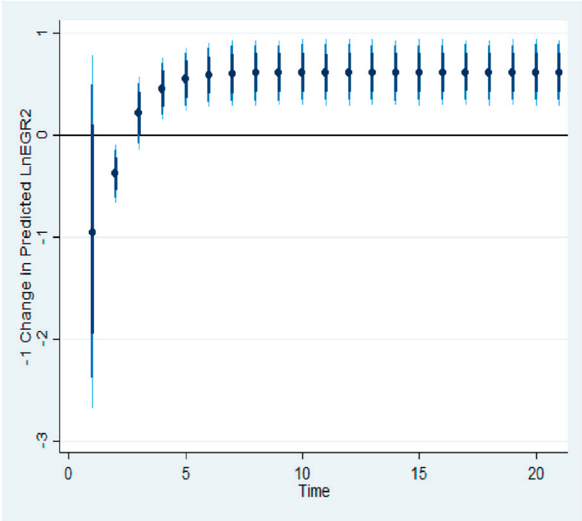

Fig. 7. −1 shock to LnEGR.[2].

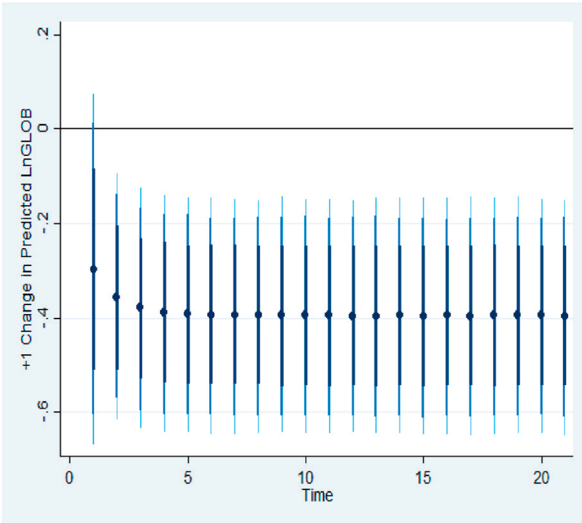

Fig. 8. +1 shock to LnGLOB.

To enhance the policy relevance of the study, we used EFP instead of CO_2 emissions preferred in previous studies. Besides, the FMOLS and DOLS techniques were applied to confirm the robustness of the findings. The empirical findings confirmed that green energy reduces the EFP in Bangladesh, although the effect is not significant. Globalization and FDV reduced the EFP, while economic growth increased the EFP figures. Also, Globalization and FDV drive the EFP, while economic growth Granger causes globalization. The findings further suggest a one-way causality from FDV to green energy, and from globalization to FDV.

5.2. Policy Recommendations

It is safe to conclude that declining the consumption of non-renewables, like fossil fuels, and promoting the consumption of cleaner energy is critical to achieving a sustainable environment in Bangladesh. Meanwhile, the overall outcomes from this research can be expected to encourage Bangladesh to comply with its commitments regarding the achievement of the environmental wellbeing targets that are listed in the United Nations SDG declarations and the Paris Agreement. Diversification of the national energy mix is required in Bangladesh.

This should involve replacing fossil fuels with cleaner alternatives like hydropower, solar, wind, and geothermal energy. To achieve this feat, government investment in renewables is inevitable. There is also a need to prioritize energy infrastructural development so as to encourage the integration of renewables in the country’s energy mix. A conducive economic environment that encourages the flow

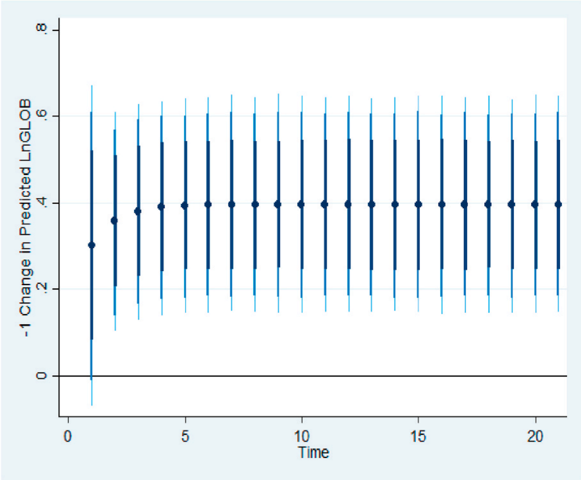

Fig. 9. −1 shock to LnGLoB.

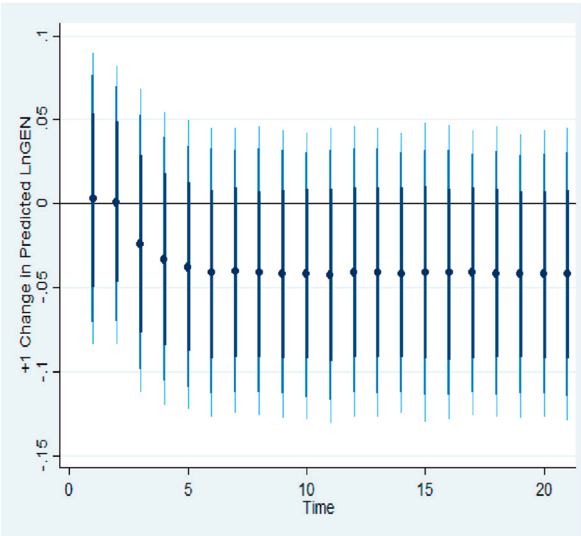

Fig. 10. +1 shock in LnGEN.

of FDI to the country's renewable energy sector would help ameliorate the country's technological constraints inhibiting the renewable energy transition in Bangladesh.

Another way to encourage renewable energy transition is for the government to promote bilateral or multilateral trade between Bangladesh and its South Asian neighbors, including Bhutan, Pakistan, Nepal, Maldives, Sri Lanka, and India, to enhance renewable energy importation. This intra-regional or cross-border trade could serve to reduce the country's EFP figures. The government should incentivize the consumption of renewables by giving low-interest loans to organizations involved in the consumption and production of renewables. This is of great importance because of the minimal involvement of the private sector in Bangladesh's energy sector.

Besides, public policies should focus on funding environmental-friendly technologies and green innovations. The funding must be on recently developed energy-saving technologies that can ensure complementarity between increased economic growth and environmental deterioration. The DARDL result statistically authenticated the EKC hypothesis. As such, it is recommended that policymakers in Bangladesh continue to focus on economic expansion without compromising the environmental attributes in the process. The proposed growth strategies are ideally to be themed on renewable energy consumption to gradually phase out the country's heavy reliance on fossil fuels and simultaneously restore environmental sustainability.

The study further revealed the importance of FDV in Bangladesh as it relates to environmental sustainability. Government policies to enhance the development of financial institutions, including the money and capital market, would contribute to environmental betterment without truncating the country's growth trajectory. The government must also ensure that policies to enhance economic growth are not achieved at the expense of the environment. Besides, financial resources should mainly be allocated to sectors engaged

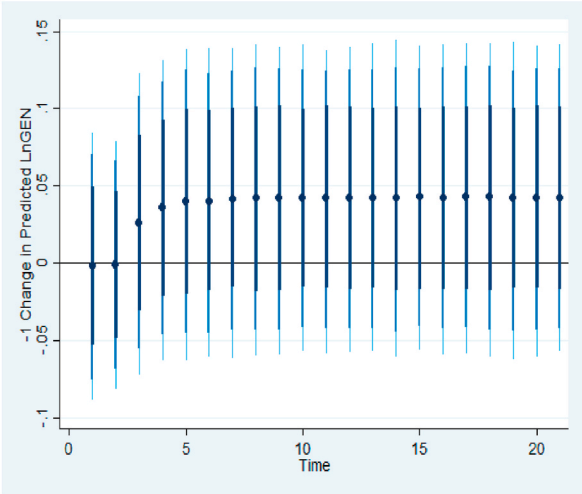

Fig. 11. −1 shock in LnGEN.

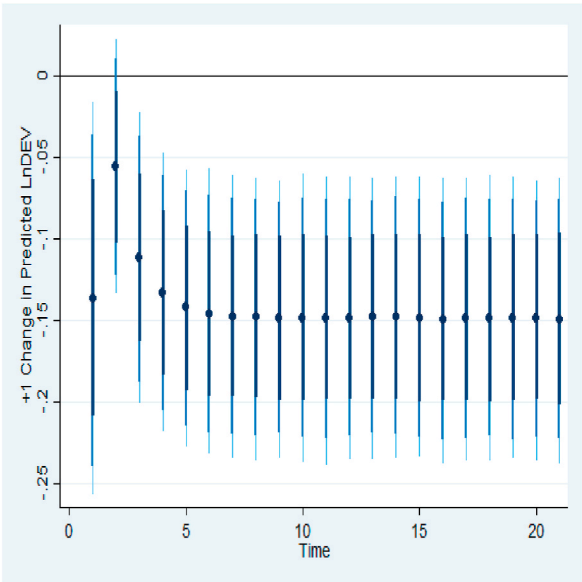

Fig. 12. +1 shock in LnFDV.

in environmentally-friendly activities. Also, there is a dire need to promote green finance in Bangladesh.

5.3. Limitations of the study

This study has its limitations. For instance, apart from data constraints, the study focused on assessing the overall environmental impacts of globalization by using the aggregated globalization index and did not delve into the individual contributions of trade globalization, political globalization, financial globalization, and social globalization. The research focused on a single developing country and the findings can be beneficial only for some other developing nations. In this regard, future empirical estimations can delve into the associations between each aspect of globalization and EFP for more detailed findings. Future research should be directed at the impact of clean energy on the various components of EFP while controlling for institutional quality. Scholars can also estimate the effects of various globalization subindices on both the sustainable development index and the load capacity factor.

Data availability statement

Data will be made available on a reasonable request.

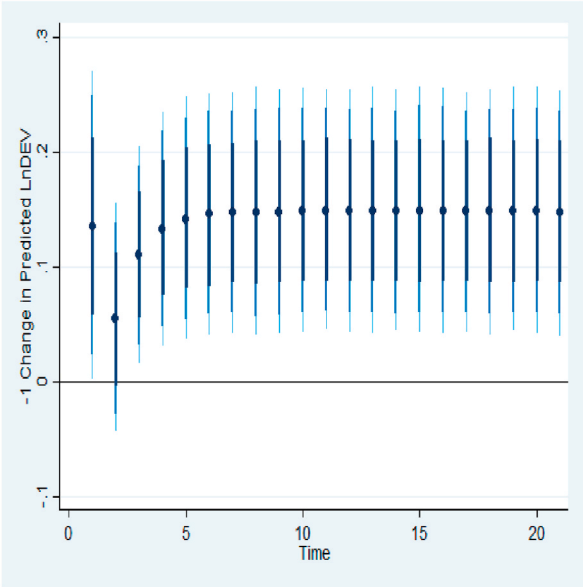

Fig. 13. −1 shock in LnFDV.

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Ethical approval

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

CRediT authorship contribution statement

Solomon Prince Nathaniel: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Zahoor Ahmed:** Writing – review & editing, Writing – original draft, Software, Investigation, Formal analysis. **Zilola Shamansurova:** Writing – original draft, Investigation. **Hossein Ali Fakher:** Writing – original draft, Methodology, Investigation.

Declaration of competing interest

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

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None.

Appendix

Table 1A
Diagnostic tests.

DW Statistics	1.8492
χ^2 ARCH	0.0467 [0.8299]
χ^2 LM	0.0298 [0.8649]
J-B Normality	0.5725 [0.7510]
χ^2 RESET	0.2996 [0.5888]
CUSUM	Stable
CUSUMSQ	Stable

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