Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03399-3

The effect of green energy production, green technological innovation, green international trade, on ecological footprints

Yadong Liu[1] · Asma Salman[2] · Kamran Khan[3] · Ch Kamran Mahmood[4] · Carlos Samuel Ramos-Meza[5] · Vipin Jain[6] · Malik Shahzad Shabbir[7]

Received: 29 January 2022 / Accepted: 18 May 2023

Abstract
The main concern of this research is to inspect the dynamic nexus among the green international trade, green technological innovation, as well as green energy production (GEP). This investigation employs dynamic least square and fully modified least square for data inspection. The dataset includes spans the years 2004 to 2021 and pertains to a sample of seven South Asian nations. Moreover, the empirical findings demonstrate a unfavourable nexus between environmental foot print (EFP) and GEP. Conversely, green international trade and green technological innovation have also an unfavourable significant relationship with EFP. Therefore, these findings suggest several strategy suggestions in regard to the territories of South Asia in the light of exact discoveries: to subsidize businesses for the establishment of sustainable tasks for the development of renewable power sources.

Keywords Green energy · Green international trade · South Asia · Green technological innovation

JEL Classification D47 · E12

1 Introduction

It is obsereved that economic growth is not discouraged by the strategies in the light of preservation energy. The preceding empirical works upheld the proof of the neutrality hypothesis, particularly with regard to sub-Saharan African nations. As of late, high-income countries of European states and North American states also supported the absence of a causal association between energy and growth relationship. Huang et al. (2022a; b) confirmed the evidence of the neutrality hypothesis for 73 nations using panel data-based dynamic estimation and found that low-income countries could not support. In contrast, Wolde-Rufael (2009) likewise used the variance decomposition test to demonstrate the existence of the neutrality hypothesis for 17 African (low-income) nations.

Although the adverse impacts of trade liberalization on environmental quality remain empirically unsettled as suggested by Andersson (2018), proper management of trade

Extended author information available on the last page of the article

Published online: 31 May 2023

liberalization policies could set a primary example in adopting the related ecological costs (Arslan et al., 2021; Bai et al., 2022; Butt et al., 2022; Cao et al., 2022; Chen et al., 2022; Dai et al., 2022; Forslid et al., 2018; Ge et al., 2022). For instance, Sadorsky (2011) provides evidence that trade restrictions and deregulation put pressure on the country's level of production and thereby intensify the total demand for energy in the trade-liberalizing countries. Nonetheless, if such an increase in demand meets a high use of non-renewables, then total greenhouse emissions could eventually go up and thus the need to scrutinize trade liberalization policies for environmental degradation. In contrast, production and consumption of national and imported GES to meet the higher energy demands can be used to cover relevant external costs, thus helping to promote the GET process at a global level (Jebli & Youssef, 2015; Liu et al., 2022a, b, c; Jun et al., 2021; Ji et al., 2022; Nawaz et al., 2021a, b, 2022a, b, c; Shabbir & Zeb, 2020).

Firstly, this area is the most vulnerable to the direct and indirect consequences of climate change (Khan et al., 2022). The region is already seeing the effects of climate change, including glacial melt, higher sea levels, wildfires, soil depletion, and other issues. In this region, irregular monsoon patterns are also rather common and considerably contribute to environmental harm (Liu et al., 2022a, b, c; Mughal et al., 2022; Muhammad et al., 2022a, b; Saleem et al., 2022; Sadiq et al., 2022; Shabbir and Wisdom, 2020; Yaqoob et al., 2022a, b; Yikun et al., 2021; Zamir & Mujahid, 2022). Its high density of people and pervasive poverty place further strain on its foundation of natural resources. The region's environmental conditions are also threatened by rising GHG emissions (Yan & Alvi, 2022).

The remaining enquiry is organized as follows: A thorough description of the current research is provided in the Sect. 2. The theoretical underpinnings of the study and suggested hypotheses are also covered in this section. Section 3 presents a summary of the study's methodology. Details on data sources and variable are also provided in this section. The empirical results of the investigation are described in Sect. 4. Section 5 of the research concluded with an evaluation of the empirical results. Future directions for research are also included in this section along with policy recommendations.

2 Literature review

The liberalization of trade boundaries to prompt more prominent two-sided and multilateral trade of products and services has been alluded to as a significant approach device to advance the dissemination of GES assets in the worldwide energy mix as archived in the current narratives (Karatayev et al., 2016; Zhang, 2018). While a few financial analysts voice the opinion that trade liberalization has unfriendly effects on nature (Kim et al., 2019; Kolcava et al., 2019), numerous researchers have reasoned that pointless exchange guidelines frequently hamper the progression of specialized aptitude and green energy resource assets, especially in middle- and low-income countries, which are transcendently dependent on conventional fossil fuel assets (Liu et al., 2021, 2022a, b, c; Nawaz et al., 2021a, b, 2022a, b, c; Painuly, 2001; Painuly, 2001; Shabbir & Wisdom, 2020; Wang et al., 2022; Yaqoob et al., 2022a, 2022b; Yaqoot et al., 2016; Yikun et al., 2021; Yu et al., 2020). The regular thinking set out in later research, discrediting the results attained in previous studies, has been the way in which international trade and natural corruption trade-offs could to a great extent be accounted for if the ecological expenses are disguised. Whereby, trade liberalization can cultivate more noteworthy utilization of GES rather than drive the market for fossil fuels more heavily. Therefore, cutting down tariffs and other trade obstructions demanded on GE imports, specifically, are regularly professed to be relevant in encouraging GET (Hashim & Ho, 2011).

Sohag et al. (2015) referenced exchange receptivity as an important macroeconomic approach instrument to encourage the innovative inflows, which are necessary to improve Asian countries' utilization of GES. Likewise, Coelho (2005) additionally opined that trade boundaries were unseemly in helping the transition from the usage of fossil fuels to biofuels among developing economies. However, as opposed to the previously mentioned positive discoveries, Pfeiffer and Mulder (2013) eluded trade receptiveness to denounce GET specifically among developing nations. It can, therefore, be concluded that the definitive impacts of trade liberalization on the general procedure of GET have been found to display heterogeneity across various research.

Aside from exploring the immediate relationship between trade receptivity and GET, plenty of studies have examined this relationship using an indirect methodology. These investigations underscored the effects of trade liberalization arrangements on CO_2 emissions, with the expectation that there will eventually be a decrease in carbon density following the economies' progression towards GET in terms of trade liberalization. The thought here is that the ignition of green energy source assets brings about lower rates of carbon emissions as well as other greenhouse emissions. Ho and Iyke (2019) in their study discovered factual proof with regard to trade receptiveness controlling CO2 discharges just over the long term in chosen Central and Eastern European countries, although strategies to trade liberalization in the short term appeared incapable of lessening the carbon emissions. Likewise, in China's Belt and Road Initiative, Sun et al. (2019) discovered the differentiating effects of trade transparency on CO_2 emissions.

Further, Padilla-Perez and Gaudin (2014) found a significant connection between innovations and economic growth in Central American economies. Through the use of questionnaires in their work, they checked the correlation between sustainable economic growth, science, technology, and innovation for countries in Central America. Irandoust (2016) applied the Granger non-causality technique in order to check the impact or role of technological innovation on energy sources, specifically renewable ones. Their empirical results suggest that technological innovation has a very important and effective duty in the nexus of green energy and growth. They employed real R&D spending as an indicator of technical advancement in the energy sector.

H1 There exists a significant relationship between green energy production and ecological footprints.

As a conclusion to the discussion above, the current research indicates that, to the highest of our knowledge, additional inspection in this area is necessary. This is due to earlier studies have employed CO_2 or GHG releases to gauge the decline in EQ. Therefore, the current inspection reexamined the relationship between GTI and ED adopting EFP as an indicator of the environment. As a result, it assumes that:

H2 There exists a significant relationship between green technological innovation and environmental degradation.

Qader et al. (2022) aims to forecast the emission of carbon. The results suggest the best performance of the nonlinear autoregressive model approach for forecasting carbon emanation in Bahrain. The findings of Murshed (2018) supported the EKC theory for South

Asian territories. Additionally, increasing the amount of clean energy used and generated was proven to be important in reducing the ecological footprints and carbon.

Additionally, the use of renewable energy could well be impacted by income disparity. For instance, societal attitudes including short-termism, individualism, and commercialism can be influenced by income disparity, which may then have an impact on the use of green or renewable energy (Muhammad et al., 2022a, 2022b). Less affluent populations struggle to gain from the adoption of renewable energy because of selfish behaviour (Yang et al., 2022). As a result, the power dynamics in between organizations will have an impact on how green energy is distributed. Additionally, clean energy is created from renewables, which can cut emissions from carbon footprint. Therefore, carbon intensity could play significant role in renewable energy (Wang et al., 2023; Xu & Zhong, 2023).

Concerning the effects of green trade on biodiversity loss, there is scant data in the literature. There have not been many studies on it. As far as we can tell, more research needs to be done on the GIT-ED linkage using an appropriate environmental proxy. As a result, the goal of the current study is to examine how GIT affects ED by employing EFP as a proxy for ED. Thus, it assumes that:

H3 There exists a significant relationship between green international trade and ecological footprints.

Abbasi et al., (2021a, 2021b, 2021c, 2021d) proposed that the issues related to ecological deterioration in significant economic complexity states could be mitigated by factors such as economic complexity, ecotourism, and energy prices. According to Iqbal et al. (2021), the results show how fiscal devolution, export diversification, and economic growth all have a favourable impact on carbon discharge in OECD economies. According to Abbasi and Adedoyin (2021), because of businesses' sustainability policies, the uncertainty of economic policy has a statistically minor impact on carbon discharges.

3 Methodology

This study contribute on three theoretical frameworks that form the basis of the current investigation are: "core macroeconomic theory, Porter hypothesis, and advancement of the H–O model by Siebert and Larrick (1992)". For GIT and GTI variables in this analysis, OECD statistics is adopted as well as GEP data are taken from WDI. Instead, the EFP variable enables access from global footprint network. This exploration employs dataset from 2004 to 2021 regarding south Asian nations including; Sri Lanka, Pakistan, India, Bangladesh, Nepal, Maldives, and Bhutan. Green energy production is taken as regressor, while regressand is ecological footprints. Whereas, green technological innovation and green internationa trade are control factors.

3.1 Econometric methodology

This review utilizes the methodology to procure the empirical consequences of the review.

$$\text{EFP}_{it} = f\left(\text{GEP}_{it,}\text{GTI}_{it}, \text{GIT}_{it}\right) \tag{1}$$

whereas green energy production is GEP; ecological footprint is EFP; green international trade is GIT; "t" is used for time period; "i" is used for cross-sectional unit; and green technological innovation is GTI.

This examination has changed all of the factors to their "ln" (natural logathimatic) structure to accomplish exact and precise outcomes. Subsequently, the experimental model of the research takes accompanying econometric structure in Eq. 2.

$$\ln\text{EFP}_{it} = f\left(\ln\text{GEP}_{it,}\ln\text{GTI}_{it}, \ln\text{GIT}_{it}\right) \tag{2}$$

3.2 Methodological foundation

The cross-sectional interdependence check is essential to obtain effective results because the CSD dilemma is highly prevalent in panel sets of data. To identify this issue, the current research employs the Pesaran CD appraisal and Breusch and Pagan (1980) investigation. CIPS, on the other hand, is more effective in capturing data on the integrated order of the sequence. In order to verify the series' stationary qualities, robustness, and integration order against the CSD problem, the current exploration uses CIPS.

$$y_{it} = \alpha_i + x_{it}B + u_{it} \quad i = 1, 2, 3, 4, \ldots, N; \quad t = 1, 2, 3, 4, 5, 6, 7, 8, \ldots, T \tag{3}$$

- y_{it} and x_{it} are integrated of similar order; $y_{it} = (1 \times 1)$ matrix encompasses regressand—x_{it} = vector of independent variables, where: $x_{it} = x_{it-1} + \varepsilon_{it}$
- $B = (k \times 1)$ slope vector
- u_{it} = error term that is assumed to be integrated of order zero

$$Y_{it} = \beta_i + \acute{X}_{it}\Upsilon + \sum_{j=-q_1}^{j=q_2} L_{ij}X_{it+j} + \mu_{it} \tag{4}$$

where vector of regressor is denoted by "X"; regressand is "Y"; and lag of the predictors at 1st difference is represented by "L".

4 Results and discussion

Table 1 displays our study variables descriptive statistics. Where GTI variable shows the maximum value in comparison with GEP, which has the lowest value.

The normality values and associated p values are shown in Table 2. Additionally, Jarque–Bera's are crosschecked in this investigation.

Table 1 Summary statistics

	LNEFP	LNGEP	LNGTI	LNGIT
Maximum	– 0.531	4.002	4.453	3.458
Median	– 0.823	3.265	2.045	3.531
Mean	– 0.821	3.023	2.184	1.501
Minimum	– 1.104	– 3.672	0.014	2.022
SD	0.123	2.431	0.715	0.128
Skewness	0.418	– 1.247	– 0.176	0.104
Kurtosis	2.154	4.218	2.361	4.370

Table 2 Examination of normality

IV	Jarque–Bera	Probability value	Decision
LNEFP	5.016***	0.0001	"Residuals are not normally distributed"
LNGEP	44.031***	0.0000	"Residuals are not normally distributed"
LNGTI	1.934	1.034	"Residuals are normally distributed"
LNGIT	1.554	0.458	"Residuals are normally distributed"

***Significance level at 1%

4.1 Examination of cross-sectional dependency

This investigation adopts the Pesaran CD and Breusch–Pagan LM test to uncover the difficulty of CSD under H_0 (null hypothesis) of "cross-sectional independence" (Table 3).

4.2 Examination of stationarity

The stationary aspects of the series, as shown in Table 4, are captured in the current research using CIPS, a 2nd-generation unit root investigation.

4.3 Test of cointegration

This research employs Westerlund's (2007) 2nd-generation cointegration framework in order to inspect the cointegrating nexus between the signified regressors in Table 5.

4.4 Hypotheses testing

There is a lot of disagreement among academics, but study by Wang et al., (2023) shows that EKC theories do exist in the 56 nations of the world. According to Yang et al., (2022)'s investigation, environmentally friendly energy can help the OECD region's reducing carbon emissions. Usman et al., (2022)'s exploration did, however, find that traditional energy sources are among the factors contributing to environmental damage in Arctic countries. Our study's findings are supported by Liu et al. (b, c), Muhammad

Table 3 Cross-sectional dependency test

Variables	Breusch–Pagan LM	Pesaran CD test	Outcome
LNEFP	24.045***	12.093	"Cross-section dependence"
LNGEP	20.374***	10.142	"Cross-section dependence"
LNGTI	17.734***	7.034	"Cross-section dependence"
LNGIT	16.803***	10.045	"Cross-section dependence"

***Signifies 1% level of significance

Table 4 Unit root examination of second generation

IV	At level		At first difference		Order of integration
	Without trend	With trend	Without trend	With trend	
LN (GEP)	− 1.363	− 1.920	− 4.910***	− 5.812***	I (1)
LN (EFP)	− 1.244	− 1.621	− 3.613***	− 3.134***	
LN (GIT)	− 1.281	− 1.472	− 7.034***	− 7.064***	
LN (GTI)	− 1.007	− 1.131	− 5.261***	− 5.071***	

Table 5 Second-generation cointegration

	Statistic	R.P.V
Gt	− 6.043**	0.028
Ga	− 7.235***	0.000
Pt	− 5.544***	0.000
Pa	− 3.986***	0.037
Decision	"Cointegration exists"	

Table 6 Hypotheses testing technique

	FMOLS DV: LNEFP		DOLS DV: LNEFP		Decision
	Coefficient	Probablity value	Coefficient	Probablity value	
Constant	0.634***	0.000	0.447**	0.023	–
LNGEP	− 1.257***	0.000	− 1.279***	0.005	H1: Supported
LNGTI	− 2.067***	0.006	− 3.117**	0.025	H2: Supported
LNGIT	− 1.128**	0.024	− 2.140***	0.002	H3: Supported
Adjusted R^2	0.625		0.724		–

**, ***Level of significance at 5% and 1%, respectively et al., (2022a, 2022b), Nawaz et al. (), Shabbir and Wisdom (2020), Wang et al., (2022), Yaqoob et al., (2022a, 2022b), Yikun et al., (2021), Yu et al., (2020), Zamir and Mujahid (2022). The decision made using the FMOLS and DOLS models is explained in Table 6.

5 Conclusion and discussion

This investigation makes an effort to provide a response to this research question; "Does green energy production, green international trade, and green technological innovation really matters for a carbon-free economy?" from 2004 to 2021. Accoringly, our empirical finding demonstrates a unfavourable nexus between EFP and GEP. Conversely, green international trade and green technological innovation have also unfavourable impacts on EFP (Table: 6) that supports the evidence that green technological advancement decreses environmental damage. Meanwhile, production in green sources of power also declines environmental damage.

The empirical results of this investigation point to the accompanying recommendations for South Asian states' policymakers. First, it is advised that the authorities of the South Asian states to offer various incentives to the firms to encourage the use of smart energy sources in manufacturing. Subsequently, the inspection suggest that states' governments levy a fine (for example, a carbon tax) on businesses that use unsustainable production methods. Then, these economies should spend more on R&D to promote green technology. Additionally, they ought to grant patents to various companies for the replacement of outdated machinery with newer technology. In order to support environmental sustainability, the administration of the region should encourage trade in greener or cleaner commodities.

Data availability The data are available on request from corresponding author.

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Authors and Affiliations

Yadong Liu[1] · Asma Salman[2] · Kamran Khan[3] · Ch Kamran Mahmood[4] · Carlos Samuel Ramos-Meza[5] · Vipin Jain[6] · Malik Shahzad Shabbir[7]

✉ Malik Shahzad Shabbir
shahzad.shabbir@ibnhaldun.edu.tr

Yadong Liu
lyd666666@qq.com

Asma Salman
asma.salman@aue.ae

Kamran Khan
kamran.khan0722@gmail.com

Ch Kamran Mahmood
arsalkamran@gmail.com

Carlos Samuel Ramos-Meza
Carlos.Ramosm@pucp.pe

Vipin Jain
vipin555@rediffmail.com

1 Department of Innovation, Enterpreneurship and Employment, Shadong Institute of Commerce and Technology, Yantai, China

2 Department of Business Administration, American University in the Amirates, Dubai, UAE

3 University of Teramo, Teramo, Italy

4 Department of Business Administration, Foundation University , Islamabad, Pakistan

5 Research Institute (IC-UAC), Universidad Andina del Cusco, Cusco, Peru

6 Department of Management, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India

7 Ibn Haldun University, Başakşehir, Turkey