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# The dynamic relationship among technological innovation, international trade, and energy production

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The primary objective of this study is to analyze the dynamic association among the green energy production (GEP), green technological innovation (GTI), and green international trade (GIT). This study uses fully modified least square (FMOLS) and dynamic least square (DOLS) for data analysis. This study uses the panel data set starts from 2000 to 2020 for eight south Asian countries. This study find a negative relationship between GEP and EFP. However, green technological innovation and green international trade have positive significant association. This study recommends several policy implications regarding the economies of south Asia (SA) based on empirical findings: to subsidize the industries for the installation of renewable projects for the production of renewable energies.

KEYWORDS

**green energy production, green technological innovation, green international trade, ecological footprints, south asian economies JEL classification: D46, E11**

## Introduction

In recent years, the world has observed a rapid increase in environmental issues as the global temperature has boosted and climate changes. Evidence shows that an increase in the level of greenhouse gas (GHG) emissions [e.g., carbon emissions ($CO_2$), nitrogen dioxide (NOx), and methane gas ($CH_4$)] are the main reason for global warming, which is a major cause of deterioration in environmental quality (Bai et al., 2022). Researchers have observed that developing economies are more likely to concentrate on increasing their economic productivity. For this purpose, they tend to increase their GDP, measured as per the head level of production of goods and services. Developing economies often use unsustainable production methods, i.e., different resources are extracted from the

environment during the production process. Researchers cited that besides the carbon emissions, unsustainable production and consumption patterns, anthropogenic or human activities, water scarcity, soil attrition, deforestation *etc.*, are also the reasons for ED (Ulucak and Khan, 2020).

Cao et al. (2022) explored a favorable association between energy consumption and environmental up-gradation in South Asian economies. Wu et al., 2021 exploration revealed that renewable energy has a favorable impact on reducing carbon emanations in the ASEAN region. Although, Usman et al., 2022 exploration confirmed that Conventional sources of energy are one of the determinants of environmental degradation in Arctic nations. These problems are not shocking for the developing economies, which are already dealing with ecological deficits due to unlimited demand for resources against limited resources (Nathaniel et al., 2021).

The present study employs a more suitable measurement of ED with the intent to answer "Does green innovation, Green trade, and Green Energy Production lead to a Carbon-Free Economy?" *The* current research is focused on the economies of South Asia for the following reasons: First, this region is the most sensitive to climate change's direct and indirect effects (Xue et al., 2021). Ice melting, rising sea levels, forest fires, soil erosion, and other climate change consequences are all present in the region. In this region, aberrant monsoon patterns are also fairly common, contributing significantly to environmental damage (Shabbir and Wisdom 2020; Muhammad et al., 2021, 2022; Yikun et al., 2021; Liu et al., 2022; Liu et al., 2022; Mughal et al., 2022; Sadiq et al., 2022; Saleem et al., 2022; Yaqoob et al., 2022). Its natural resource base is additionally strained by its high population density and widespread poverty. Increasing GHG emissions also poses a threat to the region's environmental circumstances (Nasreen et al., 2017). Keeping all the features in the mind, the present study observes that there is a dire need to provide a solution for this region's environmental conditions.

The structure of the remaining research is as follows: The second section gives a complete overview of the present research. This part also covers the study's theoretical foundation and recommended hypotheses. The study's methodological summary is presented in Section 3. This section also includes information on data sources and variable operationalization. The study's empirical findings are explained in Section 4. The study comes to a close with a review of the empirical findings in section 5. This part also includes policy recommendations and future research directions.

## Literature review

In consequence, ecological footprints, as a comprehensive tool to measure the deterioration in environmental quality have been introduced. This measure of environment gains the importance of the researchers during the second decade of the 20th century. The main benefit of this exclusive measure is that it captures the ecological data into a combined measure that can be easily compared with the analogous dynamic aptitude to highlight the fact that "how much of the ecosystem surface we use for sustaining life". Researchers pointed out the factors like renewable energies (Saleem et al., 2019; Zhang and Liu, 2019; Shabbir et al., 2020; Bai et al., 2022; Liu et al., 2022), advancement in environmental technologies (Khan et al., 2020), generation of human capital (Yao et al., 2020), specialization in environmentally friendly products (Anser et al., 2021), strict environmental regulations (Hashmi and Alam, 2019), and sustainable ways of production and consumption to deal with different environmental problems, specifically for the case of developing economies like South Asian Economies.

This section provides a comprehensive overview of the existing studies related to the work presented here. Many researchers have conducted their studies on the clean energy-environment nexus and regarded GE as an environmentally friendly source of energy that less significantly contributes to the level of carbon emissions. For instance, Destek and Sinha (2020) collected data from 24 OECD economies with the intention to investigate the contributions of green energy (GE) in the reduction of carbon emissions. Similarly, Nathaniel et al. (2020) also revealed a similar relationship between GE and CO2 for the case of the Middle East and North Africa region. Balsalobre-Lorente et al., 2022 research supports the existence of EKC hypotheses in the PIIGS region.

Summing up the above literature, the present study figures out that most of the researchers have conducted their studies on the nexus between environmental deterioration and green energy consumption with association between green energy production and ED. In addition to this, the results of the existing studies on GE-ED nexus do not reach a definite solution as some of the researchers concluded the positive, while, others concluded the negative relationship among these variables. Therefore, the present study attempts to contribute to the ongoing debate by analyzing the role of GEP on ED by employing its more suitable measure (e.g., EFP). Hence, it hypothesizes that:

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

The studies on the GTI-ED nexus are not very vast in the available literature. Many researchers have misinterpreted technological innovation (TI) with green technological innovation (GTI), but practically both are different. For instance, TI is defined as an advanced production process whose technical characteristics are significantly different from the existing offshoots. While GTIs are specifically confined to the innovation in environmentally friendly

technologies. However, most of the researchers have focused on explaining the contributions of TI on carbon emissions. For instance, Chen and Lee (2020) utilized the data of 96 nations with the purpose to analyze the role of TI on the level of CO2 emissions. After analyzing the data from 1996 to 2018 the study did not find any significant association between TI and CO2 emissions. While Yu and Du (2019) found that TI significantly increases the level of CO2 emissions in China. Zhao et al. (2021) investigated the role of financial risk and TI on the level of GHG emissions after employing the dataset of 62 nations from 2003 through 2018. Outcomes of the investigation revealed the significant contributions of TI in reducing the level of CO2 and NOx.

Summarizing the above debate present study figures out that only a few researchers have analyzed the role of GTI on the environment. To the best of our knowledge, this area requires further investigation by using a more suitable measure of the environment because previous researchers have used CO2 or GHG emissions to measure the deterioration in EQ. The present study, therefore, re-investigated the relationship between GTI and ED by using EFP as a measure of environment. Thus, it hypothesizes that:

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

Huang et al. (2022) empirically scrutinizes the association between environmental friendly source of energy, ICT (information and communication technologies), economic complexity, financial development, human capital, and ecological footprint for G-7 and E-7 countries. The study discovered, all potential factors considerably expand the ecological quality with the exception of financial development. Wen et al. (2022) discovers that an upsurge in FDI upturns environmental loss. Subsequently, the results support the presence of (PHH) Pollution Haven hypothesis in BRICS nations. Jiang et al. (2022) research findings support the asymmetric influence of environmental friendly energy on the ecology in the short run and long run for China. Liu et al., 2022 research examines if energy efficiency reduces carbon emanations while adjusting for population, economic growth, and trade. Accordingly, both short-run and long-run emanations are reduced through energy efficiency.

Summarizing the above debate, the present study figures out that there is limited evidence in the literature regarding the role of green trade on environmental deterioration. Hardly a few researchers have discussed it. As per our knowledge, the GIT-ED nexus requires further investigation by incorporating a suitable proxy of the environment. Therefore, the present study intends to analyze the role of GIT on ED by using EFP as a proxy of ED. Hence, it hypothesizes that:

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

# Methodology

The current exploration is grounded on three theoretical lenses i.e., "Core macro-economic theory, Porter hypothesis, and advancement of the H-O model".

This uses OECD statistics data set for GTI and GIT variables and WDI data set for GEP. However, global footprint network is gained for EFP variable. This study uses data set starts from 2000 to 2020 for countries of south Asian region such as; Afghanistan Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri-Lanka. The *Ecological footprints is a dependent variable and Green Energy Production as independent variable. While, Green technological innovation and Green international trade are control and policy variables of this study.*

## Econometric models

Present study employs following econometric model to acquire the empirical results of the study.

$$EFP_{it} = \mathrm{f}\left(GEP_{it}, GTI_{it}, GIT_{it}\right) \tag{1}$$

Where:

- EFP is ecological footprint in nation i at time period t
- GEP is green energy production in nation i at time period t
- GTI is green technological innovation in nation i at time period t
- GIT is green international trade in nation i at time period t

This research has transformed all the variables into their natural logathimatic form to attain more accurate and precise results. Therefore, the empirical model of the study takes following econometric form (see Eq. (2))

$$lnEFP_{it} = \mathrm{f}\left(lnGEP_{it}, ln\,GTI_{it}, lnGIT_{it}\right) \tag{2}$$

Where: ln represents the log transformation of variables.

## Methodological framework

The problem of CSD is very common in the panel data sets, the test of cross sectional dependency is, therefore, crucial to acquire efficient results. The present study employs Breusch-Pagan and Pesaran CD test to detect this problem. In the presence of CSD, so-called first generation unit root test [i.e., Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS)] does not provide the accurate conclusions about the integrated order of the series. Evidences shows that in the presence of CSD, second generation unit root test [i.e., cross-sectional Im, Pesaran and Shin (CIPS)] is more reliable to capture the information about the integrated order of the series. Therefore, the present study applies CIPS to check the series's stationary properties or integration order and robustness against the problem of CSD.

**TABLE 1** Descriptive statistics.

| | Lnefp | Lngep | Lngti | Lngit |
|---|---|---|---|---|
| *Mean* | −0.821 | 3.023 | 2.184 | 1.501 |
| *Median* | −0.823 | 3.265 | 2.045 | 3.531 |
| *Maximum* | −0.531 | 4.002 | 4.453 | 3.458 |
| *Minimum* | −1.104 | −3.672 | 0.014 | 2.022 |
| *Std. Dev* | 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 |

$$y_{it} = \alpha_i + x_{it}B + u_{it} \quad i = 1, \ldots .., N\,; t = 1, \ldots ., T \qquad (3)$$

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

$$Y_{it} = \beta_i + \acute{X}_{it}\varkappa + \sum_{j=-q_1}^{j=q_2} L_{ij}\Delta X_{it+j} + \mu_{it} \qquad (4)$$

Where:

- Y is dependent variable
- X is the vector of independent variable
- L is the lead or lag coefficient of predictors at first difference

# Results and discussion

## Values of descriptive statistics

The abopve table 1 describes the values and their importantace of all variables.

## Test of normality

Jarque-conclusions Bera's are cross-checked using pictorial assistance from box-blots in this study (Please see: Figure 1) the values of the normality test shown in Table 2 as well.

## Test of cross-sectional dependency

The present study employs the Breusch-Pagan LM and Pesaran CD test to detect the problem of CSD under the null hypothesis of "Cross-sectional independence". For more details, kindly see table 3 as below.

## Test of stationarity

The current study uses CIPS, a second-generation unit root analysis, to capture the series' stationary features as mentioned in table 4.

## Test of cointegration

This study uses second-generation cointegration technique to examine the cointegrating relationship between the represented variables in table 5.4.4Hypotheses testing

There is a long debate among scholars such as; Balsalobre-Lorente et al., 2022 research supports the existence of EKC hypotheses in the PIIGS region. Cao et al., 2022 explored a favorable association between energy consumption and environmental up-gradation in South Asian economies. Wu et al., 2021 exploration revealed that renewable energy has a favorable impact on reducing carbon emanations in the ASEAN region. Although, Usman et al., 2022 exploration confirmed that Conventional sources of energy are one of the determinants of environmental degradation in Arctic nations. The results of our study are supported by

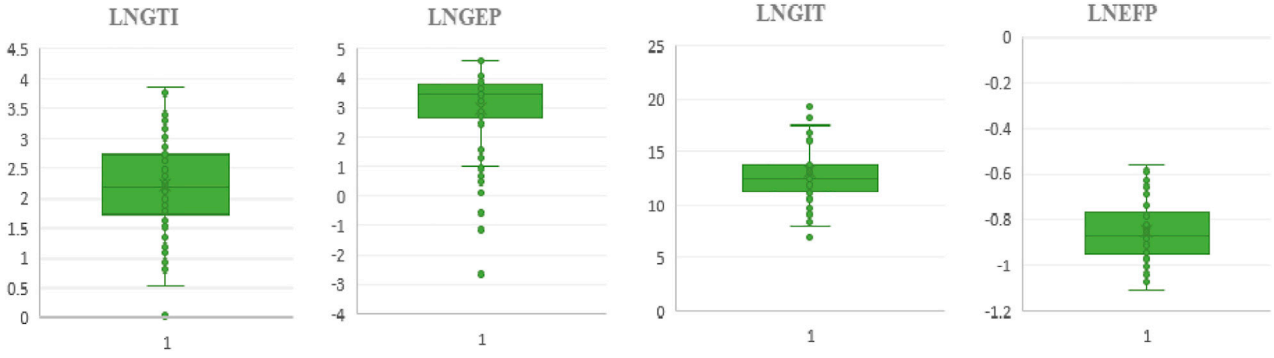


FIGURE 1
box plot.

**TABLE 2 Test of normality.**

| Variables | Jarque-bera | *p*-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"* |
| Where: *** shows the significance at the level of 1% | | | |

**TABLE 3 Analysis of cross sectional dependency test.**

| Variables | Breusch-pagan LM | *p*-value | Pesaran CD test | *p*-value | Outcome |
|---|---|---|---|---|---|
| LNEFP | 24.045*** | 0.0000 | 12.093 | 0.0000 | *"Cross-section dependence"* |
| LNGEP | 20.374*** | 0.0000 | 10.142 | 0.0000 | *"Cross-section dependence"* |
| LNGTI | 17.734*** | 0.0000 | 7.034 | 0.0000 | *"Cross-section dependence"* |
| LNGIT | 16.803*** | 0.0000 | 10.045 | 0.0000 | *"Cross-section dependence"* |
| Where: **, and *** represents the level of significance at 5% and 1% respectively | | | | | |

**TABLE 4 Unit root test of Second generation.**

| *Variables* | At level | | At first-difference | | Order of integration |
|---|---|---|---|---|---|
| | *Without trend* | *With trend* | *Without trend* | *With trend* | |
| LNEFP | −1.244 | −1.621 | −3.613*** | −3.134*** | *I(1)* |
| LNGEP | −1.363 | −1.920 | −4.910*** | −5.812*** | *I(1)* |
| LNGTI | −1.007 | −1.131 | −5.261*** | −5.071*** | *I(1)* |
| LNGIT | −1.281 | −1.472 | −7.034*** | −7.064*** | *I(1)* |

**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"* | |

(Nathaniel et al., 2020; Alola et al., 2019; Anser et al., 2021; Arslan et al., 2021; Chen et al., 2022; Dai et al., 2022; Ge et al., 2022; Jun et al., 2021; Khan et al., 2021; Khuong et al., 2021; Arif et al., 2020; Shabbir 2020; Sharma et al., 2021; among others). table 6 explains the decision on base of FMOLS and DOLS models.

## Conclusion and policy implications

This study is trying to answer of this research question; "Does green energy production, green international trade, and green technological innovation really matters for a carbon-free economy?". The empirical findings of this exploration suggest the following recommendations to the policymakers of South Asian Economies. First, it is suggested to the government of South Asian Economies to provide different incentives to the industries for the production by using efficient energy sources. Second, the study suggests that the states authorities should impose a penalty (i.e., carbon tax) on those industries that are using unsustainable ways of production. Third, these economies should increase their RandD expenditures for green technological advancement. They should also issue the patents to different industries for the up-gradation of the existing machinery, or for the installation of advanced machinery. Last

**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 R2 | 0.625 | | 0.724 | | -- |
| Note: "** and *** shows the level of significance at 5% and 1% respectively". | | | | | |

but not the least, the government of South Asian Economies should promote international trade in cleaner or greener products to promote environmental sustainability.

However, the present study suggests some future research directions to the upcoming researchers. "Nothing is perfect; nothing is imperfect. Perfection and imperfection reside in your perception." To begin, future researchers can do a replication of this study using a panel of other economies, such as the BRICS nations, to test the robustness of the results. They can also perform cross-country analysis to obtain more trustworthy or authentic results. Second, future researchers can compare the results of different environmental proxies. They might also look at some other aspects that can help them improve their EQ.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

ZM has completed the data analysis part, CS completed the Introduction section, XQ and VJ completed the Literature review section, PS wrote Methodology section, MS interpreted the data analysis section, SA wrote the discussion of results section, MM and AH wrote conclusions, future directions, limitations and abstract parts.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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