Sustainable finance, natural resource abundance, and energy poverty trap: the environmental challenges in the era of COVID-19

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Abstract
Energy poverty is a global challenge and the scarcity has been emerging as a global issue. Therefore, the relationship among energy scarcity, sustainable finance, and carbon emissions is analyzed with the help of global data from 40 developing countries until the beginning of the COVID-19 era. For empirical results’ estimation, the study analyzed a panel data ranging from 2000 to 2019. To measure the energy poverty, some part of population that has no access to energy is considered, and empirical analysis based on augmented mean group (AMG) regression method was carried out. The findings of the study suggest the inverse relation among energy poverty and carbon emissions. Moreover, a negative relationship was also observed between sustainable finance and carbon emissions. These findings highlight that alleviation of energy poverty can intensify environmental pollution. While improvement in access to clean energy will benefit society by alleviating energy poverty and controlling carbon emissions. Moreover, improvement in the share of sustainable finance in total investment may improve the environment quality by reducing carbon emissions. Therefore, it is suggested that regional plans along with sustainable finance are required on a priority basis for the promotion of clean energy to control carbon emissions and alleviate energy poverty at the household level.

Keywords Carbon emissions · Environment degradation · Energy poverty · Global data analysis · Sustainable finance

Introduction
Poverty alleviation has become one of the top challenges in all its forms to achieve sustainable economic development. At the current time, one of its concerning forms is energy poverty. Energy poverty is defined by different energy agencies, “lack of households’ access to energy and clean cooking facilities” defined by International Energy Agency (IEA 2010). In light of this definition, one can observe the deficiency of energy. This is a situation that shows the unavailability of sufficient energy to meet the basic requirements of daily life (Parajuli 2011). So it can be argued that energy poverty has become a global phenomenon and emerging challenge, particularly for developing nations. According to a report by United Nations (UN), population deprived of electricity is greater than 13% around the globe, whereas 2.6 billion people are using traditional biomass means of energy for cooking or to meet their energy and heat requirements. The majority of those individuals are living in Sub Sahara Africa, where around 570 million individuals have no access to electricity. In addition to this (Energy Progress Report 2021) defined electricity access deficit, around 36% of the global population are deprived of green energy and also they had no access to technologies for cooking 2019. This is one of the crucial reasons that “affordable and clean energy” is the 7th most important goal of United Nations Development Program that is sustainable development goal (SDG). Energy poverty is closely related to income poverty due to its affordability. This scenario prevails in country
bifurcation as well. Thus, lower-income countries tend to have higher energy poverty (Castaño-Rosa and Okushima 2021). However, there exists divergence in the outcomes of various studies (Ozturk 2010). Furthermore, energy poverty is an evolving concept; therefore, many studies focus on developing various techniques for the measurement scarcity of energy. The electricity is potentially a weaker indicator to measure energy poverty, as the limited availability or poor accounting methods do not reflect the share of traditional energy produced at micro level.

While the regions such as Latin America and the Caribbean along with Eastern and South Eastern Asian regions have the highest accessibility to electricity, where more than 95% of the total population is enjoying the facility of electrification. Since electrification is essential for economic growth due to its central role in industrial development, the employment generation process is often associated with greater access to electricity (Li et al. 2014). Thus, better employment opportunities positively affect income levels (Acheampong et al. 2021). In other words, availability of electricity for all is expected to spur economic growth. Availability of technology for green energy and for cooking is another dimension of energy poverty at the household level, which is a primary concern of the present study. The approach is different for different organization but the importance of energy remains the same, WHO-defined as the lack of clean cooking fuels and techniques can be attributed to the premature deaths of nearly 4 million people globally on annual basis due to various diseases. Thus, access to electricity and clean fuels could be used as good proxies for measurement of the energy poverty (González-Eguino 2015). The high energy demand may also lead to issues of environmental degradation. The majority of developing countries used traditional fossil fuels to generate energy; in such cases, it is expected that the alleviation of energy poverty could be harmful by increasing environmental issues. The one important aspect is to consider the improvement in access to energy is achieved by the cleaner or dirty energy inputs. The energy poverty could be improved by using clean energy production methods that may improve environmental quality along with improved access to green energy. However, the alleviation of energy poverty or improved access to electricity by means of using fossil fuels as input may improve the environmental issues. Therefore, one can assume that the role of sustainable finance, particularly the investment in clean energy projects, is also a very important factor in energy poverty alleviation and controlling carbon emissions at a macro level.

Therefore, the ongoing study presents the analysis and the impact of energy poverty, sustainable finance, and access to clean energy on carbon emissions with the help of the latest dataset from 2000 to 2019 in about 40 developing countries. Moreover, to overcome the cross-sectional dependence bias in panel data analysis, and to tackle the slope heterogeneity, the second generation of econometric methods such as augmented mean group (AMG) method with other methods such as mean group (MG) and dynamic fixed effect (DFE) is adopted to estimate robust results. As per the available literature, the earlier studies have mainly focused on either developing various measures of energy poverty and its prevalence or analyzing the causal association among growth nexus and energy producing varying results (Wang et al. 2015; Gupta et al. 2020; Shahbaz and Lean 2012 and Ozturk 2010). The importance of enhancing the use of clean fuels in household chores, particularly for cooking, has also been emphasized in various studies (Garba and Bellingham 2018; Deng et al. 2021). Keeping this aspect in view, the study follows the International Energy Agency definition, i.e., the part of the people living in this global world has no access to electricity, green energy, and tools for catering. The first objective of the study is to develop a relationship between carbon emission and energy poverty for both short-run and long-run. The second objective is to establish a short-run and long-run connection among access to clean energy and carbon emissions. The third objective is to configure the relationship between sustainable finance and carbon emissions. The fourth objective is to establish an association between natural resources consumption and carbon emissions. The fifth purpose is to show a relationship between energy intensity and carbon secretions for both time frame that are short-run and long-run. Moreover, it is also assumed that the role of sustainable finance is also very crucial in mitigating environmental challenges. Therefore, the results of the study highlight the role of sustainable finance, energy poverty, and clean energy access to mitigate pollution that is environmental particularly in the developing countries selected based on data availability. The rest of the study is organized as follows: The “Literature review” section encompasses the available literature review. Data sources and methodology have been given in the “Data and methodology” section. Empirical results and their interpretation have been postulated in the “Outcomes and discussion” section whereas the “Conclusion” section consists of a conclusion based on empirical findings.

Literature review

The subject of energy has attained a distinct status in economic literature due to its multiple influences on the economic development of various countries. Qurat-ul-Ann and Mirza (2020) carried out a meta-analysis of available work, mainly about developing countries, published from the period 2000 to 2019, and estimated energy poverty for empirical analysis. Their findings revealed that around 71% population according to different definitions may include in
the trends in cross provinces’ energy poverty in China. The China from 2000 to 2011 dropped its energy poverty and this was observed by the researchers. Nevertheless, the share of clean energy during that period remained negligible. Dogan et al. (2021) revealed that energy scarcity in Turkey was present in the range of 7 to 18% based on the difference in approaches employed for the measurement of energy poverty. They also observed that financial security was a significant determinant to observe the severity of energy poverty in the Turkish economy. The divided the energy poverty–stricken families into four groups in their study relating to India. They found a very high percentage of families, around 65%, who were living in extreme energy poverty conditions, belonging to the bottom two groups which is found by Gupta et al. (2020). Hanif et al. (2019) established an association between energy use and carbon seclusions in Asian developing economies. To mention the separate role of clean and dirty energy, they regressed renewable and nonrenewable energy sources with carbon emissions and mentioned that clean energy is essential for the emissions of carbon in Asian countries.

It is an essential component of the discussion of different variables as it is very important to accurately analyze energy poverty and to measure them so to find out its true relationship with other economic variables. Few studies developed different indices to measure energy poverty (Villalobos et al. 2021; Zhao et al. 2021; Gupta et al. 2020; Halkos and Gkampoura 2021; Wang et al. 2015), whereas Nguyen and Nasir (2021) preferred using various proxies to indicate energy poverty. For instance, a poverty index encompassing four broader dimensions of energy poverty was developed by Zhao et al. (2021). These dimensions were based on availability, completeness, affordability, and nature of energy, i.e., whether it is clean energy or not. The index for energy poverty was developed by Wang et al. (2015) relied on “availability,” “quality,” and “satisfaction.” Dogan et al. (2021) used the income-expenditure approach in three different ways to measure energy poverty. Gupta et al. (2020) used principal component analysis (PCA) method to develop a multi-dimensional energy poverty index for India. This index included 15 different indicators of energy poverty. Halkos and Gkampoura (2021) developed a composite index for energy poverty for 28 European nations. Faiella and Lavecchia (2021) incorporated an interesting aspect of heating requirement in income poverty measurement in the case of Italy and found the presence of about 3.00 million families that were experiencing fuel poverty from 2014 to 2016. However, few studies like Obeng et al. (2008) used the simplest measure for energy shortage, i.e., access to electricity for their studies based on Ghana and Brazil, respectively. Some studies relied upon other proxies of energy poverty including the accessibility of modern fuels such as the study of Chevalier and Ouédraogo (2009), while Parajuli (2011) used modern sources for cooking to capture energy poverty. Similar proxies have been used in recent studies. Nguyen and Nasir (2021) used 5 proxies, including access to electricity and clean fuels and technologies for cooking, to the measurement of energy poverty. The focus on the prices of electricity and gas to assess energy poverty was observed by Churchill and Smyth (2020), whereas the yardstick of availability of electricity and green energy for cooking was purposed by Papada and Kaliampakos (2016).

Generally, the concept of financial development is well known and it carries deep literature to highlight the secretion of carbon and the starring role of monetary enhancement. But, the present study aims to find out the reality by developing a relationship between sustainable finance and carbon emissions. It is considered that sustainable finance is the most concentrated form of financial development, as it considered only that proportion of financial development which is typically consumed to promote the technology and production of goods through cleaner production methods. The logic behind the consideration of financial development is that stable financial markets can attract more domestic and even foreign investment. Such an increase in financial development will bring more technology and innovation which will lead to efficient use of energy. Financial development encourages betterment in infrastructure and industrial development and it impacts the consumption of energy positively (Wu et al. 2020). Some studies have shown that financial development increases energy consumption (Coban and Topcu, 2013). Shabbaz and Lean (2012) observed a correlation between energy ingestion and financial advancement, and Islam et al. (2013) described that low energy consumption can be achieved by effective usage of energy and through financial development. Al-Mulali et al. (2013) perceived an upward or direct relationship for consumption and GDP in the long run. The study by Best and Burke (2018) also showed a direct association among electricity availability and economic growth. A panel data is analyzed and showed an inverse relation for energy poverty and GDP observed by Halkos and Gkampoura (2021) for 28 European countries. In the other study, Garba and Bellingham (2021) showed inverse relation for traditional fuel consumption and economic growth. Acheampong et al. (2021) found a direct relation among access to electricity and human development. Ferguson et al. (2000) also postulated similar results for the global economy with a distinction of comparatively robust correlation among income and electricity usage in the case of richer countries in comparison with others. Karanfil and Li (2015) also observed that heterogeneity exists in the relationship among electricity usage and economic growth concerning regional variation, urban population, etc. Thus, it can be observed that
various studies investigating the energy and growth nexus produce varied results. Moreover, the literature exhibiting the direct impact of green energy and tools for cooking on economic growth is limited. Only a few studies have attempted to capture the relationship. However, the majority of the available literature, indirectly suggests that clean fuels and technologies should be used for better economic performance as in studies by Garba and Bellingham (2018) and Deng et al. (2021). Energy intensity is another variable of concern that has an inverse relationship with economic growth (Deichmann et al. 2018; Díaz et al. 2019; Mahmood and Ahmad 2018).

In view of the above literature, it seems that the available literature on energy scarcity is quite inconclusive about the measurement of energy deficiency as well as its relationship with environmental issues. Therefore, the energy poverty and carbon emission relationship is still demanding the attention of researchers and policymakers to understand this channel in a precise way. Particularly, emphasis on the role of clean fuels and sustainable finance is almost jeopardized in the previous energy poverty works. Most of the research have shown the importance of clean fuels effect for cooking through the biomass fuels on economic growth rather than environmental issues. Therefore, the present study is an attempt to bridge this gap by exploring global evidence by incorporating the simplest approach to the measurement of energy poverty. Another contribution of this study is the usage of the latest data set with a AMG regression model to develop a relationship between sustainable finance, energy deficiency, and access to clean energy with environmental degradation, which has not been used in any of the available studies. The study tested the following hypotheses in long and short-term frameworks.

H10: Sustainable finance has an inverse relationship with carbon emissions.
H11: Sustainable finance has direct relationship with carbon emissions.
H20: The consumption of natural resources increases carbon emissions.
H21: The consumption of natural resources decreases carbon emissions.
H30: Carbon emission has negative association with energy poverty.
H31: Carbon emission has positive association with energy poverty.
H40: Improvement in access to clean energy reduces carbon emissions.
H41: Expansion in access to clean energy induces carbon emissions.
H50: Increase in energy intensity increases carbon secretions.
H51: Upsurge in energy intensity reduces carbon secretions.

**Data and methodology**

**Sources of data**

A dataset of 40 countries from 2000 to 2019 has been used to discover the linkages between energy poverty, sustainable finance, and carbon emissions. The selection of a period is based on the data available whereas the selection of countries has been made in light of availability to electricity. In this regard, all those countries have been excluded from the analysis to capture energy poverty that has availability to electricity which is almost 95%. This selection criterion is in line with the study of Nguyen and Nasir (2021) who did not include countries having 100% electricity or green energy for cooking. The data from 2000 to 2019 has been collected from different sources which are World Health Organization (WHO), Global Financial Development Database (GFDD), World Development Indicators (WDI), and the United States Energy Information. The sources of data for both dependent and all the independent variables are given in Table 1 that is given below.

| Variable | Name with the unit of measurement | Time period | Source |
|----------|-----------------------------------|-------------|--------|
| CO2      | Per capita metric tons (annual)   | 2000–2019   | WDI*   |
| SF       | Financial sustainable index based on profitability, liquidity, and risk (0 to 100 points) | 2000–2019 | GFDD   |
| NR       | Natural resources rent (%age of GDP) | 2000–2019 | WDI    |
| EP       | A proportion of the population has no access to electricity (% of the total population) | 2000–2019 | WDI    |
| CE       | The proportion of the population has access to clean fuels and technologies for cooking | 2000–2019 | WHO    |
| EI       | Energy intensity (1000 Btu/2015$ GDP PPP) | 2000–2019 | US EIA |

*WDI indicates world development indicators, 2020

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Model construction

The study used the model of Hanif et al. (2019) and Nguyen and Nasir (2021). Following the objectives of the present study, the models generalized functional form is as follows.

\[ CO_{2i,t} = f(SF_{i,t}, NR_{i,t}, EP_{i,t}, CE_{i,t}, EI_{i,t}, EP \times CE_{i,t}) \]  

(1)

The econometric form based on Eq. (1) can also be generalized as:

\[ CO_{2i,t} = \beta_0 + \beta_1 SF_{i,t} + \beta_2 NR_{i,t} + \beta_3 EP_{i,t} + \beta_4 CE_{i,t} + \beta_5 EI_{i,t} + \beta_6 (EP \times CE)_{i,t} + u_{i,t} \]  

(2)

In Eq. (2), energy poverty is measured in terms of various dimensions. However, this study concentrates on the dimension of accessibility. Accordingly, dependent variable is carbon emission (CO2) measured in metric tons per annum of carbon emissions per capita. Sustainable finance (FS) is measured in terms of an index that is based on profitability, liquidity, and risk. Natural resource (NR) consumption is measured by total rental fee gained from the utilization of extracted resources as a percentage of GDP. Energy poverty (EP) is measured in terms of the part of the inhabitants having no electricity. Clean energy (CE) access has been captured through the share of the population with contact to green energy and tools for cooking. Energy intensity (EI) is measured in terms of energy consumed to generate one additional unit of GDP (1000 Btu/2015$ GDP PPP).

For empirical analysis, a test proposed by Pesaran (2015) is applied to examine cross-sectional dependence. To test the heterogeneity across the panels included in the study, a test proposed by Pesaran and Yamagata is performed (2008). Furthermore, to test the unit root problem in cross-sectionally dependent data series, an augmented Cross-sectional I’m Pesaran and Shin (CIPS) unit root test is performed. Westerlund and Edgerton (2007) test is performed to examine the co-integration association among sustainable finance, energy poverty, natural resources consumption, and carbon emissions. Finally, to mitigate the cross-sectional dependence and heterogeneity in slope parameters across the cross-sections and to estimate unbiased results, the present study applied Augmented Mean Group (AMG) and Mean Group (MG) regressions. The results are presented and discussed in the next section.

Outcomes and discussion

The study used the model of Hanif et al. (2019) and Nguyen and Nasir (2021). Following the objectives of the present study, the models generalized functional form is as follows.

\[ CO_{2i,t} = f(SF_{i,t}, NR_{i,t}, EP_{i,t}, CE_{i,t}, EI_{i,t}, EP \times CE_{i,t}) \]  

(1)

The econometric form based on Eq. (1) can also be generalized as:

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Table 2 Summary statistics

| Variables | Obs. | Mean  | St. deviation | Min  | Max  |
|-----------|------|-------|---------------|------|------|
| CO2       | 720  | 38.632| 3.243         | 11.147| 45.899|
| SF        | 720  | 63.321| 4.932         | 28.438| 93.455|
| NR        | 720  | 21.721| 8.017         | 1.525 | 60.156|
| EP        | 720  | 20.816| 23.247        | 0.201 | 87.600|
| CE        | 720  | 42.268| 24.437        | 2.661 | 94.189|
| EI        | 720  | 2.540 | 2.005         | 0.186 | 11.886|

The results in Table 2 show that the minimum value of carbon emissions is calculated at 11.14 metric tons per capita, while the maximum value is observed at 45.89 metric tons per capita. The average values of the sustainable finance index, natural resources, and energy poverty are observed at the value of 63.21, 21.72, and 20.86 points respectively. To check the multi-collinearity in the pair of data series, results are given in Table 3 of correlation matrix.

In the above table, the values in the column and rows display that pairwise correlation matrix has a correlation with each other but the coefficients of correlation are less than the critical value, i.e., 0.8. Therefore, it is concluded that the proposed model is not having the issue of multicollinearity. Furthermore, to avoid estimation bias, cross-sectional dependence in the data is also observed, and in Table 4, the results are given.

In the above Table 4, test statistics are significant measured by the Pesaran’s (2015) test of cross-sectional dependence; therefore, the null hypothesis cannot be accepted which is of no cross-sectional dependence. According to the results, the data includes the cross-sectional dependence. This indicates that we cannot ensue with the first generation of econometric models to inspect the role of sustainable finance, scarcity of energy, and natural resources to increase or decrease environmental pollution in developing countries. In addition, the slope homogeneity across the panels is vital to evaluate the unbiased results; therefore, a test proposed by Pesaran and Yamagata which is a slope homogeneity test is applied and the results are shown in the Table 5 that is given below.

The results given in Table 5 are rejecting slope homogeneity null hypothesis; therefore, it can be elaborated that the model faces the issue of slope heterogeneity. This also indicates that the first generational estimation model may produce misleading results. After these preliminary tests, we also examined the stationarity in the data series by applying the second-generation unit root test Shin (CIPS) and augmented cross-sectional I’m Pesaran which produced unbiased results when panel data series experienced cross-sectional dependence. The results based on the unit root test are given in Table 6 that is given below.

In Table 6, variables are stationary at 1st difference which are natural resources, energy poverty (EP), clean energy access (CE), and energy intensity (EI), sustainable
finance (SF), and carbon emissions (CO₂). Therefore, a test to determine the long-run relationship is suggested by Westerlund and Edgerton (2007) and applied here to examine correlation among carbon emissions and other independent variables, and the results are given in Table 7.

In Table 7, all specifications of the results Pt, Gt, Ga, and Pa are showing no co-integration by rejecting the null hypothesis; therefore, the results confirm the cointegration relationship. The results of AMG, MG, and DFE are calculated in Table 8, and the results are given as follows.

In Table 8, the results of AMG show that sustainable finance has a negative relationship with carbon emissions. The long-run estimate depicts that a unit increase in sustainable finance has the ability to control emissions by about 0.234 metric tons per capita. The findings are aligned with the study of Amin et al. (2021), Alharthi and Hanif (2021), and Al-Mulali et al. (2016). The findings advocate that the increase in sustainable finance is a significant factor that may prove helpful for developing economies to control environmental issues by reducing carbon emissions. Furthermore, the results showed that natural resources and carbon emission have positive and significant association with each other. These findings show that a rise in the utilization of natural resources may enhance carbon productions in developing countries, and the results are similar to the study of

| Table 3 Results of the correlation matrix |
|------------------------------|----|----|----|----|----|----|
| GDP | LFP | CF | CE | AE | EI |
|----|----|----|----|----|----|
| CO2 | 1.000 | | | | |
| SF | 0.087 | 1.000 | | | |
| NR | 0.266 | -0.063 | 1.000 | | |
| EP | -0.124 | -0.373 | 0.156 | 1.000 | |
| CE | -0.094 | -0.422 | 0.093 | 0.698 | 1.000 |
| EI | -0.147 | -0.011 | 0.003 | 0.411 | 0.274 | 1.000 |

| Table 4 Results of the CD test |
|------------------------------|----------------------|
| Variables | Statistic |
| CO2 | 4.81*** |
| SF | 8.27*** |
| NR | 4.05*** |
| EP | 6.44*** |
| CE | 5.32*** |
| EI | 4.01*** |

1% level of significance is represented by ***

| Table 5 Slope heterogeneity test results |
|------------------------------|----------------------|
| Delta | P-value |
| Delta tilde | -4.29*** | 0.000 |
| Delta tilde adj | -6.05*** | 0.000 |

1% level of significance is represented by ***

| Table 6 Results of CIPS unit root tests |
|------------------------------|----------------------|----------------------|----------------------|
| Variables | Test | At level | 1st difference | Conclusion |
| CO2 | CIPS | 1.376 (0.928) | -0.142 (0.583) | -3.758** (0.043) | -5.932*** (0.000) | 1(I) |
| SF | CIPS | -0.863 (0.194) | 1.282 (0.091) | -6.483*** (0.000) | -6.277*** (0.000) | 1(I) |
| NR | CIPS | -2.451 (0.007) | -2.798 (0.003) | -6.775*** (0.000) | -7.248*** (0.000) | 1(I) |
| EP | CIPS | -1.708 (0.043) | 1.531 (0.063) | -8.605*** (0.000) | -7.540*** (0.000) | 1(I) |
| CE | CIPS | 0.635 (0.737) | -2.628 (0.004) | -5.398*** (0.000) | -7.661*** (0.000) | 1(I) |
| EI | CIPS | 1.533 (0.937) | -0.198 (0.421) | -2.792** (0.003) | -7.571*** (0.000) | 1(I) |

**, *** indicate significance at 5%, and 1% respectively
Badeeb et al. (2020), Guan et al. (2020), Huang et al. (2020), and Shao and Yang (2014). The results further show that a unit growth in natural resources rent may foster carbon release of about 0.45 units if all other factors are considered constant. This highlights that the massive depletion of natural resources to promote per capita income is a substantial cause of high carbon emissions in developing countries. The most interesting outcome is an association among energy poverty and carbon emissions. There is a negative association in developing countries among energy poverty and carbon emissions. The results are obvious as the developing countries improve energy access through fossil fuels; therefore, the inverse association between energy poverty and carbon emissions is apparent (Hanif et al. 2019). The results reveal that 1-unit increase in energy poverty reduces carbon release by 0.73 units. The results also show that improved contact to green energy helps to control carbon emissions as there exists a negative correlation between these variables, and the results are in line with Salim and Rafiq (2012), Hanif et al. (2019), Alharthi and Hanif (2020), Hanif (2018a, b, c), and Hanif (2018a). However, the results also show that a unit increase in green energy availability has the potential to shrink carbon productions by about 0.36 units by keeping other factors constant. The findings spotlight that improvement in access to clean energy will be helpful to mitigate carbon emissions in developing countries. The results also show a positive relationship between per capita energy use to produce goods and carbon emissions, and findings are also advocated by the work of Li et al. (2022), Nathaniel and Iheonu (2019), Hanif (2018b), Pata (2018), and Hanif (2017). It means that the addition in energy intensity is a major cause of high carbon emissions in developing countries. Moreover, an interaction term was introduced to highlight the importance of clean energy access and energy poverty to reduce carbon emissions. The negative coefficient of interaction term highlights that improvement in access to clean energy will help to reduce carbon emissions and also assist to reduce energy poverty in developing countries. The long-run results of the present study show that the high energy intensity to produce goods is a primary challenge for developing countries to control carbon emissions and concerning environmental issues. Developing countries need to adopt clean production methods which usually required less energy and are considered efficient to lower the level of energy intensity and mitigate carbon emissions. In other words, the energy-efficient industry will promote clean production at a macro level and the use of efficient home

| Table 7 Tests for cointegration |
|-------------------------------|
| Dependent variable CO2        |
| Statistic based on groups     |
| Statistic based on panels     |
| Test statistic                |
| Gt                            |
| Ga                            |
| Pt                            |
| Pa                            |
| P-value                       |
| 0.00                          |
| 0.00                          |
| 1% level of significance is represented by *** |

| Table 8 Long-run and short-run results |
|---------------------------------------|
| Dependent variable: CO2 emissions     |
| Variables                            |
| AMG                                   |
| Coefficient | SE  | Coefficient | SE  | Coefficient | SE  |
| Long-run coefficients                  |
| SF                                      |
| −0.243*** 0.134                   |
| −0.173** 0.093                   |
| NR                                      |
| 0.451** 0.227                  |
| −0.271*** 0.102               |
| −0.125* 0.073                  |
| EP                                      |
| −0.737*** 0.321                 |
| −0.331** 0.148               |
| −0.125* 0.073                 |
| CE                                      |
| −0.365*** 0.101                |
| −0.125* 0.073                |
| −0.141 0.093                  |
| EI                                      |
| 0.583* 0.338                  |
| 0.311 0.217                   |
| 0.254 0.163                  |
| EP*CE                                 |
| −0.321*** 0.119              |
| −0.121* 0.073               |
| −0.028* 0.016               |
| Short-run coefficient              |
| ∆SF                                   |
| −0.034*** 0.012                 |
| 0.036** 0.019                |
| 0.004 0.003                  |
| ∆NR                                   |
| 0.254 0.168                   |
| 0.142 0.098                 |
| 0.032 0.017                  |
| ∆EP                                   |
| −0.249** 0.142                |
| 0.051* 0.029                |
| 0.153* 0.091                 |
| ∆CE                                   |
| −0.196 0.122                   |
| 0.043 0.031                 |
| 0.094 0.072                  |
| ∆EI                                   |
| 0.161 0.099                   |
| 0.117 0.088                 |
| 0.166 0.104                 |
| ∆EP*CE                                 |
| −0.022* 0.013                  |
| 0.058*** 0.021               |
| 0.007* 0.004                 |
| ECT                                   |
| −0.249*** 0.081                |
| −0.092** 0.046               |
| −0.031* 0.018                |

*, **, *** depict 10%, 5%, and 1% significance levels respectively. ∆ as a difference operator. The estimates of AMG are obtained from the xtmg command in Stata. The first panel shows the long-run relation and speed of adjustment. The second panel represents the shorts-run parameters. Here, SE denotes standard error.
appliances will lessen the energy demand. Such initiatives at macro and micro levels may generate a major difference to reduce energy intensity and alleviate energy poverty. The long-run estimates also emphasized that regional efforts are inevitable to increase the share of clean energy in the total energy system to alleviate energy poverty through improved access to environment-friendly electricity. In the short run, the results of AMG show that sustainable finance, energy poverty, and interaction term have a negative and significant association with carbon productions in developing countries. While the effect of natural resources and energy intensity are insignificant factors that have a positive association with carbon emissions in the short-run period. Availability of green energy to all has an insignificant and inverse association with carbon productions. The coefficient of error correction term (ECT) carries a negative sign and possesses a significant relationship with carbon emissions. The estimated model is converging towards the equilibrium path with a speed of 24% per annum shown by the negative sign. The observed outcomes indicate that sustainable finance and energy poverty increase carbon emission and are significant factors in the long-run as well as short-run periods.

**Conclusion**

The study determined a relationship between sustainable finance, natural resources, energy poverty, and carbon emissions in developing countries. To measure energy poverty, a proportion of population deficiency with primary access to clean fuels for cooking is used to develop its association with environmental degradation. The study also used DFE, MG, and AMG estimation methods to estimate reliable results. These results show that the economies with severe energy poverty are consuming less energy at the household level. Therefore, the findings advocate that high energy poverty has a negative relationship with environmental degradation. However, the findings show that improved access to clean energy is an important aspect to control carbon emissions. Therefore, the study concludes that the alleviation of energy poverty in developing countries could only be environmentally friendly if access to clean energy will increase in such countries. Otherwise, the efforts to alleviate energy poverty could increase the severity of environmental challenges in the form of high carbon emissions, if energy access will improve through fossil fuels. The findings also highlighted that excessive use of natural resources is significantly contributing to massive carbon emissions and boosting environmental issues. According to the findings of the present study, the high energy intensity to produce goods is also challenging for developing countries to overcome environmental issues. To lower the level of energy intensity, developing countries need to adopt such production methods which required less energy. In other words, the energy-efficient industry and home appliances may generate a major difference to reduce energy intensity at the macro and micro levels. In light of the results, it is recommended that efforts should be made to increase access to clean energy and to alleviate poverty at the regional level. Although renewable or clean energy sources are expensive, therefore, joint efforts by developing countries are essential to meet the environmental challenges and to reduce the severity of energy poverty. Such joint efforts in the form of relaxed and subsidized policies to import renewable infrastructure, photovoltaic panels, and advanced machinery at the domestic level may prove a helpful policy framework to alleviate energy poverty through improved access to clean energy sources at the domestic level. There is also a need to communicate the importance of renewable energy sources at the grass root level; this will motivate the national industry and domestic individuals to adopt clean energy sources to meet their energy demands. Such efforts may prove helpful to alleviate energy poverty, diminishing natural resource depletion, and suppress the surging environmental issues in developing countries. Nevertheless, the study has a few limitations, and the results may be further improved by considering other important variables like urbanization, institutional quality, carbon taxing, carbon literacy, and employing refined measures of energy poverty.

**Author contribution** Xie Baiwei: initial draft preparation, review of literature, data collection, and tabulation; Imran Hanif: methodological framework and technical advice. Sarah Wasim: econometric result estimation, hypothesis testing; Sidra Rehman: result interpretation and diagnostic testing.

**Availability of data and materials** Not applicable.

**Declarations**

**Ethical approval** This is an original work that has not been submitted anywhere else for publication.

**Consent to participate** All authors have contributed to the submitted paper. There is no conflict of interest to disclose.

**Consent for publication** The paper is submitted with the mutual consent of the authors for publication in Environmental Science and Pollution Research.

**Competing interests** Not applicable.

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