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Environmental sustainability amidst financial inclusion in five fragile economies: Evidence from lens of environmental Kuznets curve

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ABSTRACT

Economic growth comes with it environmental trade-off on environmental sustainability. This occurrence is evidence on a global scale as it stems from human anthropogenic activities driven by the consumption of energy sources from fossil-fuel origin. On this premise, the present study focuses on five fragile economies with huge energy and sustainability targets to explore the nexus between economic growth and the environment. The present study is distinct from previous studies in scope by the construct and inclusion of a financial inclusion index with the aid of Principal component analysis (PCA), human development to the economic growth-environment argument. To this end to reach evidence-based outcomes second generational panel analysis is employed. The Durbin-Hansen cointegration test traces the long-run equilibrium relationship between the study variables. Subsequently, an augmented mean group (AMG) estimator is employed to explore the relationship between the outlined variables. Furthermore, the present study finds support for the pollution haven hypothesis for the selected fragile economies. The plausible explanation is due to weak trade and environmental treaties in the examined countries. However, the renewable energy human development index help mitigates environmental degradation. Thus, the present study advocates the need for energy transition and investment into new technological innovation in research and development to attain sustainable development goals and environmental sustainability resonated in UNSDGs-11,12 and 13. Additionally, financial inclusion plays a vital role in the five fragile energy-environment mixes. The current study presents vital policy directives in the concluding section for individual countries and the entire bloc for more effective policy direction.

1. Introduction

Economic growth is based on globalization, industrialization, human development, natural resource utilization, and technological improvement [1] and financial development is an important part of economic development [2] since finance is evaluated as one of the main drivers for development worldwide [3]. Financial inclusion, which is a component of financial development, comes to the world agenda as the cause of poverty in the 2000s [4] and explains the improvement in quantity, quality, and efficiency of financial goods and services triggering the development of financial sectors and institutions [5]. Financial inclusion is interrelated with financial resilience and climate change resilience and handling climate change can increase through financial inclusion and financial resilience [6]. As a new adaptation strategy for climate change, financial inclusion can decrease environmental degradation and economic growth [7,8]. Building a sustainable world is one of the vital aims due to the loss of natural resources and environmental pollution [9,10]. Thus, reducing the effect of climate change is a crucial policy for environmental challenges and economic growth. When economic activities increase, retraining greenhouse gas emissions (GHG) such as carbon dioxide emissions becomes the main aim of environmental sustainability in the world [11] and financial barriers are the significant obstacles to using an eco-friendly systems such as solar home systems and environmental sustainability [12].

The drivers of the United Nations' Sustainable Development Goals (SDGs) are 17 and eight of the 17 goals are about financial inclusion.

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SDG 1 focuses on the financial inclusion adaptation strategy for climate change, which can reduce poverty [7]. SDG 6 contains the stimulating effect of financial inclusion on the management of water and sanitation. SDG 7 includes that financial inclusion supports access to funding for sustainable energy. SDG 8 is about helpings to investments in financial inclusion. SDG 9 emphasizes encouraging sustainable industrialization and eco-friendly improvement with coming financial inclusion. Financial inclusion's promoting effect on sustainable cities and societies is mentioned in SDG 11 and the SDG 12 asserts that financial inclusion supports sustainable production and consumption patterns. Finally, according to SDG 13, financial inclusion advocates minimizing climate change effects [13,14]. These situations indicate that affordable financial goods and services trigger the use of clean technologies and the adoption of environmental protective services [15].

The debate on the relationship between financial inclusion and environmental sustainability is observed by Refs. [16–22]; and [7,15,23]; and [24] since the determining ambiguous environmental consequences of financial inclusion is a vital debate. At the household level, if financial inclusion is high, the household can purchase electrical appliances and use energy-intensive commodities and this situation triggers higher GHG [15]. Also, at the firm level, financial inclusion can stimulate investments in industrial processes, which mean an increase the GHG such as carbon emissions (CO2) [25]. Thus, financial inclusion is evaluated as an affecting factor in environmental well-being [26]. However, in the literature, there is also an opinion that the barriers to green finance and energy efficiency technology are loosened by financial inclusion [27] and financial inclusion has an increasing effect on accessing, affording, and adopting better environmental practices, which decrease the climate change [28]. Thus, the relationship between financial inclusion and environmental sustainability could be negative or positive and there is theoretically no consensus about the nexus of financial inclusion on environmental sustainability [29].

Climate change brings burdens to developing countries and fragile economies have little effort to mitigate the effects of climate change [30,31]. Climate change's effects are immense in fragile countries such as fragile five economies, where governments try to ensure social services as the cause of deeper fragility and an environment of violent conflict. This effort makes solving climate and environmental issues difficult for governments since fragile countries try to resolve the fragility crisis. Also, fragile economies do not have capable of resolving the climate and environmental issues and the fragility crisis altogether [32]. Moreover, fragile economies are highly exposed to climate risks due to multifaceted challenges such as livelihood risks and agriculture, which are linked to climate change [33,34]. Thus, having a fragile economy, being an underdevelopment country, and vulnerability to climate change's effect is extremely correlated [35].

The share of envirenmantal degradation of fragile economies in the world is %9.22 [36] and Turkey, South Africa, Brazil, Indonesia, and India are fragile five economies. As a developing country, South Africa is one of the important contributors to GHG and environmental pollution [37]. Also, Brazil takes important precautions regarding climate change (https://climateknowledgeportal.worldbank.org/country/brazil) and the [38] reports that the Mediterranean Basin is significantly impacted by climate change and thus, Turkey exposes to the big climate change risk [39]. Moreover, Indonesia is vulnerable to the effect of climate change [40]. Finally, the industrial process sector significantly increases GHG in India over the decade. In this way, these countries are exposed to the effects of climate change and environmental degradation.

In brief, the nexus of financial inclusion and environmental sustainability may achieve the SDGs in two ways. The first way is that financial inclusion increases sustainable development through affordable financial goods and services [4,41] and the second way is that environmental sustainability accelerates sustainable development with environmental protection policies [42,43]. These situations bring to the agenda that as a phenomenon, financial inclusion could affect environmental sustainability. Moreover, the share of GHG emissions of fragile economies in the global share constitutes % 9.22, and this situation makes focusing on the relationship between financial inclusion and environmental sustainability for fragile five countries, which have economic, political, social, and environmental problems, necessary. The importance of the relationship between climate change, which is a result of environmental pollution, and financial inclusion, which is an adaptation strategy for climate change, for fragile economies, constructs the motivation of this study, which tries to determine the relationship between financial inclusion and environmental sustainability. Within this scope, Augmented Mean Group (AMG) cointegration analysis and [44] panel causality analysis are employed. According to the findings, there is a long-term relationship between variables. Also, the study finds that financial inclusion decreases environmental degradation and increases the environmental sustainability of South Africa and Indonesia. Finally, the study provides evidence that there is bidirectional causality between financial inclusion and environmental sustainability.

This study makes some contributions to the literature and tries to detect the nexus between financial inclusion and environmental sustainability since financial inclusion may stimulate economic growth and environmental sustainability by decreasing poverty. There are a few studies about the impact of financial and economic development [45]; [46] [47]; and environment [48,49] in the literature; however, to determine the relationship between financial inclusion and environmental sustainability with their indexes forms is not yet discussed to the best of our knowledge. Also, indexes of financial inclusion and environmental sustainability include various indicators and the existing literature evaluates the environmental impacts of financial inclusion with some indicators but not index. Thus, using several indicators instead of a single indicator provides more comprehensive assessments of financial inclusion and environmental sustainability since financial inclusion and environmental sustainability terms have various and comprehensive indicators. This study includes fragile five economies in this study since no study tries exploring the nexus of financial inclusion and environmental sustainability for fragile five economies. Therefore, there is a need to determine the effect of financial inclusion and environmental sustainability on fragile five economies. Also, this study firstly examines the relationship between the financial inclusion index and the environmental sustainability index by using AMG cointegration analysis and [44] panel causality analysis. This situation is one of the original values of our study. Finally, this study constructs policy implications to provide environmental sustainability for fragile five economies and supports the decision-making process regarding financial inclusion.

The rest of this study is organized as follows. Section two reports the literature review and section three gives information about the data. Section four introduces the methodology. Section five discusses the findings and Section six includes the conclusion and policy implications.

2. Literature review

The main aim of this study is to determine the relationship between environmental degradation, which means low environmental sustainability, and financial inclusion. This study also try to determine the relationship between gross domestic income (GDP) per capita, renewable energy consumption, foreign direct investments, and human development index with environmental sustainability. Within these scopes, the literature is summarized in this section.

2.1. The nexus between environmental degredation and financial inclusion

Factors such as industrialization, globalization, and high financial inclusion affect the growth of an economy ([50]; [51]; [52]). Financial inclusion is the main factor, which increases economic growth by encouraging financial development [7], and can increase environmental degradation by rising household purchasing power and energy consumption in a growing economy [53]. However, financial inclusion can have a deterioration-reducing effect on environmental degradation [15]. and the high financial inclusion level creates positive effects on the environment by increasing the adoption of better environmental conditions and practices, which reduce the effects of climate change [28]. Therefore, the lack of consensus on the relationship between financial inclusion and environmental sustainability ensures that the discussions continue [15,54].

[55] find that the application of information and communication technology supports environmental protection and financial inclusion and reduces the effects of CO_2 [27]. demonstrate the positive effect of financial inclusion on environmental degradation for the 15 countries with the highest CO_2 [56]. use five different financial inclusion variables for China and determine that four of these five financial inclusion variables positively contribute to environmental degradation [57]. investigate the impact of financial inclusion on China's pollution and CO_2 in the period of 2011–2017 and show that high financial inclusion reduces CO_2. [58] examined the relationship between financial inclusion and environmental quality and assert that high financial inclusion improves renewable energy consumption and CO_2 emissions in China. [59] study the relationship between financial inclusion and CO_2 and claim that there is a negative nexus of financial inclusion and CO_2 at the regional level in China.

Ahmad et al. [60] investigate the effect of financial inclusion on environmental degradation in eight countries of the ASEAN region between 2000 and 2019 period and indicate that the cause of environmental degradation is financial inclusion, energy consumption, and economic and urban development [15]. study the relationship between financial inclusion and CO_2 for 31 Asians in the period of 2004–2014 and claim that financial inclusion triggers environmental degradation by increasing CO_2 emission. Similarly, [24,54,61,62]; and [63] demonstrate that financial inclusion increases environmental degradation.

[64] detect that financial inclusion increases environmental degradation in the middle-income countries, while financial inclusion reduces environmental degradation in high-income countries from 2004 to 2019 for 170 countries [7]. research an inverted U-shaped relationship between financial inclusion and environmental degradation, and find that this relationship is negative at first and then this relationship turns positive [65]. claim that the environmental degradation in the Euro Area harms financial inclusion, but these negative effects mitigate by the spread of innovation [52]. examine the relationship between financial inclusion and CO_2 in Chinese cities and indicate the negative relationship in some cities. On the other hand, there is research, which supports that there is no relationship between financial development and financial inclusion, and environmental sustainability [66–70]. In this study, we follow the hypothesis below.

H1. There is a statistically uncertain (+, -, and insignificant) nexus between environmental degradation and financial inclusion.

2.2. The nexus between global degradation and per capita income

The Environmental Kuznets Curve (EKC)-Inverted U Hypothesis is used to test the hypothetical relationship between environmental pollution/degradation level and per capita income. EKC hypothesis explains that the quality of life deteriorates in the early stages of the economic development process and then, this degradation decreases [71]. Thus, the environmental degradation trend may increase in the early stages of economic growth but the environmental degradation may gradually decrease with the increase in income and the sensitivity to live in a cleaner and more sensitive environment in the later periods [72]. The first empirical study investigating the validity of the EKC hypothesis is conducted by [72], who support that the inverse-u hypothesis is valid.

[73] examine the validity of the EKC hypothesis based on the data for the 1993–2017 period CO_2 and GDP per capita on the 5 largest countries in the G-20 economy and determine that the EKC hypothesis is valid between for the relationship CO_2 and GDP. Also, [74–76]; and [77] assert the validity of peripheral Kuznets curve. On the other hand, [78–81]; Azam and [82–84] find that the EKC is invalid. In this context, the hypothesis, which is tested, is given below.

H1a. The EKC hypothesis is valid for the nexus between environmental degradation and income.

2.3. The nexus between environmental degradation and renewable energy

Renewable energy sources, which are also called green energy, mean having minimum damage to the environment during production, being renewed without being fossil sourced, and having low CO_2 amount released into the atmosphere. Renewable energies are needed due to the increase in climate change and the degradation of the natural balance with globalization. Within the scope of this need, the "Kyoto Protocol" is created to the awareness of climate change effects [85]. [86] examines the relationship between renewable energy, economic growth, and the environment for 129 countries in the years between 1990 and 2013 and demonstrates that renewable energy has a positive effect on CO_2. [87] investigate the effects of economic development, natural resources, industrial production, renewable energy consumption, and total reserves on environmental degradation in 38 OECD countries between 1995 and 2019 period using the dynamic panel method and conclude that renewable energy consumption and natural resources reduce environmental degradation, while economic development, industrial production, and total reserves increase the environmental degradation. Also, [88–90]; and [91] reveal similar findings to the findings of [87]. On the other hand [81], and [92] determine that the effect of renewable energy on CO_2 is insignificant. For the renewable energy variable, the hypothesis, which is tested, is given below.

H1b. There is a statistically significant negative nexus between environmental degradation and renewable energy consumption.

2.4. The nexus between environmental degradation and foreign direct investments

Foreign direct investments can have both positive and negative effects on the environment. While foreign direct investments cause environmental degradation due to increasing economic activities and creating a change in the structure of the industry, however, these investments can reduce environmental degradation with the use of existing superior technologies and the effect of ongoing new knowledge and method. The positive and negative effects are evaluated within the scope of the "pollution haven/heaven" and "pollution halo hypothesis" [93].

While the pollution haven hypothesis defends the negative effects of foreign direct investments on the environment, the pollution halo hypothesis defends the positive effects of foreign direct investments. In developing countries, environmental degradation increases due to insufficient environmental awareness and the intensification of polluting industries, while in developed countries, environmental degradation decreases due to the use of environmentally friendly technological tools in production and environmentally friendly investments [94].

[95] research the effect of foreign direct investment on environmental degradation in Asian economies and claim that foreign direct investments hurt financial development and economic growth and financial development and economic growth increase environmental degradation [93]. determine that the pollution haven hypothesis is accepted in low and middle-income countries in line with the findings of [79,96]; [97], [57]; and [98]. However, [99,100]; and [101] show an insignificant relationship between foreign direct investment and environmental degradation. Moreover, [102,103]; and [104] find that foreign direct investments reduce CO_2. For the foreign direct investment variable, the hypothesis, which is tested, is given below.

H1c. There is a statistically significant positive nexus between environmental degradation and foreign direct investment.

2.5. The nexus between environmental degradation and human development

To determine the level of development of the countries, taking into account the social and cultural elements along with the economic elements are necessary. Social welfare and quality of life (health, education, and economic life) construct human development, which becomes an important part of the socioeconomic dimension. The main factors affecting the environmental factors of countries are population, unemployment, production efficiency, poverty, and income distribution. In this context, the difference in environmental awareness activity in underdeveloped, developing countries and developed countries has different findings. With the understanding of the importance of the level of human development, the Human Development Index (HDI) is created and published by the United Nations Development Program (UNDP) in line with the Human Development Report [105].

The empirical findings for the relationship between HDI and environmental degradation have different features according to time and country [60]. study the impact of human capital, ecological footprint, and institutional quality for the 1987–2014 period and reveal that financial development increases the ecological footprint and deteriorates the ecological quality in the short and long terms, while human capital and institutional quality play an important role in improving the environmental quality in the short and long terms. Moreover, [106,107]; and [108] find similar results to Ref. [60]. For the HDI variable, the hypothesis, which is tested, is given below.

H1d. There is a statistically significant negative relationship between environmental degradation and human development.

Finally, the literature is summarized on the relationship between income per capita, renewable energy consumption, foreign direct investments, human development index, and environmental sustainability in Table 1.

3. Data

The current study explores the effect of financial inclusion on environmental sustainability over the highlighted variables on the selected fragile economies under consideration. Within this scope, the financial inclusion index and environmental sustainability index are developed, which comprehensively represent financial inclusion and envirenmental sustainability including diversity dimensions for fragile five economies, which are Turkey, South Africa, Brazil, Indonesia, and India, in the 1990–2019 period. There is no consensus that how financial inclusion is commonly measured in the literature [126] due to the broad concept of financial inclusion and envirenmental sustainability [26]. Thus, the present study includes comprehensive indicators for measuring the financial inclusion index and envirenmental sustainablility index. Subsequently, ten financial indicators data for constructing financial inclusion index and these financial indicators are private credit by deposit money banks, private credit by deposit money banks, deposit money banks' assets, central bank assets, mutual fund assets, life insurance premium volume, nonlife insurance premium volume, credit to government and state-owned enterprises, bank credit to bank deposits, stock market capitalization [127]. assert that households may have many bank accounts, however, household use bank accounts for a few services, having a bank account may be insufficient for representing the financial system, and credit and deposits are more suitable indicators for the financial system. Thus [126], is followed and used data-related deposits and credits. Moreover, data related to deposits and credits and financial inclusion indicators mentioned above go back to the 1990 year, but the span of data such as bank account, automated teller machines (ATMs) per 100,000 adults, and branches of commercial banks per 100,

Table 1
Literature review.

Researcher/ Researchers	Term	Country/ Countries	Findings
[72]	Changing over time	42 countries	There is an inverted U relationship for the EKC hypothesis
[88]	1980–2009	Malaysia	Electricity, which is produced with renewable energy, decreases CO2 emissions and the EKC hypothesis is valid.
[109]	1970–2011	Iran	Environmental degradation increases and environmental quality decreases since financial development increases.
[49]	1980–2010	102 countries	Financial development and environmental quality are significant factors for economic growth..
[110]	1977–2010	17 OECD ülkesi	Renewable energy consumption reduces CO_2.
[86]	1990–2013	129 countries	Renewable energy increases CO_2 in low-income countries and decreases CO_2 in high-income countries.
[111]	1980–2015	Pakistan	Energy consumption, financial development, economic growth, and trade increase the CO_2 emissions.
[84]	1991–2012	85 developing and developed countries	Renewable energy consumption reduces CO2 emissions and the EKC hypothesis is not valid.
[89]	1985–2016	BRIC countries	Renewable energy consumption reduces CO2 emissions and the EKC hypothesis is invalid.
[112]	1986–2014	SAARC countries	The pollution haven hypothesis is valid in the short run but the pollution haven hypothesis is not valid in the long run.
[113]	2002–2015	Developing 19 Asia countries	FDI reduces air pollution.
[_wang_et_al_2019b]	1990–2015	OECD Counties	Human development reduces CO_2 emissions in the long run.
[15]	2004–2014	31 Asian countries	Financial inclusion is the cause of CO_2 emissions.
[93]	1971–2011	Developed and developing countries	While the pollution haven hypothesis is accepted in low and middle-income countries, but the pollution hypothesis is not valid in high-income countries.
[114]	1990–2016	D-8 countries	Energy consumption reduces environmental degradation.
[115]	1990–2016	ASEAN countries	Renewable energy consumption insignificantly reduces environmental pollution.

(*continued on next page*)

Table 1 (*continued*)

Researcher/ Researchers	Term	Country/ Countries	Findings
[116]	2005–2015	G7 and BRICS countries	The pollution haven hypothesis is valid for BRICS countries and the pollution shelter hypothesis is not valid for G7 countries.
[108]	2000–2014	Brazil, India, China, and South Africa	Human development negatively affects CO_2 emissions.
[117]	1996–2014	50 African countries	Renewable energy consumption reduces CO_2 emissions.
[73]	1993–2017	China, France, Russia UK and USA	There is an inverted N relationship for the EKC hypothesis. Also, there is a bidirectional causality between CO_2 and per capita income.
[95]	1980–2018	21 Asian countries	The pollution haven hypothesis is valid and financial development increases CO_2
[118]	2000–2018	29 Asia-Pacific countries	There is an inverted U relationship for the EKC hypothesis. Renewable energy consumption reduces CO_2 in some countries.
[55]	1995–2019	Six oil exporting countries	The relationship between the human development index and carbon intensity is u-shaped for the EKC hypothesis.
[60]	1987–2014	17 developing countries	While human capital and institutional quality play an important role in improving environmental quality, financial development increases the ecological footprint,
[60]	2000–2019	Eight countries in the ASEAN region	The increase in financial inclusion increases environmental degradation.
Dagar et al. (2022)	1995–2019	38 OECD countries	Renewable energy consumption reduces environmental degradation.
[61]	1990–2017	Pakistan, India, Bangladesh, and Sri Lanka	Financial inclusion causes CO_2 emissions
[119]	1990–2017	Pakistan	Non-renewable energy consumption and trade openness increase environmental degradation.
[13]	1992–2018	G-20 countries	FDI inflows in G-20 countries increase CO_2 and thus the pollution haven hypothesis is valid for G-20 countries.
[120]	2007–2019	42 OBRI countries	Financial inclusion increases environmental degradation.
[121]	2004–2018	OIC countries	Financial inclusion increases CO_2 emissions.
[57]	2011–2017	30 Chinese provinces	Financial inclusion reduces environmental degradation.
[122]	2004–2019	RCEP countries	Financial inclusion increases CO_2 emissions
[29]	1998–2019	South Asia	Financial inclusion leads to higher CO_2 emissions.
[123]	2004–2019	BRICS countries	Financial inclusion reduces environmental degradation
[124]	2005–2020	30 Chinese provinces	Financial inclusion reduces environmental degradation.
[60]	1995–2018	Seven OECD countries	Financial inclusion increases environmental degradation.
[125]	2000–2017	E-7 countries	HDI increases the ecological footprint.

Source: authors compilations.

000 adults data is short compared to financial inclusion indicators used in this study. Thus, to create financial inclusion index, the financial inclusion indicators, which represent financial goods and services and whose data can be accessed between the 1990–2019 period, are taken into account. Values of the financial inclusion index vary between 0, which is the lowest financial inclusion value, and 100, which is the highest financial inclusion value since the high value of this index score shows high financial inclusion level.

To represent environmental sustainability, an environmental sustainability index is measured including population density, methane emissions, nitrous oxide emissions, fertilizer consumption per hectare of arable land, coal consumption per populated land area, CO_2 emissions per $ GDP, CO_2 emissions per capita, vehicles GDP per capita, number of mammals threatened, and number of birds threatened following [128, 129]. Values of the environmental sustainability index vary between 0, which is the most sustainable value, and 100, which is the most unsustainable value since the high value of this index shows environmental degradation. This study include to anaylsis some independent variables such as real GDP per capita, R-square of GDP per capita, foreign direct investment, renewable energy consumption, and human development index following literature [49,118,130–132] since envirenmental sustainability is affected by many indicators. The data are collected from World Bank's Global Financial Development Database, World Development Indicators Databank, Our World in Data, and Human Development Reports. The variables of this study are summarizeb in Table 2.

This study measures two indexes for financial inclusion and environmental sustainability by using principal component (PCA) analysis following [128] with the mentioned variables in Table 1. Firstly, all variables are standardized suggested by Refs. [133,134] and secondly, PCA is employed to construct the weight of financial inclusion index and environmental sustainability index and Table 3 reports the PCA findings for two indexes.

Table 3 shows that the first two components explain 79% of the total variance of the environmental sustainability index and the first two components explain 78% of the total variance of the financial inclusion index. Meanwhile, the Kaiser-Meyer-Olkin test indicates that the sample is adequate and Bartlett's test proves that there are correlations between the variables of the PCA for both indexes.

4. Method

This study aims to determine the nexus of environmental sustainability and financial inclusion in this study by using econometric

Table 2
Variables used in the analysis.

Descriptions of indicators for two indexes	Variable Types
Private credit by deposit money banks to GDP (%)	Financial Inclusion
Deposit money banks' assets to GDP (%)	Financial Inclusion
Central bank assets to GDP (%)	Financial Inclusion
Mutual fund assets to GDP (%)	Financial Inclusion
Life insurance premium volume to GDP (%)	Financial Inclusion
Nonlife insurance premium volume to GDP (%)	Financial Inclusion
Credit to government and state owned enterprises to GDP (%)	Financial Inclusion
Bank credit to bank deposits (%)	Financial Inclusion
Stock market capitalization to GDP (%)	Financial Inclusion
Population density (people per sq. km of land area)	Environmental Sustainability
Methane emissions	Environmental Sustainability
Nitrous oxide emissions	Environmental Sustainability
Fertilizer consumption per hectare of arable land	Environmental Sustainability
Coal consumption per populated land area	Environmental Sustainability
CO_2 emissions per $ GDP	Environmental Sustainability
CO_2 emissions per capita.	Environmental Sustainability
Vehicles GDP per capita	Environmental Sustainability
Numberof mammals threatened	Environmental Sustainability
Percentage of birds threatened	Environmental Sustainability

Abbreviations	**Variables Used in the Analysis**	**Variable Types for Analysis**
GDPPER	Real GDP per capita	Independent Variable
$GDPPER^2$	Quadratic form of GDP per capita	Independent Variable
REW	Renewable energy consumption	Independent Variable
FIEX	Financial inclusion index	Main Independent Variable
SEIX	Environmental sustainability index	Dependent Variable
HDI	Human development index	Independent Variable

Table 3
PCA findings for measuring indexes.

Total Variance Explained for Components			
Environmental Sustainability Index	Eigenvalues	% of Variance	Cumulative Variance
1	6.144	0.683	0.683
2	0.995	0.11	0.7931
3	0.66	0.073	0.866
4	0.466	0.052	0.918
5	0.34	0.038	0.956
6	0.225	0.0251	0.981
7	0.082	0.009	0.99
8	0.055	0.006	0.997
9	0.033	0.0034	1
The Bartlett's Test: 573.98[a], Kaiser- Meyer-Olkin Test: 0.888			
Financial Inclusion Index	Eigenvalues	% of Variance	Cumulative Variance
1	4.523516	0.503	0.503
2	2.492928	0.277	0.78
3	0.828561	0.092	0.872
4	0.512113	0.057	0.929
5	0.376220	0.042	0.97
6	0.140870	0.016	0.986
7	0.075345	0.008	0.995
8	0.050074	0.005	0.999
9	0.000371	0.0000	1.000
The Bartlett's Test: 520.98[a], Kaiser- Meyer-Olkin Test: 0.57			

[a] Indicates statistical significance at 1% significance level.

method. The econometric method used in the study is second generation econometric method and these method take into the cross-section dependency account. In this context, considering the cross-section dependency increases the reliability and consistency of the econometric results obtained.

Wthin the spope of this study, firstly, the environmental sustainability and financial inclusion indexes are constructed with PCA analysis. Secondly, the homogeneity tests are run as well as cross-section dependency tests, and investigate whether there is a cointegration relationship for the panel data through the Durbin-Hansen cointegration analysis. Thirdly, the long-run cointegration coefficients using the Augmented Mean Group (AMG) model are estimated. Finally, the causality relationship with [44] panel causality analysis is examined. In brief, the analysis flow of this study is reported in Fig. 1.

4.1. Cross-section dependency test

Cross-section dependency can be expressed as the effect of an economic shock in one country on the economic indicators of other countries. Recently, after globalization inter-country dependency is increasing and to conduct cross-sectional dependency tests have a great importance.

To determine the cross-section dependency in panel data, Breusch-Pagan CD_{LM1} (1980) [135], CD_{LM} [135], CD_{LM2}, and [136] LM_{adj} tests are developed in the literature. As one of the cross-section dependency tests, Breusch-Pagan CD_{LM1} (1980) is the first developed model, which is given in Equation (1).[1]

In Equation (1), ṗ is the estimation of the binary correlation. The main hypothesis for this test is that there is no cross-sectional relationship and if $T\rightarrow\infty$ N is constant, Breusch-Pagan CD_{LM1} (1980) test, which has a chi-square asymptotic distribution at $\frac{N(N-1)}{2}$ degrees of freedom, may be used when the time dimension (T) is larger than the cross-section dimension (N) [137]. On the other hand, CD_{LM2}, which is included in Equation (1) and developed by Ref. [135]; can be used both when the time dimension is large and the cross-section size is large in Eguation (2).

When $N > T$, the [135] CD_{LM} test shows large deviations and deteriorates in the level, and the deviations increase since N increases [136]. develop the CD test for cross-section dependence in cases where $N > T$. This test is presented in Equation (3), which is used when N is greater than T ($N > T$).

The [135] CD_{LM} test is based on the sum of the correlation coefficients between cross-section residuals. The other cross-section dependency test, which is reported in Equation (4), is the deviation-corrected LM_{adj} test developed by Ref. [138]. In Equation

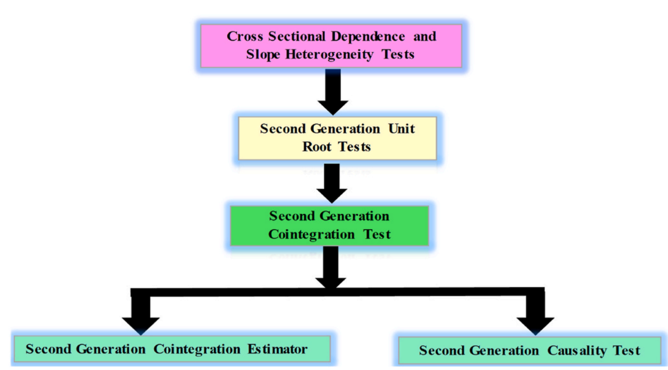

Fig. 1. Flow of the analysis.

[1] All equations of methodology are given in Appendix.

(4), μ is the mean of T_{ij}, $(T-k)\rho ij^2$, $\frac{\nu^2}{T_{ij}}$ is the variance of $(T-k)\rho ij^2$. According to Equation (4), the test statistics asymptotically show a standard normal distribution [138]; [139]. The [135] CD_{LM} test is used when N is greater than T (N > T).

4.2. Homogeneity test

This study tries to detect homogeneity for the model [140]. develop Equation (5) to determine homogeneity regarding a large sample and Equation (6) to test for a small sample.

4.3. Panel unit root test

This study examines the stationarity level of variables through the CADF test [136]. With CADF, a unit root test can be performed on each cross-section unit (for each country) in the series of the panel. Thus, the stationarity of the series can be calculated for the panel as a whole and each cross-section separately. The CADF test, which assumes that each country is affected by time effects and takes into spatial autocorrelation account, is used in cases of T > N and N > T.

After runing the cross-sectional dependency and homogeneity tests, the Cross-Sectionally Augmented Dickey-Fuller (CADF), which is second-generation unit root tests, is employed in this study. The CADF is based on the panel unit root test regression model, which is developed by Ref. [136] and called the extended Dickey-Fuller test, and is shown in Equation (7) and Equation (8). The CIPS statistics, which are the average of the t statistics calculated for each cross-section, are given as follows:

$$\text{CIPS }(N,T) = t - \text{bar} = N^{-1}\sum_{i=1}^{N} t_i(N,T)$$

The hypotheses of theCIPS test are given below:

H_0: $\beta_i = 0$ the series is not stationary.

H_1: $\beta_i < 0$ the series is stationary.

4.4. Panel cointegration test

[141] cointegration method can be used to test the existence of long-term relationships between non-stationary and cross-section dependent variables. In this method, i) the dependent variable should not necessarily be stationary; ii) some of the explanatory variables can also be used if they are stationary; iii) different test statistics can be calculated for hypotheses, which consider both panel homogeneity and panel heterogeneity [142]: 196–199).

Using the Durbin-H panel cointegration analysis developed by Ref. [142]; the long-term relationship between the series can be examined. The presence of cointegration in the panel is detected by using the [142] Durbin-H method since there is a cross-section dependence between the series. The [142] Durbin-H method, provided that the dependent variable is I(1), if the independent variables are I(1) or I(0), allows cointegration analysis and takes common factors into account [142]. The hypotheses of the test are given as follows:

H_0: $\varnothing_i = 1$, There is no cointegration relationship. (i = 1,2, ….n)

H_1: $\varnothing_i < 1$, There is a co-integration relationship. (i = 1,2, ….n)

The existence of a cointegration relationship is tested separately for group and panel dimensions in Ref. [142] Durbin-H method. The autoregressive parameter is allowed to differ between sections for the [142] Durbin-H group test and the rejection of the H_0 hypothesis of the [142] Durbin-H group test indicates the existence of a cointegration relationship at least for some sections. On the other hand, the autoregressive parameter is the same for all sections in Ref. [142] Durbin-H panel cointegration test and under this assumption, the rejection of the H0 hypothesis shows that there is a cointegration relationship for all cross-sections [143].

4.5. Emirmahmutoğlu and Köse [44] Panel causality analysis

This study uses [44] panel causality analysis based on [144] causality analysis. In Ref. [44] causality analysis, as in [145] causality analysis, whether the variables contain a unit root and the variables are cointegrated is not important. Therefore, this method has more advantageous than other causality methods [44]. panel causality analysis is given in Equation (10) and Equation (11) for the bivariate VAR model and in these equations, d max indicates the maximum integration level for each i in the system.

4.6. Estimating long-run Co-integration coefficients

AMG method is used to estimate the long-term coefficients of the models. In this method, there is no requirement, that the integration degrees of the variables in the model are the same and the dependencies between cross-sections are taken into account and different coefficients can be estimated for the cross-section equations.

The present study estimates the long-term cointegration coefficients by using the AMG method, which is developed by Ref. [146] and takes into account the cross-sectional dependence of the general panel and country-specific coefficients. The AMG test is an estimator used when the series is stationary at the 1st difference, giving the overall panel and the individual coefficients of the countries.

5. Findings

This study focuses on five fragile economies with huge energy and sustainability targets to explore the nexus between financial inclusion and the environment. For this purpose, firstly, this study examines multicollinearity with correlation analysis and Variance Inflation Factor (VIF) tests. The correlation analysis and VIF tests are reported in Table 4 and Table 5, respectively.

According to the results of Table 4, there is a positive correlation between environmental degradation and financial inclusion, per capita income, and foreign direct investments and there is a negative correlation between environmental degradation and human development, and renewable energy consumption. Table 5 indicates that VIF values are below 10 and tolerance values are above 0, and there is no multicollinearity problem.

The cross-section dependency is tested and Table 6 and Table 7 show the cross-sectional dependency test results for variables and model.

Table 6 presents the results of the cross-section dependency test between series. According to the findings of Table 6, the basic hypothesis, which assumes that there is no cross-sectional dependence, is rejected, and there is a cross-sectional dependence between the series.

Table 7 reports the results of the cross-section dependency test for the model. According to the findings of Table 7, the probability values are less than 0.05 significance level, the H_0 hypothesis is rejected, and there is a cross-section dependency in the model. After making a cross-section dependency test, a homogeneity test is employed and Table 8 reports homogeneity test results for models.

Table 8 indicates that the basic hypothesis based on the homogeneity of the model is rejected at the 1% significance level and the coefficients are heterogeneous. Detecting the stationarity of the variables has

Table 4
Correlation matrix.

	SEIEX	FIEX	GDPPER	FDI	HDI	REW
SEIEX	1.0000					
FIEX	0.4737	1.0000				
GDPPER	0.3580	0.5031	1.0000			
FDI	0.4435	0.0519	0.2971	1.0000		
HDI	−0.4189	0.3865	0.6151	0.4591	1.0000	
REW	−0.2773	−0.2015	−0.6006	0.1096	−0.5679	1.000

Table 5
VIF and tolerance values of the ındependent variables.

Variable	VIF	1/VIF
HDI	7.97	0.125521
GDPPER	7.42	0.134759
REW	1.93	0.518506
FDI	1.77	0.565579
FIEX	1.40	0.713912
Mean VIF	4.10	

Table 6
Cross-sectional dependence test result for the variables.

Variables	CD_{LM1} [147]	CD_{LM2} [135] CD_{lm})	CD_{LM} [135] CD)	Bias-adjusted CD test
SEIEX	37.252***	6.094***	−2.431 ***	0.782
FIEX	38.075***	4.974***	−3.728***	9.183***
GDPPER	32.243***	4.686***	−1.852**	6.956***
$GDPPER^2$	32.804***	5.099***	−1.759**	7.304***
REW	35.640***	5.733***	−3.156***	6.940***
FDI	34.059***	5.380***	−3.263***	3.763***
HDI	26.746***	3.745***	−3.176***	9.640***

Note: *, **, and *** indicate significance levels at %10, %5, and %1, respectively.

Table 7
Cross-sectional dependency tests result for the model.

Cross-Sectional Dependence Tests	Statatistic	Probability
cd Lm1 [147]	101.876	0.000
d LM2 [135] CDlm)	20.544	0.000
d LM [135] CD)	7.293	0.016
Bias-adjusted CD test	23.716	0.000

Table 8
Homogeneity test result for models.

Homogeneity Tests	Statatistic	Probability
Delta_tilde:	3.866	0.000
Delta_tilde_adj:	4.514	0.000

important for choosing the right model and measuring the spurious regression. Thus, the stationary test is employed and Table 9 shows CADF unit root test results.

Table 9 reports the results of the CADF unit root test applied for each variable. The CADF test statistics values calculated separately for each variable are smaller than the value of −3.87 at a 5% significance level compared with the critical table value of [136]; and the CIPS values are smaller than the CIPS critical table value of [136] at 5% significance level. In this case, the H_0 hypothesis is accepted at the I(0) level and the H_1 hypothesis is rejected for the variables. In brief, all the variables for the panel are stationary at the I(1) level. On the other hand, cointegration for group and panel is made in this study and Table 10 reports the Durbin Hansen cointegration test results.

Durbin Hansen cointegration test results in Table 10 show that the probability values of group and panel statistics obtained in the model are less than a 5% significance level. In this case, the H_0 hypothesis is rejected and there is a cointegration relationship between the series for the country groups and the overall panel, and the model. Also, after the Durbin Hansen cointegration test, AMG long-run test is made and Table 11 reports AMG long-run results and Fig. 2 summarizes these findings.

Finally, this study uses a panel causality test and Table 12 presents EmirMahmutoğlu and Köse's panel causality test results and Fig. 3 reports the findings of EmirMahmutoğlu and Köse's panel causality test as a figure.

The effect of financial inclusion on environmental degradation is not statistically significant for both countries and the panel [132]. states that low-cost financing of people of different income levels of society and increasing access to funds may have a positive effect on environmental degradation. [76,132,148,149]; and [150] detect that financial inclusion is an effective factor in reducing environmental degradation. However [76], claim that financial inclusion reduces environmental degradation only in high-income countries. In this context, the countries examined in this study are not high-income countries and are fragile five countries and the findings of the panel are in line with the findings of [76]. Also, our findings can be explained by the low level of financial inclusion for the fragile five countries. According to Ref. [44] panel causality results, there is no causality between environmental degradation and financial inclusion, and this finding also supports the finding of long-term coefficients.

This study examines whether the EKC hypothesis is valid for the fragile five countries. According to our findings, there is a U (β_2 <0, β_3>0) peripheral Kuznets curve for the fragile countries. In other words, while environmental degradation firstly decreases, environmental degradation increases over time. This finding is claimed by [151] and [130]. According to Ref. [130]; environmental degradation is low before industrialization, but environmental degradation accelerates with large industrialization for developing countries such as Turkey, Greece, Egypt, Chile, Ecuador, India, and South Africa. Moreover [130], find that the inverted U-shaped hypothesis is valid for developed countries in line with the findings of this study since there are young industries in developing countries. On the other hand, the findings of the EmirMahmutoğlu and Köse Panel causality test show that there is unidirectional causality from per capita income to environmental degradation. According to this finding, the change in income affects environmental degradation by supporting the Kuznet curve hypothesis.

Table 10
Durbin Hansen cointegration test results.

Durbin-H Group	Durbin-H Panel	Result
−2.274**(0.011)	−2.650***(0.004)	Cointegrated

Table 9
CADF Unit root test.

	SEIEX		FIEX		GPPER		$GDPPER^2$		FDI		HDI		REW	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
1	−1.36	−3.95	−047	−5.49	−1.67	−3.64	−1.67	−3.53	−3.01	−2.97	−2.17	−3.41	−1.60	−3.40
2	−2.73	−3.15	−0.19	−4.45	−2.80	−3.78	−2.76	−3.74	−2.47	−3.74	−2.42	−2.45	−1.66	−2.79
3	−3.47	−3.61	−1.93	−4.65	−1.99	−3.51	−1.88	−3.53	−2.59	−4.49	−2.02	−1.97	−1.66	−2.46
4	−2.47	−5.78	2.31	−2.29	0.73	−3.29	0.93	−2.83	−1.90	−3.36	−0.70	−2.86	−2.14	−2.72
5	−2.67	−3.32	−1.01	−2.08	−1.11	−3.19	−1.00	−3.13	−2.13	−6.53	−1.43	−3.38	−0.36	−2.99
6	−2.54	**−3.96**	−0.25	**−3.79**	−1.37	**−3.48**	−1.28	**−3.35**	−2.42	**−4.22**	−1.75	**−2.81**	−1.48	**−2.87**

Not: (1: Brazil, 2: Turkey, 3: South Africa,4: India, 5: Indonesia, 6: Panel). Max. Lag has been selected as two (2) and optimal lags specified according to Schwarz information criteria. CADF critical values for both fixed and trend are −4.67 (%1), −3.87 (%5), and-3.49 (%10) [136]). Panel critical values for both fixed and trend are −3.10 (%1), −2.86 (%5), and −2.73 (%10) [136]). Panel statistic is the average of CADF statistics.

Table 11
AMG long-run test results.

Panel	FIEX	GPPER	GDPPER^2	FDİ	HDI	REW	Constant
Brazil	0.544 [0.515] (1.05)	**−7.128* [5.756] (-1.70)**	**0.647** [0.013] (2.35)**	0.369 [0.673] (0.55)	−7.118 [15.706] (−0.45)	**−0.213* [0.100] (-1.79)**	74.838 [85.817] (0.87)
Turkey	−0.210 [0.978] (0.22)	**−8.451* [4.788] (-1.76)**	**0.878** [0.052] (2.36)**	**1.171* [0.105] (1.69)**	11.578 [8.183] (1.412)	**−0.131** [0.063] (-2.06)**	**74.187* [90.957] (1.91)**
South Africa	−0.841 [0.608] (−1.06)	−125.460 [154.166] (−0.81)	14.965 [17.868] (0.84)	**0.740*** [0.095] (3.50)**	**−14.825*** [5.948] (-5.94)**	0.096 [0.126] (0.77)	1058.538 [1333.38] (0.79)
India	0.858 [1.260] (0.68)	−7.220 [9.792] (−0.74)	1.269 [1.401] (0.91)	−0.118 [0.236] (−0.50)	−41.008 [25.989] (−1.58)	−0.136 [0.096] (−1.41)	70.366 [71.003] (0.99)
Indonesia	−1.651 [1.490] (−0.94)	**−43.085** [18.286] (-2.36)**	**5.280** [2.343] (2.25)**	0.073 [0.086] (0.43)	**−23.180*** [21.165] (-1.10)**	**−0.167** [0.074] (-2.26)**	**369.297*** [138.405] (2.67)**
Panel	0.260 [0.456] (−0.57)	**−38.269* [22.856] (-1.67)**	**4.647* [2.713] (1.71)**	**0.138*** [0.094] (2.75)**	**−14.910* [0.494] (-1.79)**	**−0.110** [8.694] (-2.05)**	**330.244* [190.817] (1.73)**
Wald chi2(4) = 21.50*** and Prob > chi2 = 0.000							

Note: *, **, and *** indicate significance levels at %10, %5, and %1, [… …] are error terms, and (…. .) are z-statistics.

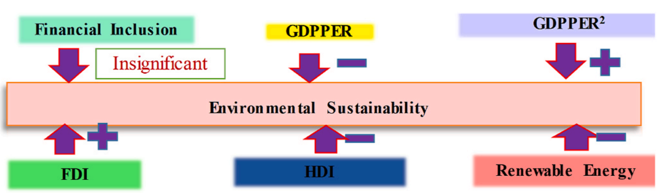

Fig. 2. Graphical schematic from AMG Estimations.

According to the pollution haven hypothesis, particularly, the governments of underdeveloped and developing countries follow flexible policies towards environmental standards to have a larger share of FDI in the international arena [152]. This situation causes firms to seek to benefit from lower production costs to move their activities to develop countries [153] by accelerating environmental degradation. The findings of this study support the pollution haven hypothesis and indicate that FDI reduces environmental degradation in line with the findings of [131] and the findings of [154]; which cover BRICS countries, the findings of [155]; which cover Turkey, and the findings of [156]; which cover developing countries.

According to the findings of the EmirMahmutoğlu and Köse Panel causality test, there is two-way causality between FDI and environmental degradation and these variables affect each other. According to Ref. [157]; human development is a factor, which plays a role in reducing CO_2 emissions as an overlooked factor, and the findings of this study support the findings of [157]. [49,158] find that HDI reduces environmental degradation in line with the findings of this study.

The HDI mainly focuses on the well-being of household and indicates the degree of providing an environment that may provide full access to the resources needed for a good standard of living [159]. Meanwhile, improvement in HDI is strongly linked to technical progress in the increase of energy efficiency and technical development, which can reduce GHG [160]. This study proves that the positive developments in HDI have a positive effect on environmental degradation by supporting the findings of [49,158]. The EmirMahmutoğlu and Köse Panel causality test findings provide evidence for a unidirectional causality relationship between HDI and environmental degradation.

Table 12
EmirMahmutoğlu and Köse panel causality test.

Variables	Brazil	Turkey	South Africa	India	Indonesia	Panel
SEIX to FIEX	1.121 (0.360)	0.048 (0.826)	1.756 (0.185)	2.241 (0.205)	1.799 (0.180)	10.293 (0.256)
FIEX to SEIX	0.800 (0.685)	0.743 (0.690)	1.121 (0.361)	0.720 (0.396)	1.679 (0.200)	16.265 (0.106)
SEIX to GDPPER	**5.140* (0.077)**	0.935 (0.627)	2.510 (0.285)	**3.248* (0.071)**	0.543 (0.461)	15.409 (0.118)
GDPPER to SEIX	**16.928*** (0.00)**	**13.183*** (0.001)**	**11.833*** (0.005)**	0.269 (0.786)	**20.232*** (0.000)**	**33.877*** (0.000)**
SEIX to GDPPER^2	**6.066** (0.048)**	1.041 (0.594)	2.524 (0.283)	**3.117* (0.077)**	0.536 (0.464)	**16.282* (0.092)**
GDPPER^2 to SEIX	**18.240*** (0.000)**	**12.633*** (0.002)**	**11.788*** (0.009)**	**2.442 (0.118)**	**21.187*** (0.000)**	**34.826*** (0.000)**
SEIX to FDI	1.885 (0.390)	0.400 (0.527)	**5.258* (0.072)**	2.285 (0.131)	2.608 (0.106)	**16.978* (0.075)**
FDI to SEIX	1.702 (0.190)	**13.579*** (0.000)**	**11.420** (0.011)**	0.142 (0.706)	0.219 (0.950)	**22.638** (0.012)**
SEIX to HDI	2.240 (0.135)	0.364 (0.546)	2.391 (0.122)	0.166 (0.684)	1.678 (0.195)	13.457 (0.199)
HDI to SEIX	0.796 (0.672)	1.115 (0.831)	**5.672* (0.065)**	1.995 (0.369)	**3.378* (0.095)**	**25.815*** (0.008)**
SEIX to REW	0.740 (0.390)	4.741*** (0.029)	0.078 (0.780)	0.180 (671)	0.418 (518)	**16.301* (0.082)**
REW to SEIX	**5.880* (0.056)**	**7.959*** (0.005)**	1.271 (0.649)	0.207 (0.589)	**9.292*** (0.00)**	**18.845** (0.042)**

Note: *%10,**%5, and ***%1 indicate level of significance causality, respectively and (….) are probability values.

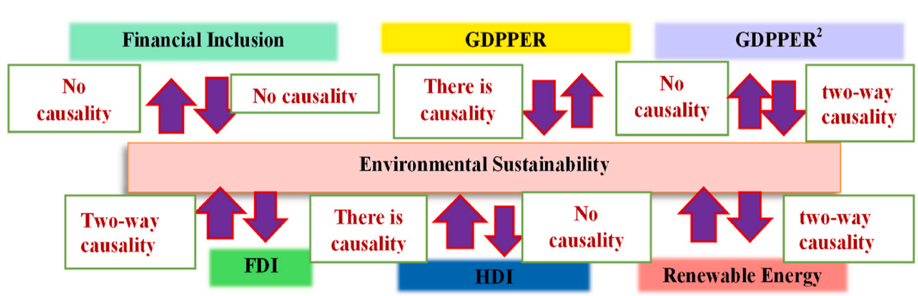

Fig. 3. Graphical schematic for the Findings of EmirMahmutoğlu and Köse's Panel Causality Test.

According to Ref. [161]; renewable energy sources provide significant benefits to the environment and play a role in improving human health. In this context, the findings of this study support the findings of [161]; which assert that renewable energy consumption reduces environmental degradation. In addition, the findings of this study support the findings of [110,162]; and [118]. Also, the causality test shows that there is bidirectional causality between renewable energy consumption and environmental degradation in line with the findings of [163].

One of the most important factors affecting environmental sustainability is the use of renewable energy due to the effect of GHG on environmental degradation. Reducing GHG may significantly prevent environmental degradation. In this context, the use of renewable energy has great importance since renewable energy may reduce GHG [164]; [162]. The findings of this study determine that the use of renewable energy has a positive effect on environmental sustainability by reducing environmental degradation. According to the EmirMahmutoğlu and Köse Panel causality test findings, there is two-way causality the renewable energy and environmental sustainability.

6. Conclusion and policy recommendation

The findings of the study reveal important results for the fragile five countries investigated. This study finds that the effect of financial inclusion on environmental degradation is statistically insignificant. The literature does not agree on the insignificant impact of financial inclusion on environmental degradation. While some studies suggest that financial inclusion triggers consumption and increases environmental degradation [65,121], some studies show that financial inclusion decreases environmental degradation and increases environmental sustainability [49]. The finding of this study can be explained by the fact that financial inclusion is not realized sufficiently in five fragile countries. Moreover, the existence of a U-shaped relationship regarding the EKC hypothesis is determined. This finding means that environmental degradation is gradually increasing. Also, this study demonstrates that the pollution haven hypothesis is valid for five fregile countries. Finally, this study reveals that human development and renewable energy consumption reduce environmental degradation.

The countries examined in this study have large budget deficits, and these countries can act more aggressively to close their budget deficits and may ignore some environmental laws to produce more and attract more foreign investment. However, a sustainable environment is essential for a sustainable economy and policy-makers need to include the environment in their aggressive growth strategies.

This study has some limitations. The time interval is narrow and some financial inclusion and environmental sustainability indicators are not reached for fragile five countries since there is a lack of data of these indicators. Also, the countries defined as the fragile five within the scope of the sample have different financial, political, environmental, and regional features. One of the limitations of the study is the comprehensiveness of the financial inclusion and environmental sustainability terms and the lack of consensus in the literature for their scope. In future studies, by regarding the environmental degradation and financial inclusion indexes created by this study, the impact of financial inclusion on the environment may research for different country groups and this situation may emerge strong findings. Also, instead of using an index format for financial inclusion and environmental sustainability, various indicators of these variables may be used for the analysis. Finally, different method and time interval for determining the relationship between financial inclusion and environmental sustainability may be used.

Credit author statement

Abdulkadir Barut: Conceptualization; Formal analysis; Methodology. **Emine Kaya:** Validation; Visualization; Data curation. **Sevgi Cengiz:** Writing original draft; Investigation. **Festus Victor Bekun**: Writing - original draft; Writing, Validation; Visualization; Supervision, and Corresponding

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.

Data availability

Data will be made available on request.

Appendix

$$LM = T \sum_{i=1}^{N-1} . \sum_{J=\dot{I}+1}^{N} \dot{p}_{ij}^2 \tag{1}$$

$$CD_{LM} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})} \sum_{i=1}^{N-1} . \sum_{J=\dot{I}+1}^{N} \dot{p}_{ij}^2 - 1} \tag{2}$$

$$CD_{LM} = \sqrt{\frac{\mathbf{2T}}{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})}} \sum_{i=1}^{N-1} . \sum_{J=\dot{I}+1}^{N} \dot{p}_{ij} \tag{3}$$

$$LM_{adj} = \sqrt{\frac{\mathbf{2T}}{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})}} \sum_{i=1}^{N-1} . \sum_{J=\dot{I}+1}^{N} T\,\dot{p}_{ij} \quad \frac{T-k\ \dot{p}_{ij}^2 - uT_{ij}}{\sqrt{\frac{\nu^2}{T_{ij}}}} \tag{4}$$

$$= \sqrt{N}\left(\frac{N^{-1}\widetilde{S}-k}{2k}\right) \sim X^2 k \tag{5}$$

$$\widehat{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\widetilde{S}-k}{v(T,k)}\right) \sim N(0,1) \tag{6}$$

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \overline{y}_{t-1} + d_i \Delta \overline{y}_t + e_{it} \tag{7}$$

$$t_i(N,T) = \frac{\Delta y_i' \overline{M}_w y_{i,-1}}{\widehat{\sigma}_i \left(y_{i,-1}' \overline{M}_w y_{i,-1}\right)^{1/2}} \tag{8}$$

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i+d\ \max_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+d\ \max_i} A_{12,ij} y_{i,t-j} + \upsilon_{i,t}^x \tag{10}$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i+d\ \max_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+d\ \max_i} A_{22,ij} y_{i,t-j} + \upsilon_{i,t}^y \tag{11}$$

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