How does the energy transition shape inclusive green growth in the European Union?

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Abstract

Amidst the growing issues of global warming and non-inclusiveness, inclusive green growth (IGG) has become an aspiration for all countries. Countries worldwide, including those in the European Union (EU), are transitioning from non-renewable to renewable energy to preserve the environment. However, there is currently a lack of comprehensive research investigating the nexus between energy transition and IGG. This paper aims to explore the impact of energy transition on IGG in 25 EU countries from 1995–2021. We develop composite indices for both IGG and renewable energy transition targeted to EU economies and employ advanced econometric approaches such as the pooled mean group-autoregressive distributed lag (PMG-ARDL) model, Driscoll-Kraay standard errors (DKSE) method, feasible generalised least square (FGLS) method, panel corrected standard errors (PCSE) method, to uncover relevant associations. The PMG-ARDL deals with potential endogeneity and simultaneously provides short-run and long-run estimates, while the DKSE, FGLS, and PCSE methods provide consistent outcomes in the presence of cross-sectional dependence, autocorrelation, and heteroscedasticity among the error terms. Results indicate that the renewable energy transition hampers IGG in the short run but fosters it in the long run in the EU economies. Additionally, financial development and internet access enhance IGG, whereas government expenditure, inflation, and economic globalisation have negative impacts. The findings suggest that EU countries should stimulate investment by public-private partnerships in renewable energy technologies and promote the use of renewable energy to make their economic growth green and inclusive.

Keywords: Energy transition, Inclusive green growth, European Union, Panel analysis

JEL codes: C23, N34, O44, Q30

1 Introduction

With rapid economic growth, the world has been grappling with global warming and climate change. In addition, the growth attended by most of these economies does not include the marginalised and vulnerable groups of society. Therefore, in the changing world economic scenario, most nations want to achieve inclusive economic growth while protecting the environment (Fay 2012; Li et al. 2021; Jia et al. 2023). Hence, inclusive green growth (IGG) is the central attraction of researchers, academicians, and policymakers. It refers to pursuing a path of economic growth that ensures social equity and conserves the environment (GGKP 2016; Jha, Sandhu, and Wachirapunyanont 2018). Meanwhile, due to mounting environmental pressure, countries worldwide transit their energy use pattern and resort to renewable energy. According to the National Oceanic and Atmospheric Administration (Lan, Trans, and Thoning 2024), carbon dioxide (CO_2) emissions amount was 278 ppm before the industrial revolution, but they reached 316, 365, 400, and 417 ppm in 1959, 1998, 2015, and 2022, respectively. If the CO_2 emissions continue to grow at this pace, the global temperature may rise by 5–6 ℃ by the end of this century (Tollefson 2020). Therefore, decarbonising the economy is necessary for avoiding catastrophic climate disasters (Codina and Semmler 2024). Increasing renewable energy consumption reduces the level of CO_2 emissions and makes the energy system sustainable (Alvarado et al. 2019). The special report of the Intergovernmental Panel on Climate Change (IPCC 2018) states that to limit global warming to 1.5 ℃, 70–85% of the world's electricity must come from renewable energy by 2050. Henceforth, the renewable-based energy transition is crucial for achieving the target. Since the enforcement of the Kyoto Protocol in 2005, the world has achieved commendable progress in energy transition (For further discussion, see Appendix Note A.1). Recently, the 28th Conference of the Parties (COP28) of the United Nations Framework Convention on Climate Change, held in the United Arab Emirates during November–December 2023, is a crucial collective effort to accelerate the energy transition to achieve net-zero emissions by 2050. Though energy transition has achieved significant growth, the question of whether energy transition can promote IGG and bring sustainability in all three spheres needs to be answered. Our study is an endeavour towards this. In this paper, we attempt to address the research question of how energy transition influences IGG in the European Union (EU).

In the last decade, energy transition in the EU has progressed notably. According to the Energy Transition Index ranking published by the World Economic Forum (WEF 2024), seven EU countries have placed in the top ten. These countries are Sweden (1st), Denmark (2nd), Finland (3rd), France (5th), Austria (8th), Estonia (9th), Netherlands (10th). Though fossil fuels have dominated the EU's energy basket, the share of renewable energy has increased admirably. Figure 1 clearly presents the EU's energy use pattern. "European Green Deal" has set the target to reduce greenhouse gas (GHG) emissions by at least 55% by 2030 compared to the 1990s.

Additionally, the Renewable Energy Directive aims to consume 42.5% of EU energy in the form of renewable energy by 2030 (Widuto 2023).

[Figure 1 here]

However, the Russia-Ukraine war has disrupted the energy supply to the EU countries. Therefore, these economies must find new sources of energy that are sustainable, which makes the transition to renewable energy more vital in these regions. On the other hand, though the European region is economically developed, income inequality has risen from 1995–2021 (The Gini index was 28.02 in 1995 and went up to 29.42 in 2021). The intra-regional inequality is also quite prominent. In 2021, Bulgaria had the highest Gini index score at 38.9, while Slovakia had the lowest at 22.1. Additionally, the region has not achieved the desired green economy targets, as seen in Table 1. Therefore, despite the commendable progress of the energy transition in the EU, the question of whether or not the energy transition can bring inclusiveness to the growth of the EU while making it green has remained unanswered. Thus, studying the association between energy transitions and IGG in the EU economies becomes imperative.

Table 1. Descriptive statistics of the inclusive green growth variables

	1995		2010		2019		2021	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Infant mortality rate	8.524	4.391	4.228	2.008	3.220	1.028	3.052	0.990
Income inequality	28.016	4.069	29.552	3.397	29.472	3.794	29.416	3.851
Forest Cover	34.674	16.380	36.347	16.148	36.868	16.100	36.923	16.070
Ambient PM.2.5 mortalities	697.908	346.061	520.872	317.262	414.115	292.327	409.619	288.586
Natural resources rent	0.689	0.855	0.775	0.928	0.376	0.412	0.459	0.468
Environmentally friendly technologies	9.818	7.449	14.464	5.712	9.959	3.916	11.477	3.335

Source: Authors' construct; *Note*: Initial data of 2021 for ambient PM.2.5 mortalities and environment-friendly technologies have been extrapolated.

While numerous studies have delved into the effects of transitioning to renewable energy on economic, environmental, and societal aspects, very few have addressed its impact on IGG. Additionally, there is a noticeable absence of research investigating the factors influencing IGG in EU countries. In order to address these gaps, the study aims to explore the influence of energy transition on IGG across 25 EU economies from 1995–2001. Advanced econometric techniques, including the Pedroni and the Westerlund panel cointegration tests, the pooled mean group-autoregressive distributed lag model, Driscoll-Kraay standard errors method, feasible generalised least square method, panel corrected standard errors method, and Dumitrescu-Harlin causality test are employed to achieve this objective.

The panel cointegration tests assure the existence of long-run relationships among the selected variables. The regression outcome shows that energy transition impedes IGG in the short run but enhances it in the long run, as in the case of EU countries. Further, government expenditure, inflation, and economic globalisation have adverse effects on IGG, but financial development and internet access favour it. In addition, the finding of the panel causality test indicates that there is a two-way causality between energy transition and IGG, financial development and IGG, and economic globalisation and IGG. On the other hand, one-way causality running from inflation and internet access to IGG and from IGG to government expenditure has been observed.

This study contributes to the existing literature in several ways. First, it is the first of its kind to investigate the liaison between energy transition and IGG within the EU context. Second, it devises composite indices for IGG and renewable energy transition tailored to the EU economies, which acutely portray the condition of sustainable development and energy transition in this region. Last, by employing advanced econometric techniques, this study offers methodological contributions, such as energy transition having a negative short-run impact but a positive long-run impact on IGG—an insight not captured in previous studies.

The remainder of the paper is structured as follows: Section 2 offers a brief review of related literature, Section 3 provides the data sources and econometrics methods employed, Section 4 discusses the results, and Section 5 ends with conclusions and policy implications.

2 Related literature

Energy transition can influence IGG through the economy, environment, and society. Accordingly, we provide the literature review on three aspects: Energy transition and economic sustainability, energy transition and environmental sustainability, and energy transition and social sustainability.

2.1 Energy transition and economic sustainability

The detrimental impact of fossil fuels on the environment urges countries worldwide to shift their energy consumption to renewable energy. This leads the researchers to investigate the linkage between renewable energy transition and economic growth. Apergis and Payne (2010) explored the impact of renewable energy consumption on economic growth in 20 Organisation for Economic Co-operation and Development (OECD) countries from 1985–2005. The study confirmed the positive impact of renewable energy on economic growth for those countries. Another study by Apergis and Payne (2011) established the profound impact of renewable energy usage on economic growth for six Central American countries. For 34 OECD countries, Inglesi-Lotz (2016) affirmed that total renewable energy consumption and an increase in the share of renewable energy consumption both have a promotional effect on economic growth.

Bhattacharya et al. (2016) studied the impact of renewable energy consumption on economic growth in the top 38 renewable energy-consuming countries spanning 1991–2012. The findings showed that renewable energy enhanced the prosperity of those economies. Similarly, Rafindadi and Ozturk (2017) asserted that renewable energy consumption increased Germany's per capita GDP. Further, in a study of 103 countries, Chen, Pinar, and Stengos (2020) found that renewable energy consumption positively affected economic growth in OECD countries. However, renewable energy amplified economic growth in non-OECD and developing countries after a certain threshold period. In addition, Jan, Durrani, and Khan (2021) noticed that renewable energy spurred economic prosperity more efficiently than other sources in Pakistan. Similar kind of findings can be observed from the studies by Iqbal, Tang, and Rasool (2023) and Z. Wang et al. (2021) for BRICS countries and ten Asian countries, respectively.

However, some studies have different opinions. In a Turkish survey, Ocal and Aslan (2013) found that an increase in the share of renewable energy consumption in the total final energy consumption hampered economic growth. These findings are supported by the studies of Maji, Sulaiman, and Abdul-Rahim (2019) and Tenaw (2022) in the case of 15 West African countries and 20 Sub-Saharan countries, respectively. At the initial stage, the development of renewable energy technologies is associated with higher costs, leading to higher energy prices. This discourages people from adopting it and thus negatively affects the economy. Therefore, to get the beneficial impacts of renewable energy, the deployment of renewable energy must cross a critical threshold level.

2.2 Energy transition and environmental sustainability

Studies across different regions and periods unanimously argued that using renewable energy brings environmental sustainability. During the analysis, they used different indicators of environmental degradation, such as CO_2 emissions, ecological footprint, and carbon footprint. Gill, Viswanathan, and Hassan (2018) evaluated the influence of an increase in the share of renewable energy production on CO_2 emissions in Malaysia over the period 1970–2011. The study revealed that renewable energy reduced CO_2 emissions in Malaysia. Similar findings can be observed in a study by Murshed et al. (2021), which indicated that non-fossil fuel and hydroelectricity consumption curbed the carbon footprint in Bangladesh. Further, in a study of 15 Asian economies, Anwar et al. (2022) explained that an increase in the share of renewable energy consumption enhanced environmental quality. Afshan, Ozturk, and Yaqoob (2022) constructed a composite energy transition index and scrutinised the impact of the energy transition on the ecological footprint in 27 OECD countries during 1990–2014. The study confirmed that energy transition promoted environmental sustainability by curbing ecological footprint.

In addition, Kazemzadeh (2024) explored the impact of energy transition on the environment using the ratio of renewable energy to non-renewable energy consumption and observed that energy transition reduced environmental degradation. The study further stated that the impact of energy transition is more intense on higher quantiles of CO_2 emissions. The same findings can be noticed in a study by Liao et al. (2023) for ten OECD countries. Moreover, studies by Salahodjaev et al. (2022) and Gao and Chen (2023) reported that an increase in the share of renewable electricity production augmented environmental quality in 45 Europe and Central Asia countries and 21 industrialised countries, respectively. A study by Sadiq et al. (2023) established that renewable energy mitigated environmental degradation in BRIC countries. Other studies shared the same vision (Gu and Liu 2023; Kongkuah 2024; Yang et al. 2023; Ahmad et al. 2023). Therefore, from the above discussion of literature, it can be confirmed that the transition from non-renewable to renewable energy makes the environment sustainable.

2.3 Energy transition and social sustainability

While plenty of researchers focused on finding the impact of renewable energy transition on the economy and environment, few studies delved into the social impact of renewable energy transition. Apergis and Salim (2015) studied the impact of renewable energy consumption on unemployment in a panel of 80 countries from 1990-2013. The study reported that renewable energy consumption increased unemployment for the overall panel, though the results varied across different regions. However, these findings are inconsistent with the findings of the studies by Khobai et al. (2020) and Naqvi, Wang, and Ali (2022) for South Africa and ten European countries, respectively. The studies found that renewable energy usage reduced unemployment in these economies. In addition, Ram, Aghahosseini, and Breyer (2020) performed an analytical job creation assessment for the global power sector from 2015–2050 and reported that 100% electricity generation from renewable sources by 2050 would create job opportunities from about 21 million in 2015 to nearly 35 million in 2050.

Further, Topcu and Tugcu (2020), in a study of 23 developed economies, revealed that increasing the share of renewable energy consumption reduced income inequality. Sasmaz et al. (2020) explored the impact of renewable energy on the human development index in 28 OECD countries over the period 1990–2017. The study reported an increase in the share of renewable energy improved human development in these economies. The findings are similar to the findings of the studies by Z. Wang et al. (2021) and Kaewnern et al. (2023) for BRICS countries and the top ten human development countries, respectively. In a study for India, Mamidi, Marisetty, and Thomas (2021) found that the transition to clean energy amplified household development. On the other hand, Nketia et al. (2022) and Iddrisu, Ofoeda, and Abor (2023) indicated that increasing the share of renewable energy consumption had a negative impact on inclusive growth across 48 African and 30 Sub-Saharan African (SSA) countries, respectively. Likewise, in the case of economic sustainability, the deployment of renewable energy must reach beyond a certain threshold level to attain social sustainability.

2.4 Other factors affecting IGG

Along with renewable energy transition, other variables can influence IGG directly or indirectly. Ghourchian and Yilmazkuday (2020) carried out a study on the impact of government consumption expenditure on economic growth in a group of 83 countries during 1960–2014. The findings of the study established that government consumption expenditure hampered economic growth. Further, a study by Onifade et al. (2020) also confirmed that government recurrent expenditures negatively affected economic growth in Nigeria from 1981 to 2017. The effect of government expenditure on income disparity was examined by Sidek (2021) over a sample of 122 countries and revealed that government expenditure reduced the income gap in those countries. Pham (2024), in his research of 35 Asian countries spanning from 2000 to 2022, documented that government expenditure diminished the unemployment rate. Further, Le and Ozturk (2020) showed that government expenditure degraded the environmental quality by enhancing economic activities and luring more trade and investment activities in 47 emerging markets and developing economies. However, a study by Bilal et al. (2022) confirmed that government expenditures and inflation improved environmental quality in Germany spanning 1971–2016. Baharumshah, Slesman, and Wohar (2016) showed that inflation dampened economic growth in 94 developing and emerging countries from 1976–2010.

Conversely, for 79 developing countries, Uddin and Rahman (2023) reported that inflation boosted spending and investment, further stimulating economic growth. In addition, Law and Soon (2020) examined the association between inflation and income inequality for 65 developed and developing economies over the period 1987–2014. The study revealed that inflation exacerbated income inequality in those countries. A study by Rahman et al. (2022) showed that inflation increased CO_2 emissions in Pakistan. Furthermore, Ofori and Figari (2023) explored the impact of economic globalisation on IGG in 23 African countries from 2000–2020. They found that economic globalisation negatively affected IGG in those countries. Cioaca et al. (2020) showed that information and communication technology promoted sustainable development in 28 EU countries by stimulating economic growth and reducing income inequality. A study by Ofori, Gbolonyo, and Ojong (2022) revealed that information and communication technologies (ICT) fostered IGG while financial deepening hampered it in 23 African countries from 2000–2020. The study further revealed that trade openness deteriorated environmental quality in those economies. Similarly, a study by Xin et al. (2023) concluded that the digital economy promoted IGG in China. However, another study by Ofori, Figari, and Ojong (2023) reported that ICT harmed IGG, whereas financial development promoted it in 20 SSA countries over the period 2000–2020. Henceforth, it can be concluded that the effect of ICT and financial development depends on the policy framework of countries. The study further concluded that foreign direct investment (FDI) and trade openness enhanced environmental degradation.

2.5 Literature gap

The review of related literature reveals that numerous studies have examined the influence of energy transition on the three dimensions of sustainability—social, economic, and environmental—individually. However, there is a notable lack of research addressing the impact of energy transition on IGG, which integrates all three dimensions to provide a comprehensive view of sustainability. This gap leaves a void in understanding the overall impact of energy transition on sustainable development.

Additionally, while several studies have explored the factors influencing IGG, particularly in regions such as China and Africa, similar research is conspicuously absent for EU nations despite their significant role in advancing global sustainability. Moreover, prior studies often rely on a single indicator to represent energy transition, failing to capture its dynamic and multifaceted nature.

In order to address these gaps, this study constructs composite indices for both IGG and renewable energy transition and investigates the impact of renewable energy transition on IGG across 25 EU nations over the period 1995–2021. This approach provides a more nuanced understanding of the relationship between energy transition and sustainable development within the EU context.

3 Theoretical framework

By drawing on the insights from the related literature, the conceptual linkages between the dependent and independent variables are illustrated in Figure 2. The energy transition influences IGG through three interconnected pillars: economy, society, and environment.

Economic Impact of Energy Transition: The relationship between the energy transition and economic growth is shaped by the development stage of renewable energy sources. In nations with lower shares of renewable energy, investments in such technologies tend to be more expensive compared to traditional energy sources. Consequently, during the early phases of renewable energy adoption, economic growth may face setbacks (Tenaw 2022). However, as investments in renewable energy expand, production costs decline due to economies of scale and technological advancements, ultimately fostering economic growth (Iqbal, Tang, and Rasool 2023).

[Figure 2 here]

Social Implications of Renewable Energy: The initial high costs of renewable energy make it less accessible to low-income groups, potentially exacerbating societal inequalities (Iddrisu, Ofoeda, and Abor 2023). Over time, as renewable energy becomes more widely available and affordable, its adoption increases, enhancing social equity and well-being (Kaewnern et al. 2023).

Environmental Benefits: Renewable energy consumption improves environmental quality by reducing greenhouse gas emissions, which, in turn, enhances the overall living conditions of the population (Gu and Liu 2023).

Role of Government Expenditure: The impact of government expenditure on IGG depends on its composition. Revenue-focused expenditures may hinder economic growth (Ghourchian and Yilmazkuday 2020) and degrade environmental quality by driving resource-intensive economic activities (Le and Ozturk 2020). Conversely, government spending on social infrastructure, such as healthcare, education, and public amenities, supports social sustainability (Sidek 2021).

Financial Development: A robust financial system promotes economic prosperity by facilitating investments in eco-friendly projects, reducing environmental degradation, and fostering socio-economic inclusion through broader access to banking systems. Thus, financial development positively influences IGG (Ofori, Figari, and Ojong 2023).

Inflation and IGG: High inflation adversely affects IGG by lowering purchasing power, creating uncertainty for investments (Baharumshah, Slesman, and Wohar 2016), widening income inequality (Law and Soon 2020), and degrading environmental quality (Rahman et al. 2022).

Economic Globalisation: While economic globalisation enhances a country's global integration, it may expose nations to environmental risks, particularly if weak regulations allow for pollution havens. As a result, globalisation can negatively impact IGG (Ofori, Gbolonyo, and Ojong 2022).

ICT and IGG: Information and communication technology (ICT) promotes IGG by improving access to information, creating employment opportunities, and fostering higher incomes. ICT also enhances environmental sustainability through energy efficiency and social awareness campaigns (Xin et al. 2023).

This framework provides a comprehensive understanding of the mechanisms through which energy transition and other variables influence IGG across economic, social, and environmental dimensions.

4 Material and methods

4.1 Data sources and variable construction

The study employs annual data from 25 EU nations[1] over the period 1995–2021. The selection of the time period and countries is based on data availability. The outcome variable of our study is IGG. The data of IGG is not directly available. We have formulated a composite index of IGG by following the study of Ofori, Gbolonyo, and Ojong (2022). This index incorporates sustainable development's social, economic, and environmental perspectives. The detailed method of constructing the IGG index is described in the next section. The key explanatory variable of our study is the renewable energy transition (RET). Previous studies have taken different proxies of energy transition—the ratio between electricity generated by renewable energy and fossil fuels (Afonso, Marques, and Fuinhas 2021), renewable energy consumption and generation (Shahbaz et al. 2022), the share of primary energy from renewable energy sources (Dogan et al. 2022).

However, according to a report by the International Energy Agency (IEA 2019), one indicator cannot be enough to grasp the complexity of energy transition to clean energy. Therefore, we have created a composite index of RET by incorporating the indicators suggested by the IEA. Apart from energy transition, there are other factors that can influence IGG, and if we do not control their effects, this may lead to biased results. Therefore, the study includes financial development (FD), government expenditure (GE), inflation rate (IR), economic globalisation (EG), and internet access (INTR) as control variables. They are opted from the previous literature on IGG (Ghourchian and Yilmazkuday 2020; Le and Ozturk 2020; Law and Soon 2020; Ofori, Gbolonyo, and Ojong 2022; Ofori and Figari 2023; Xin et al. 2023). The description and data sources of the variables (including energy transition indicators) are provided in Table 2. All the variables are transformed into natural logarithms. This will reduce the sharpness of the data and express the coefficients in terms of elasticity.

[1] The selected countries are Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

Table 2. Description and sources of energy transition indicators and control variables

	Description	Source
Energy transition indicators		
Carbon emissions	CO_2 emissions from energy (Million tonnes)	EI (2023)
Final energy carbon intensity	The ratio of energy-related carbon emissions to total final energy consumption (gCO_2 per megajoules)	IEA (2023)
Share of renewable electricity generation	The ratio of electricity generation from renewables to total electricity generation	EIA (2023)
Carbon intensity of power	Carbon intensity of power index (2000 = 100) calculated using the power generation CO_2 emissions from fuel combustion.	IEA (2023)
Energy intensity	energy consumption per GDP (1000 Btu/2015$ GDP PPP)	EIA (2023)
Renewable energy investment	Net addition to yearly renewable energy installed capacity (million kilowatts)	EIA (2023)
Control variables		
Financial development	Financial development index	IMF (2023)
Government expenditure	General government final consumption expenditure (% of GDP)	WDI (2023)
Inflation rate	Inflation, consumer prices (annual %)	WDI (2023)
Economic globalisation	Economic globalisation index	KOF (2023)
Internet access	Individuals using the internet (% of the population)	WDI (2023)

Source: Authors' construct; *Note:* EIA represents Energy Information Administration; EI represents the Energy Institute; WDI represents World Development Indicator; OECD represents the Organisation for Economic Co-operation and Development; IMF represents the International Monetary Fund; WGI represents Worldwide Governance Indicator; KOF represents Konjunkturforschungsstelle.

4.2 Construction of IGG index

The term IGG was first introduced during the 2012 G20 Summit under Mexico's presidency. IGG represents a development paradigm that harmonises economic growth, social equity, and environmental sustainability (GGKP 2016; Jha, Sandhu, and Wachirapunyanont 2018). In simpler terms, IGG embodies the integration of these three pillars to foster a balanced and inclusive approach to growth (Ofori, Gbolonyo, and Ojong 2022; Wu et al. 2024). According to the Global Commission on the Economy and Climate, achieving "inclusive, high-quality, and resilient" growth is a critical priority for sustainable development (Morgan 2014). This notion of "better growth" encompasses raising incomes, alleviating poverty, improving public health, making cities more livable, enhancing resilience, promoting innovation, and reducing GHG emissions.

Given its centrality to sustainable development, understanding the factors that drive IGG across economic, environmental, and social dimensions is crucial. The United Nations' adoption of the 17 sustainable development goals (SDGs) in 2015 underscores the urgency of achieving sustainable growth by 2030 (UN 2015). However, quantifying IGG poses challenges due to its complexity and multidimensional nature. Researchers have primarily adopted two broad methodological approaches to construct Inclusive Green Growth (IGG) indices: Data

Envelopment Analysis (DEA) and index-based aggregation methods. Each of these approaches offers distinct conceptual and empirical advantages depending on the objective and scope of the study. The DEA approach relies on a non-parametric input-output framework using linear programming to estimate efficiency frontiers. One of its key strengths lies in its ability to accommodate multiple inputs and outputs without assuming a predefined functional form. In the context of IGG, this method has been advanced through the use of the Generalised Malmquist-Luenberger index, which incorporates both desirable outputs (such as economic growth) and undesirable outputs (such as environmental degradation and social costs) (Oh, 2010; Zhu and Ye, 2018; Ren et al., 2022). This framework enables a dynamic assessment of green growth by capturing both improvements in efficiency and shifts in the technology frontier over time.

In contrast, index-based approaches—as exemplified by Jha, Sandhu, and Wachirapunyanont (2018) in their IGG index developed for the Asian Development Bank—rely on aggregating a set of pre-selected indicators, often aligned with the SDGs. These indicators typically span economic, social, and environmental dimensions and are combined using either equal or weighted scoring techniques. While such indices offer valuable cross-country comparability and policy communication advantages, they are often sensitive to variable selection and weighting schemes. This study employs the indexing method, leveraging Principal Component Analysis (PCA). PCA is a robust dimensionality reduction technique that addresses collinearity among the 23 selected indicators while retaining their multi-dimensionality. This method produces a set of principal components (PCs), enabling the derivation of a unified IGG index from diverse indicators. Before constructing the index, the selected indicators, grouped into social, economic, and environmental categories, are discussed below.

Social indicators—evaluate a nation's inclusiveness. Access to improved sanitation and potable water signifies a population's ability to meet basic needs. Higher access rates reflect greater inclusivity. Conversely, increased population density often exacerbates resource exploitation, environmental degradation, pollution, and disease transmission, ultimately lowering the quality of life. Thus, population density has a negative correlation with sustainable development. Life expectancy at birth and infant mortality rates are proxies for healthcare quality and well-being. Higher life expectancy and lower infant mortality positively contribute to IGG (Jha, Sandhu, and Wachirapunyanont 2018). Transport infrastructure is also integral to sustainable development. This study uses two indicators as proxies[2]: air transport, measured by registered carrier departures worldwide, and railway infrastructure, measured by total rail length. Both positively influence the IGG index (Ofori and Figari 2023).

Economic indicators—assess a country's prosperity. Rising per capita GDP is essential for fostering economic opportunities. However, equitable income distribution is equally important for quality growth. Income inequality, measured by the Gini coefficient, negatively impacts sustainable development, as a higher Gini coefficient reflects income concentration among the wealthy. Human capital, indicative of education quality, is vital for sustainable development. High unemployment rates, however, inhibit IGG by straining economies (Ofori, Gbolonyo, and Ojong 2022).

Environmental indicators—focus on conservation efforts. While agriculture ensures food security and reduces resource depletion, it can also harm the environment via GHG emissions. This study includes agricultural methane emissions to account for agriculture's environmental impact. Forests play a pivotal role in environmental conservation by producing oxygen, absorbing CO2, and preserving biodiversity. Rising global temperatures and higher natural resource rent values, which signify faster depletion rates, negatively impact IGG (Ofori, Figari, and Ojong 2023). Air pollution's adverse effects are captured through indicators like mean population exposure to PM2.5, mortality from ambient PM2.5 exposure, and welfare costs of premature mortalities (in GDP terms). Carbon productivity, reflecting the decoupling of GDP growth from CO2 emissions, positively contributes to sustainable development. Renewable energy consumption promotes environmental sustainability by replacing fossil fuels, which contribute to global warming and climate change. Environment-friendly technologies further mitigate the negative impacts of human activities and conserve the environment (Li et al. 2021).

To construct the IGG index, we apply Principal Component Analysis (PCA), following the methodology of Kumar, Nagar, and Samanta (2007). This approach allows us to derive weighted indices for each sustainability pillar—social, economic, and environmental—by transforming correlated indicators into orthogonal principal components. The data sources and definitions for all indicators used are listed in Table 3, and Table 4 maps these indicators to relevant UN SDGs. Specifically, the social sustainability index comprises seven indicators, the

[2] Other indicators of transport infrastructure such as maritime and road are not included due to unavailability of data for all EU nation over selected time period.

economic index four indicators, and the environmental index twelve indicators. These sub-indices are then integrated to construct the overall IGG index.

Before applying PCA, all indicators are normalised using the min-max scaling method to ensure comparability across different units and scales. For each country, PCA is conducted separately to reflect country-specific variation in indicator dynamics, resulting in distinct sets of weights for each national IGG index. This country-specific application of PCA ensures that the resulting indices are sensitive to contextual differences in sustainability patterns. We calculate the index values using the weighted average of all PCs to retain the complete information embedded in the dataset, thereby capturing 100% of the total variance (for technical details, see Appendix Note A.2). This avoids arbitrary selection of principal components and eliminates the risk of information loss. A flow chart explaining the mechanism of PCA is given in Figure 3.

Table 3. Description and sources of inclusive green growth variables

	Description	Source
Social sustainability		
Sanitation	Population with access to improved sanitation (% total population)	OECD (2023)
Potable water	Population with access to improved drinking water sources (% total population)	OECD (2023)
Population density	Population density, inhabitants per square kilometre	OECD (2023)
Infant mortality	Mortality rate, infant (per 1,000 live births)	WDI (2023)
Life expectancy	Life expectancy at birth, total (years)	OECD (2023)
Air transport	Air transport, registered carrier departure worldwide	WDI (2023)
Railway transport	Rail lines (total route-km)	WDI (2023)
Economic sustainability		
Income growth	GDP per capita, PPP (constant 2017 international $)	WDI (2023)
Income inequality	Gini index (0 = Lowest; 1 = Highest)	Solt (2023)
Human capital index	Human capital index, based on years of schooling and returns to education	PWT (2023)
Unemployment	Unemployment, total (% of the total labour force)	WDI (2023)
Environmental sustainability		
Agricultural land	Agricultural land (% of land area)	WDI (2023)
Forest cover	Forest area (% of land area)	WDI (2023)
Temperature	Annual temperature change	OECD (2023)
Exposure to ambient PM.2.5	Mean population exposure to PM2.5	OECD (2023)
Ambient PM.2.5 mortalities	Mortality from exposure to ambient PM2.5	OECD (2023)
Ambient PM.2.5 welfare cost	Welfare costs of premature mortalities from exposure to ambient PM2.5, GDP equivalent	OECD (2023)
Methane emission	Agricultural methane emissions (thousand metric tons of CO_2 equivalent)	WDI (2023)
Carbon productivity	Demand-based carbon productivity, GDP per unit of energy-related CO_2 emissions (constant 2015 US dollars per kilogram)	OECD (2023)
Natural resources rent	Total natural resources rents (% of GDP)	WDI (2023)
Renewable energy	Renewable energy consumption (% of total final energy consumption)	WDI (2023)
Fossil fuel consumption	Fossil fuel energy consumption (% of total)	WDI (2023)

Environment-friendly technologies	Development of environment-related technologies, % all technologies	OECD (2023)

Source: Authors' construct; *Note:* WDI represents World Development Indicator; OECD represents Organisation for Economic Co-operation and Development; SWIID represents Standardized World Income Inequality Database; PWT represents Penn World Table. Some data points are imputed using interpolation and extrapolation techniques (For details, see Appendix Table B.1).

Table 4. Mapping IGG indicators to SDG

Sustainable development goals	Inclusive green growth indicators
1. No poverty	–
2. Zero hunger	Agricultural land
3. Good health and well-being	Infant mortality, life expectancy
4. Quality education	Human capital index
5. Gender equality	–
6. Clean water and sanitation	Sanitation and potable water
7. Affordable and clean energy	Renewable energy and fossil fuel consumption
8. Decent work and economic growth	Income growth and unemployment
9. Industry, innovation, and infrastructure	Environment-friendly technologies, air transport, and railway transport
10. Reduced inequalities	Income inequality
11. Sustainable cities and communities	Population density, exposure to ambient PM.2.5 ambient PM.2.5 mortalities, ambient PM.2.5 welfare cost
12. Responsible consumption and production	Natural resources rent
13. Climate action	Temperature, Methane emission, and Carbon productivity
14. Life below water	–
15. Life on land	Forest cover
16. Peace, justice, and strong institutions	–
17. Partnership for the goals	–

Source: Authors' construct

[Figure 3 here]

The scree plots generated from the PCA applied to Denmark are presented in Figure 4, while the corresponding scatter plots are illustrated in Figure 5. The scree plots display the eigenvalues associated with each principal component, enabling an assessment of their relative importance. The scatter plots, on the other hand, visualise the orthogonality of the principal components. As shown in Figure 5, the principal components are clearly uncorrelated, reaffirming the PCA's dimensional independence.

[Figure 4 here]

To further aid interpretation, Figure 6 presents biplots for the social, economic, environmental, and overall IGG indicators for Denmark, respectively. Each biplot integrates both the scores of individual observations and the loadings of variables onto a single two-dimensional plot. The points in the biplot represent individual observations based on their scores on the first two PCs—where proximity among points indicates similarity in their sustainability profiles. The arrows (vectors) denote the original variables and illustrate both their direction and strength of contribution. Vectors pointing in the same direction suggest positive correlations, while those in opposing directions indicate negative relationships. Longer vectors imply a greater contribution to the explained variance, highlighting variables that exert a stronger influence in shaping each index. Moreover, PCA results for Denmark are detailed in Appendix Tables B.2, B.3, B.4, B.5 and B.6[3]. A comparative analysis of IGG scores for 1995 and 2021 is illustrated in Figure 7, showing Czechia's leading IGG score in 1995 and Denmark's top position in 2021. Additionally, social, economic, and environmental trends for 1995 and 2021 are also visualised in Figure 7.

[Figures 5-7 here]

4.2 Empirical modelling

The relationship between IGG and energy transition in the presence of control variables can be expressed by the following expression:

$$IGG_{it} = f(RET, FD_{it}, GE_{it}, IR_{it}, EG_{it}, INTR_{it}) \quad (1)$$

where all the variables are previously defined, and subscript *i* and *t* are the number of cross-sections and time periods, respectively. The logarithmic form of the relationship can be expressed in the following way:

$$LnIGG_{it} = \beta_0 + \beta_1 LnRET_{it} + \beta_2 LnFD_{it} + \beta_3 LnGE_{it} + \beta_4 LnIR_{it} + \beta_5 LnEG_{it} + \beta_6 LnINTR_{it} + u_{it} \quad (2)$$

where β_0 is the intercept, β_i $(i = 1,2, \ldots ,6)$ represents the elasticity parameter to be estimated and u_{it} is the independent and identically distributed error term.

4.3 Econometrics Methods

Before proceeding to estimation, we need to check cross-sectional dependence (CD), which is crucial in studying panel data. Increasing globalisation and trade liberalisation have increased interdependence among countries, and ignorance of this may lead to misleading conclusions (Salahuddin, Gow, and Vink 2020). In this study, four CD tests - Breusch-Pagan Lagrange multiplier (LM) test, Pesaran scaled LM test, Pesaran CD test, Bias-adjusted LM test (Breusch

[3] Results of PCA for other countries are not provided due to space constraint. However, they are available upon request.

and Pagan 1980; Pesaran 2021; Pesaran, Ullah, and Yamagata 2008)–are carried out. The results of these tests indicate the presence of CD in the data.

In order to check the time series properties of the variables, the cross-sectionally augmented Im-Pesaran-Shin (CIPS) unit root test (Pesaran 2007) is employed, which considers the CD problem. Before estimating the model, it is required to confirm the presence of a long-run relationship among the variables. Otherwise, it may be a spurious estimation. In order to check cointegration among the concerned variables, the study applies the Pedroni (Pedroni 2004) and the Westerlund (2005) cointegration tests. Further, the study conducts diagnostic tests, including the variance inflation factor (VIF) test for multicollinearity, the Wooldridge test for autocorrelation, the modified Wald test for group-wise heteroskedasticity, the slope homogeneity test developed by Bolmquist and Westerlund[4] (2013), and the Hausman (1978) test between fixed and random effect model.

The study estimates the empirical relationship among underlying variables using the pooled mean group-autoregressive distributed lag (PMG-ARDL) model proposed by Pesaran, Shin, and Smith (1999). The PMG-ARDL model is a dynamic model that can capture the long-run and short-run effects of explanatory variables simultaneously. It is suitable when heterogeneity exists among the panel and allows for the specific lag structure of the variables. One of many appealing features of the model is that it can be applied irrespective of the order of integration of the variables, i.e., when some variables are I(0) and others are I(1) [but not I(2)]. Further, the PMG-ARDL model pools the long-run coefficients while allowing short-run coefficients, intercept, and speed of adjustment to vary across panels. Being a dynamic model, it also takes into account the potential endogeneity among the variables.

Following Pesaran, Shin, and Smith (1999), the PMG-ARDL model for this study can be expressed as follows:

$$\Delta LnIGG_{it} = \beta_0 + \rho_i LnIGG_{it-1} + \beta_1 LnRET_{it-1} + \beta_2 LnFD_{it-1} + \beta_3 LnGE_{it-1} + \beta_4 LnIR_{it-1} + \beta_5 LnEG_{it-1} + \beta_6 LnINTR_{it-1} + \varphi_{ij} \sum_{j=1}^{p-1} \Delta LnIGG_{it-j} + \omega_{1ij} \sum_{j=0}^{q-1} \Delta LnRET_{it-j} + \omega_{2ij} \sum_{j=0}^{q-1} \Delta LnFD_{it-j} + \omega_{3ij} \sum_{j=0}^{q-1} \Delta LnGE_{it-j} + \omega_{4ij} \sum_{j=0}^{q-1} \Delta LnIR_{it-j} + \omega_{5ij} \sum_{j=0}^{q-1} \Delta LnEG_{it-j} + \omega_{6ij} \sum_{j=0}^{q-1} \Delta LnINTR_{it-j} + u_{it} \quad (3)$$

Equation (3) can be expressed in the error correction form as follows:

[4] This test is robust in the presence of heteroscedasticity and serial correlation problems.

$$\Delta LnIGG_{it} = \beta_0 + \rho_i ECT_{it-1} + \varphi_{ij} \sum_{j=1}^{p-1} \Delta LnIGG_{it-j} + \omega_{1ij} \sum_{j=0}^{q-1} \Delta LnRET_{it-j} + \omega_{2ij} \sum_{j=0}^{q-1} \Delta LnFD_{it-j} + \omega_{3ij} \sum_{j=0}^{q-1} \Delta LnGE_{it-j} + \omega_{4ij} \sum_{j=0}^{q-1} \Delta LnIR_{it-j} + \omega_{5ij} \sum_{j=0}^{q-1} \Delta LnEG_{it-j} + \omega_{6ij} \sum_{j=0}^{q-1} \Delta LnINTR_{it-j} + u_{it} \quad (4)$$

Where $ECT_{it-1} = LnIGG_{it-1} - \theta_1 LnRET_{it-1} - \theta_2 LnFD_{it-1} - \theta_3 LnGE_{it-1} - \theta_4 LnIR_{it-1} - \theta_5 LnEG_{it-1} - \theta_6 LnINTR_{it-1}$ and ρ_i is the coefficient of error correction term that indicates the speed of converging the model to long-run equilibrium after any shock in explanatory variables in the short run. Statistical significance of ρ_i ensures the existence of non-linear cointegration among the underlying variables. Moreover, $\theta_1(= -\frac{\beta_1}{\rho})$, $\theta_2(= -\frac{\beta_2}{\rho})$, $\theta_3\left(= -\frac{\beta_3}{\rho}\right), \theta_4\left(= -\frac{\beta_4}{\rho}\right), \theta_5\left(= -\frac{\beta_5}{\rho}\right), and\ \theta_6\left(= -\frac{\beta_6}{\rho}\right)$ are the long-run coefficients of LnRET, LnFD, LnGE, LnINF, LnEG, and LnINTR, respectively, which are the same across panels and $\omega_{1ij}, \omega_{2ij}, \omega_{3ij}, \omega_{4ij}, \omega_{5ij},\ and\ \omega_{6ij}$ are their short-run coefficients, which vary across panels. However, if the pooling assumption does not hold, the MG estimator is applicable. The MG estimator developed by Pesaran and Smith (1995) allows both the long-run and short-run coefficients to vary across panels. To choose between PMG and MG estimators, we run the Hausman test, where the null hypothesis is the PMG estimator[5].

One of the main limitations of PMG-ARDL is that it does not consider CD, which is found in this study. Further, the data suffers from autocorrelation and heteroscedasticity problems. Therefore, in order to check the robustness of the result obtained from PMG-ARDL, the study also employs the fixed effect model with the Driscoll-Kraay standard errors (DKSE) method introduced by Driscoll and Kraay (1998), the feasible generalised least square (FGLS) method advocated by Parks (1967), and the panel-corrected standard errors (PCSE) method pioneered by Beck and Katz (1995). These methods estimate standard errors, which are robust to the presence of CD, autocorrelation, and heteroskedasticity problems Hoechle (2007) and thus provide unbiased and consistent outputs. Lastly, the study carries out the Dumitrescu-Harlin (D-H) causality test proposed by Dumitrescu and Hurlin (2012) to check the direction of causality among variables. The D-H causality test considers the CD problem. The D-H causality model is illustrated below:

$$y_{it} = \tau_i + \sum_{k=1}^{K} \delta_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \lambda_i^{(k)} x_{i,t-k} + \varepsilon_{it} \quad (5)$$

[5] For further details, kindly refer to Pesaran, Shin, and Smith (1999) and Pesaran and Smith (1995).

where τ_i denotes the constant value, $\delta_i^{(k)}$ represents the autoregressive parameters and $\lambda_i^{(k)}$ refers to the regression coefficients. The null and alternative hypotheses of the D-H causality test can be defined as follows:

$$H_0: \lambda_i = 0 \quad \forall i = 1,2,\ldots,N \tag{6}$$

$$H_1: \begin{Bmatrix} \lambda_i = 0 \quad \forall i = 1,2,\ldots,N_1 \\ \lambda_i \neq 0 \quad \forall i = N_1+1, N_1+2,\ldots,N \end{Bmatrix} \tag{7}$$

The null hypothesis indicates that there exists no causality for any cross-sectional units in the panel, whereas the alternative hypothesis implies that there exists causality for at least one cross-sectional unit in the panel. A flowchart organising and illustrating the steps involved in the overall framework is presented in Figure 8.

[Figure 8 here]

5 Results and discussion

5.1 Descriptive statistics

The discussion starts with descriptive statistics of the concerned variables, which are given in Table 5. It is found from the descriptive statistics that IR has the highest variation (SD = 41.683), whereas FD has the lowest (SD = 0.208). This implies that the inflation level largely varies across these countries while they are experiencing similar financial development. Further, IGG, RET, GE, and IR are positively skewed, whereas FD, EG, and INTR are negatively skewed. The Jarque-Bera statistic shows that all the variables do not follow a normal distribution except GE. From the heat plot of the correlation matrix (Figure 9), it is evident that RET and INTR are positively correlated with IGG, whereas GE and IR are negatively correlated with it. However, FD and EG have no significant correlation with IGG. Further, the correlations between explanatory variables are not high. Therefore, the problem of severe multicollinearity can be precluded from our study, which is more evident from the VIF test (Table 6).

[Figure 9 here]

Table 5. Descriptive statistics of study variables

Variables	Abbreviation	Mean	Std. Dev.	Skewness	Jarque-Bera
Inclusive green growth	IGG	100.142	4.041	20.819	7083111.000***
Renewable energy transition	RET	100.000	1.575	0.445	27.190***

Financial development	FD	0.531	0.208	-0.238	46.535***
Government expenditure	GE	20.006	3.004	0.079	1.484
Inflation rate	IR	5.452	41.683	24.045	10267956.000***
Economic globalisation	EG	75.822	9.818	-0.988	150.553***
Internet access	INTR	53.017	31.332	-0.378	61.920***

Source: Authors' construct; *Note*: *** denotes a 1 % significance level. (For details, see Appendix Table B.7)

Table 6. Variance inflation factor of explanatory variables

	VIF	1/VIF
LnINTR	2.887	0.346
LnEG	2.028	0.493
LnRET	1.767	0.566
LnIR	1.691	0.592
LnFD	1.451	0.689
LnGE	1.083	0.923
Mean VIF	1.818	

Source: Authors' construct.

5.2 CD and CIPS unit root tests

After confirming the absence of multicollinearity problems and before proceeding with estimation, we need to check the CD and stationary properties of the variables while dealing with panel data. Tables 7 and 8 display the results of four CD tests and the CIPS unit root test, respectively. The CD test results provide evidence of the presence of CD in data for all variables. Therefore, second-generation methods are applicable to this study. Accordingly, the result of the CIPS unit root test indicates that IGG, RET, FD, IR, and INTR are stationary at level, i.e., I(0), whereas GE and EG are stationary at the first difference, i.e., I(1). Since the variables are in mixed order, i.e., I(0) and I(1), and none of the variables are I(2), the PMG-ARDL model is appropriate.

Table 7. Results of the Cross-section dependence tests of study variables

	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LnIGG	6972.302***	272.396***	271.915***	78.184***
LnRET	5919.413***	229.412***	228.931***	76.095***
LnFD	3248.361***	120.366***	119.886***	49.257***
LnGE	1728.663***	58.325***	57.844***	17.345***
LnIR	2713.479***	98.530***	98.050***	47.973***
LnEG	4976.365***	190.912***	190.431***	64.821***
LnINTR	7726.351***	303.180***	302.699***	87.882***

Source: Authors' construct; *Note*: *** denotes a 1 % significance level.

Table 8. Result of the CIPS unit root test of study variables

	With constant		With constant and trend	
	Level	First difference	Level	First difference

LnIGG	-3.144***	-5.100***	-3.097***	-5.172***
LnRET	-2.497***	-5.558***	-2.914***	-5.645***
LnFD	-2.560***	-5.324***	-3.201***	-5.414***
LnGE	-1.637	-4.549***	-1.905	-4.693***
LnIR	-3.158***	-4.986***	-3.129***	-5.167***
LnEG	-2.519***	-4.876***	-2.457	-4.963***
LnINTR	-3.508***	-4.795***	-3.928***	-4.653***

Source: Authors' construct; *Note:* *** denotes a 1 % significance level.

Since all the variables are not stationary at the level, we need to check the existence of a long-run relationship among the underlying variables. For this, the Pedroni (2004) and the Westerlund (2005) cointegration tests were carried out. The results of the panel cointegration tests reported in Table 9 provide evidence for the existence of a long-run relationship among variables.

Table 9. Results of panel cointegration tests among underlying variables

	Test statistics
Pedroni cointegration test	Modified Phillips-Perron t = -0.673
	Phillips-Perron t = -2.036***
	Augmented Dickey-Fuller t = -5.668***
Westerlund cointegration test	Variance ratio = -2.1081**

Source: *Authors' construct; Note*: ** and *** denote 5% and 1% significance level, respectively.

5.3 PMG-ARDL Estimation

After finding a long-run relationship among the variables, we can now estimate the relationship. But before, pre-diagnostic checks are required. A perusal of the results of pre-diagnostic tests in Table 10 shows that data are not poolable and have autocorrelation and heteroskedastic problems. The result of the slope homogeneity test confirms the presence of heterogeneity among panels. In addition, the result of the Hausman test shows the presence of a fixed effect in the model. Table 11 reports the result of the PMG-ARDL model.

Table 10. Results of pre-diagnostic tests

	Test statistics
Poolability test	F (24, 644) = 1.46*
Modified Wald	χ^2 (25) = 280000***
Wooldridge test	F (1, 24) = 54036.538***
Slope homogeneity test	Δ = 7.991***, Δ_{adj} = 9.526***
Hausman test	χ^2 (6) = 25.75***

Source: Authors' construct; *Note*: *** denotes a 1 % significance level.

A perusal of Table 11 reveals that the coefficient of the error correction term is significant at the 5% level, and its value is negative. Therefore, it again confirms the existence of cointegration among the concerned variables. It further implies that after any shock in the explanatory variables, the system converges to equilibrium by 0.038% annually. In addition, according to the Hausman test, the null hypothesis cannot be rejected, which makes PMG estimators applicable to our study. RET has a negative short-run impact but a positive long-run impact on IGG in the selected EU economies. A 1% increase in RET results in a 0.038% decrease in IGG in the short run, whereas a 1.354% increase in IGG in the long run. The development of renewable energy technologies and plants is initially associated with higher costs and uncertainty, which makes this project less profitable. Therefore, profit-seeking investors remain reluctant to make their investments. Further, because of the expense of renewable energy sources, only richer people can afford them and improve their well-being, which further amplifies the inequality in society. Hence, when countries are transitioning from non-renewable to renewable energy, it can hamper their prosperity and increase inequality, thus ultimately inhibiting IGG (Maji, Sulaiman, and Abdul-Rahim 2019; Tenaw 2022).

However, in the long run, with proper government policies, when the development of the renewable energy industry reaches that threshold level from where large-scale effect starts to operate, costs go down, and profits increase. This lures more private investors in this industry and makes renewable energy more available, which further stimulates the economic growth of a country (J. Wang et al. 2023). With the availability of renewable energy sources, prices decrease, and more people can benefit from them. In addition, the consumption of renewable energy reduces GHG emissions, lessens catastrophic climate vents and thus makes the environment more sustainable (Sadiq et al. 2023), which ultimately stimulates the well-being of the people. Further, energy transition creates more job opportunities, reduces income inequality, and increases human development (Ram, Aghahosseini, and Breyer 2020; Topcu and Tugcu 2020; Kaewnern et al. 2023). Henceforth, RET has a favourable impact on IGG in the long run.

Considering the control variables, GE hampers IGG in both the long and short run in these selected nations. A 1% increase in GE reduces IGG by 0.295% and 0.017% in the long and short run, respectively. Government spending can retard economic growth if it is more recurrent spending (Onifade et al. 2020). Further, government expenditure degrades environmental quality by raising economic activities (Le and Ozturk 2020). Though public spending on social protection by EU member states is substantially high (Eurostat 2024), which increases inclusiveness in the economy, it may fail to serve the ‘growth’ and ‘green’ part, and the ultimate impact on IGG is detrimental.

Inflation promotes IGG in the short run but deteriorates it in the long run. A 1% increase in IR increases IGG by 0.002% in the short run but decreases it by 0.020% in the long run. Mild inflation is good for the economy as it stimulates investment by creating profit-making opportunities for investors (Uddin and Rahman 2023). However, sustained high inflation hampers economic growth as it reduces purchasing power and creates a dubious environment for investment (Baharumshah, Slesman, and Wohar 2016). Moreover, inflation widens the income gap (Law and Soon 2020) and degrades environmental quality (Rahman et al. 2022). As a result, inflation has a negative impact on IGG in the long run. On the other hand, FD, EG, and INTR only have significant long-run effects on IGG in these countries. A 1% increase in FD and IR inflates IGG by 0.117% and 0.008%, respectively, while a 1 % increase in EG reduces IGG by 0.351%. A developed financial system channels more investments in green projects and brings socio-economic sustainability by including more people into the banking system. Further, access to information can empower individuals, which may result in greater work prospects and higher earnings. This will ultimately boost IGG and aid in reducing social inequality. On the other hand, economic integration of the EU economies with the rest of the world may fail to serve the lower stratum of society or degrade environmental quality, thus lowering IGG. These findings are akin to studies by Ofori and Figari (2023) and Xin et al. (2023).

Table 11. Result of the PMG-ARDL model

	Coefficient	Std. Error
Long Run Equation		
LnRET	1.354***	0.143
LnFD	0.117***	0.026
LnGE	-0.295***	0.046
LnIR	-0.020***	0.006
LnEG	-0.351***	0.050
LnINTR	0.008***	0.002
Short Run Equation		
ECT(-1)	-0.038**	0.015
D(LnIGG(-1))	0.121*	0.067
D(LnRET)	-0.007	0.025
D(LnRET(-1))	-0.054**	0.022
D(LnFD)	0.001	0.002
D(LnFD(-1))	0.002	0.002
D(LnGE)	-0.017***	0.003
D(LnGE(-1))	0.005	0.004
D(LnIR)	0.001	0.001
D(LnIR(-1))	0.002*	0.001
D(LnEG)	0.008	0.010
D(LnEG(-1))	0.009	0.007
D(LnINTR)	-0.001	0.001
D(LnINTR(-1))	0.000	0.001
C	-0.038***	0.015

Hausman test	χ^2 (6) = 1.87

Source: Authors' construct; *Note*: *, **, and *** denote 10%, 5%, and 1% significance levels, respectively.

5.4 DKSE, FGLS, and PCSE Estimations

In order to validate the findings of the PMG-ARDL model, the study employs DKSE, FGLS, and PCSE methods. These methods are consistent in the presence of autocorrelation, heteroscedasticity, and CD. Therefore, they will give robustness to the findings of the PMG-ARDL model. The results are displayed in Table 12. The impact of RET on IGG is found to be positive through all three models, which establishes the consistency of the findings of the study. This statement is also true for the control variables. According to the findings of these three methods, FD and INTR enhance IGG, while GE, IR, and EG hinder it. However, all the coefficients are statistically significant only in the FGLS method.

For further sensitivity analysis, we employ the augmented mean group (AMG) estimator introduced by Eberhardt and Teal (2010) and the dynamic common-correlated effects (DCCE) estimator advocated by Chudik and Pesaran (2015). Both estimators address the problems of nonstationarity, cross-sectional dependence, and slope heterogeneity. The results are consistent with those of PMG-ARDL, DKSE, FGLS, and PCSE, which strengthens the reliability of our study findings. For further details, see Appendix Table B.8.

Table 12. Results of DKSE, FGLS, and PCSE methods

	DKSE	FGLS	PCSE
LnRET	0.594***	0.094***	0.214
	(0.102)	(0.007)	(0.190)
LnFD	0.033	0.017***	0.040**
	(0.028)	(0.001)	(0.019)
LnGE	-0.038	-0.045***	-0.072**
	(0.030)	(0.001)	(0.034)
LnIR	-0.003	-0.0009***	-0.004
	(0.003)	(0.0003)	(0.006)
LnEG	-0.090	-0.057***	-0.170***
	(0.068)	(0.003)	(0.046)
LnINTR	0.005**	0.004***	0.002
	(0.002)	(0.0002)	(0.004)
Constant	2.387	4.549***	4.603***
	(0.296)	(0.039)	(0.855)
F (6, 26)	233.15***		
Wald $\chi^2(6)$ for FGLS		2408.23***	
Wald $\chi^2(6)$ for PCSE			16.61***

Source: Authors' construct; *Note*: ** and *** denote 5% and 1% significance levels, respectively.

5.5 D-H causality test

Model estimation does not provide any information regarding the direction of causality among the variables. Therefore, the study further carries out the D-H causality test. Table 13 exhibits the findings of the D-H causality test. The table shows that a bidirectional causality exists between RET and IGG, FD and IGG, and EG and IGG. On the other hand, a unidirectional causality runs from IR and INTR to IGG. Further, a unidirectional causality running from IGG to GE has been found.

Table 13. Result of the D-H causality (null hypotheses) test with respect to IGG

	W-Stat.	Zbar-Stat.	Direction
RET, FD, EG (bidirectional)			
LnRET ≠ LnIGG	5.190***	12.283***	LnRET ↔ LnIGG
LnIGG ≠ LnRET	5.821***	14.176***	
LnFD ≠ LnIGG	4.449***	10.060***	LnFD ↔ LnIGG
LnIGG ≠ LnFD	3.294***	6.597***	
LnEG ≠ LnIGG	7.880***	20.354***	LnEG ↔ LnIGG
LnIGG ≠ LnEG	2.357***	3.786***	
INF, INTR, GE (unidirectional)			
LnINF ≠ LnIGG	5.579***	13.452***	LnINF → LnIGG
LnIGG ≠ LnINF	1.520	1.273	
LnINTR ≠ LnIGG	8.675***	22.740***	LnINTR → LnIGG
LnIGG ≠ LnINTR	1.107	0.036	
LnGE ≠ LnIGG	1.257	0.484	LnIGG → LnGE
LnIGG ≠ LnGE	3.199***	6.311***	

Source: Authors' construct; *Note*: *** denotes a 1 % significance level. ≠ denotes no causality, whereas → and ↔ denote unidirectional and bidirectional causality, respectively.

6 Conclusion and policy implication

The objective of the study is to explore the impact of RET on IGG in 25 European economies over the period 1995-2021. The empirical analysis of the study is based on advanced econometric techniques, including the PMG-ARDL model, DKSE, FGLS, PCSE methods, and the D-H causality test. The present study is in line with previous literature (Bhattacharya et al. 2016; Topcu and Tugcu 2020; Gao and Chen 2023), exploring the impact of renewable energy transition on three aspects of sustainability—economy, society, and environment—but separately. The novelty of this study, on the other hand, lies in considering all three aspects of sustainability together. For this purpose, the study using 23 indicators has devised a composite index of IGG, which reflects most of the SDGs (SDG 2-4, 6, 7-10, 12 and 15) and unravelled the complete impact of RET on IGG, more so in the EU. Further, where most of the previous studies have used a single indicator of energy transition, the current study has developed a composite index that can capture the complexity of energy transition more prominently.

Therefore, the study provides more comprehensive findings that will be more applicable to the context of the EU. First, the panel cointegration test results confirm the long-run relationship among the concerned variables. The PMG-ARDL model results reveal that RET diminishes IGG in the short run while augmenting it in the long run in the selected EU countries. Second, the study discovers that FD and INTR foster IGG while GE, INF, and EG decline it in the long run in these economies.

Furthermore, the findings of DKSE, FGLS, and PCSE methods provide robustness to the result of the PMG-ARDL. Third, according to the result of the D-H causality test, a bidirectional causality prevails between RET and IGG, FD and IGG, and EG and IGG. On the other hand, a unidirectional causality running from IR and INTR to IGG and from IGG to GE has been found. Moreover, our study provides greater avenues to the UN's SDGs as it comprehends how renewable energy transition fosters IGG in the EU.

Based on the findings, the study suggests fostering a renewable-based energy transition in the EU countries. Despite seven EU countries ranking in the top ten of energy transitioning countries, other countries such as Cyprus, Ireland, Czech Republic, and Italy lag behind and perform poorly in terms of energy transition (WEF 2024). Disparities have been found in the share of renewable energy sources among EU nations. Some countries' shares are far higher than the current EU average (around 22%), such as Sweden (62.6%), Finland (43.1%), and Latvia (42.1%), while most of the countries have lower renewables shares than the EU average, with Belgium, Ireland, the Netherlands, Malta, and Luxembourg having the lowest shares (all under 13%). These intra-EU inequalities could restrict the overall benefit of energy transition, and hence, it is essential for each EU member state to promote energy transition. However, there are some practical challenges in boosting energy transition. Initially, energy transition is accompanied by higher costs and may have a negative impact on IGG. In the long run, with new renewable plants and technologies, energy transition can bring desirable sustainability to the economy, society, and environment. Therefore, these countries will have to cross the first hurdle to get the beneficial impacts of the energy transition. This can be done by channelling more investments towards renewable energy deployment (Bhattacharya et al. 2016). However, EU nations may find difficulties in funding energy transition due to rising defence expenditures as a result of the Russia-Ukraine war. Special care is indeed required in this regard.

On the other hand, more attention should be paid to the EU's manufacturing sector since the manufacturing sector is highly energy intensive and hence is experiencing growing competition in net-zero technologies (Graevenitz and Rottner 2023). In this context, the "European Green Deal" adopted by the EU nations is a key strategy for promoting a just and inclusive transition. Therefore, EU countries should focus on making the strategy successful. The study further suggests accelerating the wide penetration of ICTs and developing the digital infrastructure throughout these economies to make their growth inclusive and green. This policy implication allies with the policy provided by Xin et al. (2023) for the Chinese cities. However, the digital divide, which is still significant in the EU, could be an obstacle (In 2021, just 54% possessed basic or above basic digital skills (Eurostat 2023). Henceforth, the government of these regions should also focus on skill development programs. Further, these countries should be careful while integrating with other nations economically, as economic integration may fail to include the lower section of society and worsen environmental quality. Therefore, if these economies' policymakers want to promote IGG, they must rethink and redesign their FDI and trade policies (Ofori and Figari 2023). Though the above-mentioned policies are recommended for EU nations, they are also applicable to other similar developed economies such as Japan, Singapore, South Korea, Australia, New Zealand, the United States, and the United Kingdom. In addition, renewable energy transition is equally essential for transition economies like Brazil, China, India, Indonesia, Russia, Turkey, and so on. These economies are on a transition path and will require a large amount of energy in the coming years. If they use more renewable energy source, it will make their progress more sustainable ecologically while ensuring social equity. However, their challenges may be different than those of developed nations.

Despite its substantial contribution to the existing body of knowledge, the study has certain limitations. The study is based on country-specific and annual-level data, which reduces the granularity of the analysis. The IGG index developed in this study does not cover all 17 goals, which limits the complete understanding of sustainability in these regions. Further, the study does not test the potential asymmetry in the relationship between RET and IGG.

Future research could explore the temporal and geographical scope beyond the study's limitations, incorporating more comprehensive data sources and alternative methodologies to validate causality relationships. A deeper analysis of sector-specific impacts and policy mechanisms could provide valuable insights for policymakers promoting IGG amidst energy transitions. Asymmetry modelling techniques can capture the asymmetric nature of this relationship, while comparative studies across regions could enhance external validity and inform broader policy discussions on sustainability.

Appendix A: Notes

A.1. Smil (2010) defines energy transition as "the change in the composition (structure) of primary energy supply, the gradual shift from a specific pattern of energy provision to a new state of an energy system." The ongoing energy transition from fossil fuel to renewable energy is driven by global concerns over growing greenhouse gas emissions, climate change and energy security. Since the ratification of the Kyoto Protocol in 2005, energy transition has progressed significantly. In 2021, the total installed capacity of renewable electricity was 3064 gigawatts, producing about 8000 terawatt-hours of electricity (IRENA 2022). In 2022, renewable energy consumption increased by 13%, reaching about 46 exajoules (EJ). Most of this (more than 70%) came from wind and solar energy, reaching nearly 20 EJ and 13 EJ, respectively (EI 2023). Energy transition-related investment grew by 21% globally, reaching just USD 1 trillion in 2021 (BloombergNEF 2022). Renewable energy is the largest share, attracting USD 366 billion (excluding large hydropower).

A.2. The PCA transforms highly correlated variables (indicators) into mutually orthogonal principal components (PCs), i.e., $corr\ (P_i, P_j)\ =\ 0$, where P_i and P_j are the i^{th} and j^{th} PCs. The PCs have the property that the first component holds the largest proportion; the second component holds the second largest proportion of total variation in all indicators, and so on. If we compute as many PCs as the number of indicators, we can fully explain the total variation of all indicators. The composite index (CI) is defined as the weighted average of all PCs: $CI = \frac{\lambda_1 P_1 + \lambda_2 P_2 + \cdots + \lambda_k P_k}{\lambda_1 + \lambda_2 + \cdots + \lambda_k}$

where $P_1, P_2, \dots, P_k$ are the k-number of PCs and $\lambda_1 > \lambda_2 > \cdots > \lambda_k$ are the successive eigenvalues of the $k\ \times\ k$ correlation matrix of the indicators. The eigenvalues of the correlation matrix R can be computed by solving the determinant equation $|R - \lambda I| = 0$.

Corresponding to each eigenvalue (λ_i), the $k \times 1$ eigenvector can be obtained by solving the matrix equation $(R - \lambda_i I)\alpha_i = 0$. Finally, the PCs are obtained as normalised linear functions of the standardised variables:

$$\begin{aligned} P_{1,it} &= X_{it}\alpha_1 \\ P_{2,it} &= X_{it}\alpha_2 \\ &\vdots \\ P_{k,it} &= X_{it}\alpha_k \end{aligned}$$

where X_{it} refers to the vector of standardised variables for the i^{th} country in t time period. However, before applying PCA, all the variables are normalised to ensure that they are positively related to the index. The following normalisation method has been followed:

For negative indicators, $x_{ij} = \frac{Max(X_{ij}) - X_{ij}}{Max(X_{ij}) - Min(X_{ij})}$

For positive indicators, $x_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})}$

where $Max(X_{ij})$ and $Min(X_{ij})$ are the maximum and minimum values of the j^{th} observation of i^{th} country. It will transform all the indicators on a scale of 0–1, where the lowest value is 0 and the highest value is 1.

Appendix B: Tables

.1: Information about extrapolated and interpolated data

Variables	Time Period (Method)	Country
Sanitation	1995-1999[a]	All countries
Potable water	1995-1999[a]	All countries
Methane emission	2021[b]	All countries
Exposure to ambient PM.2.5	1996-1999[c], 2020-2021[b]	All countries
Ambient PM.2.5 mortalities	2020-2021[b]	All countries
Ambient PM.2.5 welfare cost	2020-2021[b]	All countries
Environment-friendly technologies	2020-2021[b]	All countries
Human capital index	2020-2021[b]	All countries
Agricultural land	1995-1999[b]	Belgium
Renewable energy	2021[b]	All countries
Fossil fuel consumption	2016-2021[b]	All countries
Carbon productive	2019-2021[b]	All countries

Source: Authors' construct; *Note*: a, b, and c denote linear extrapolation, five-year moving average extrapolation, and linear interpolation, respectively

Table B.2. Principal components and eigenvalues for IGG and its sub-indices (Denmark)

Component	Eigenvalue	Difference	Proportion	Cumulative	KMO Statistics
Social sustainability					
Comp1	5.330	4.492	0.761	0.761	0.649
Comp2	0.838	0.220	0.120	0.881	0.732
Comp3	0.618	0.468	0.088	0.969	0.828
Comp4	0.150	0.097	0.021	0.991	0.715
Comp5	0.052	0.043	0.007	0.998	0.901
Comp6	0.009	0.005	0.001	1.000	0.755
Comp7	0.004		0.001	1.000	0.775
					0.761
Economic sustainability					
Comp1	2.887	1.805	0.722	0.722	0.635
Comp2	1.082	1.061	0.271	0.992	0.676
Comp3	0.021	0.012	0.005	0.998	0.718

Comp4	0.010	-	0.002	1.000	0.088
Overall	-	-	-	-	0.606
Environment sustainability					
Comp1	9.034	7.741	0.753	0.753	0.848
Comp2	1.293	0.469	0.108	0.861	0.865
Comp3	0.824	0.398	0.069	0.929	0.676
Comp4	0.426	0.214	0.035	0.965	0.937
Comp5	0.212	0.122	0.018	0.982	0.730
Comp6	0.090	0.044	0.007	0.990	0.733
Comp7	0.047	0.016	0.004	0.994	0.930
Comp8	0.031	0.005	0.003	0.996	0.289
Comp9	0.026	0.011	0.002	0.999	0.891
Comp10	0.015	0.012	0.001	1.000	0.825
Comp11	0.003	0.003	0.000	1.000	0.766
Comp12	0.000	-	0.000	1.000	0.883
Overall	-	-	-	-	0.814
IGG					
Comp1	2.886	2.791	0.962	0.962	0.664
Comp2	0.095	0.077	0.032	0.994	0.909
Comp3	0.019	-	0.006	1.000	0.703
Overall	-	-	-	-	0.742

Source: Authors' construct; *Note*: KMO refers to Kaiser-Meyer-Olkin.

Table B.3. Eigenvectors for social sustainability (Denmark)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7
SANIT	0.380	0.025	0.564	-0.403	-0.341	-0.116	0.494
POP	-0.422	-0.005	-0.239	0.248	-0.227	0.352	0.727
POWAT	0.411	0.012	0.054	0.759	-0.482	-0.085	-0.112
INFT	0.421	-0.008	-0.195	0.229	0.648	-0.319	0.459
LIFEXP	0.430	0.008	0.079	-0.009	0.224	0.868	-0.071
AIR	-0.260	0.761	0.479	0.252	0.246	0.017	-0.006
RAIWAYS	-0.280	-0.648	0.590	0.289	0.263	0.026	-0.002

Source: Authors' construct

Table B.4. Eigenvectors for economic sustainability (Denmark)

Variable	Comp1	Comp2	Comp3	Comp4
INCGRO	0.562	0.264	0.784	-0.022
INEQ	-0.582	0.111	0.400	0.699
HCI	0.585	-0.055	-0.381	0.714
UNEMP	-0.053	0.957	-0.285	-0.034

Source: Authors' construct

Table B.5. Eigenvectors for environmental sustainability (Denmark)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9	Comp10	Comp11	Comp12
AGRIC	-0.252	-0.163	-0.196	0.918	0.092	0.007	0.128	0.005	0.023	0.051	0.004	0.004
FOREST	0.329	0.091	-0.041	0.070	0.155	-0.068	0.170	0.010	-0.169	-0.056	-0.887	0.034
TEMP	-0.173	0.172	0.896	0.126	0.317	0.034	0.120	0.024	0.053	-0.036	-0.010	0.004
AMB	0.314	0.169	-0.015	0.177	0.329	0.233	-0.771	0.231	-0.064	0.154	0.046	0.010
AMBMORT	0.328	-0.106	0.025	0.027	0.171	0.130	0.212	-0.292	-0.294	0.232	0.182	-0.728
AMBCOST	0.327	-0.119	0.021	0.013	0.177	0.125	0.245	-0.259	-0.349	0.231	0.253	0.682
METHANE	0.299	-0.319	0.070	0.009	-0.133	0.662	0.241	0.339	0.403	-0.111	-0.018	0.004
NATRES	0.061	0.843	-0.089	0.145	-0.321	0.299	0.182	-0.118	0.059	0.101	0.062	0.009
RENENER	0.327	0.083	0.013	0.163	-0.009	-0.118	-0.013	-0.053	-0.169	-0.871	0.233	-0.015
CARPRO	0.316	0.182	-0.095	0.016	0.220	-0.498	0.322	0.571	0.206	0.186	0.234	-0.025
FOSFUEL	0.326	-0.044	0.055	0.094	0.023	-0.243	-0.135	-0.565	0.690	0.065	-0.022	0.044
ENVTECH	0.282	-0.165	0.360	0.216	-0.727	-0.241	-0.166	0.132	-0.207	0.204	-0.025	-0.002

Source: Authors' construct

Table B.6. Eigenvectors for IGG (Denmark)

Variable	Comp1	Comp2	Comp3
Social	0.583	-0.324	-0.745
Economic	0.570	0.817	0.090
Environment	0.580	-0.477	0.660

Source: Authors' construct

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Table B.7. Period-wise descriptive statistics of control variables

	1995		2010		2019		2021	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Financial development	0.401	0.174	0.582	0.195	0.536	0.204	0.529	0.204
Government expenditure	20.365	3.546	20.817	3.013	19.747	3.005	20.959	3.076
Inflation rate	12.885	15.686	1.912	1.557	1.766	0.997	2.949	1.185
Economic Globalisation	64.056	13.397	77.249	7.401	80.591	5.366	80.332	5.240
Internet access	2.048	2.945	69.410	14.764	84.196	8.171	88.338	6.576

Source: Authors' construct

Table B.8. Results of AMG and DCCE estimators

	AMG	DCCE
L.LnIGG		-0.318***
		(0.065)
LnRET	0.277***	0.066**
	(0.004)	(0.029)
LnFD	0.004	-0.003
	(0.004)	(0.005)
LnGE	-0.009	-0.018***
	(0.009)	(0.006)
LnIR	0.0003	-0.0004
	(0.0010)	(0.0006)
LnEG	-0.007	-0.001
	(0.020)	(0.008)
LnINTR	0.010***	0.0014**
	(0.001)	(0.0006)
Constant	3.235***	0.570***
	(0.195)	(0.198)

Source: Authors' construct; *Note*: ** and *** denote 5% and 1% significance levels, respectively.

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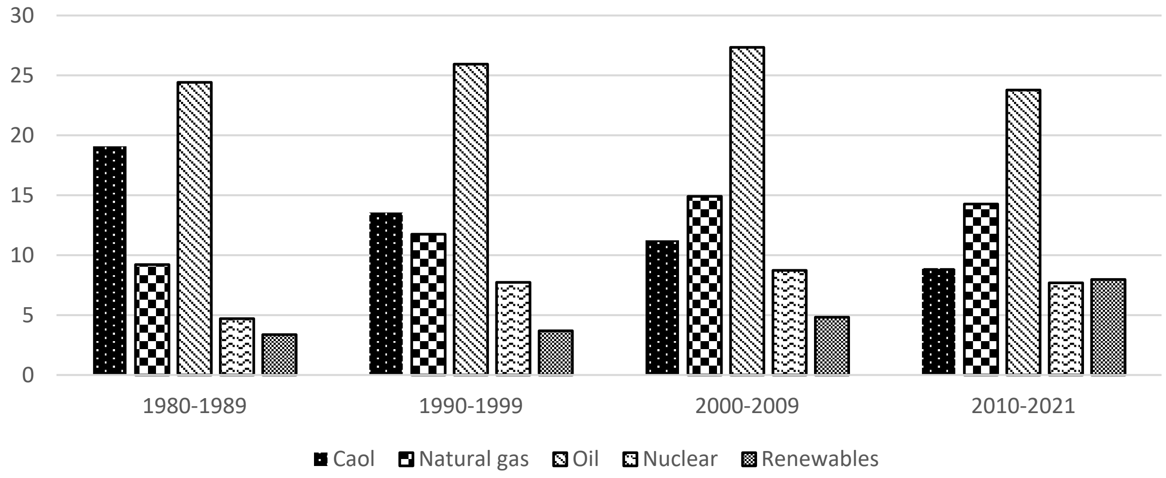
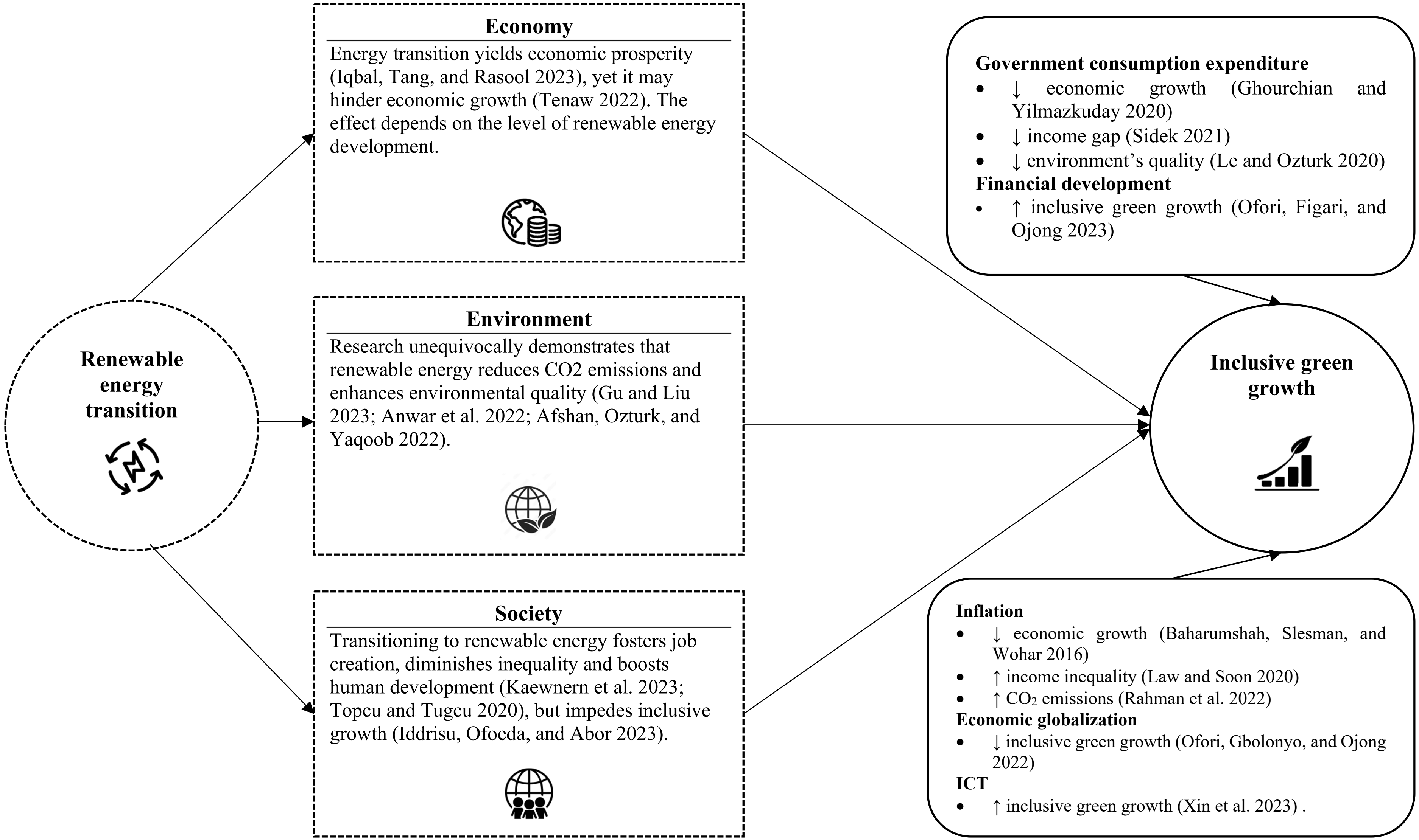
Figures

Figure 1. Periodic average of energy consumption by sources of EU



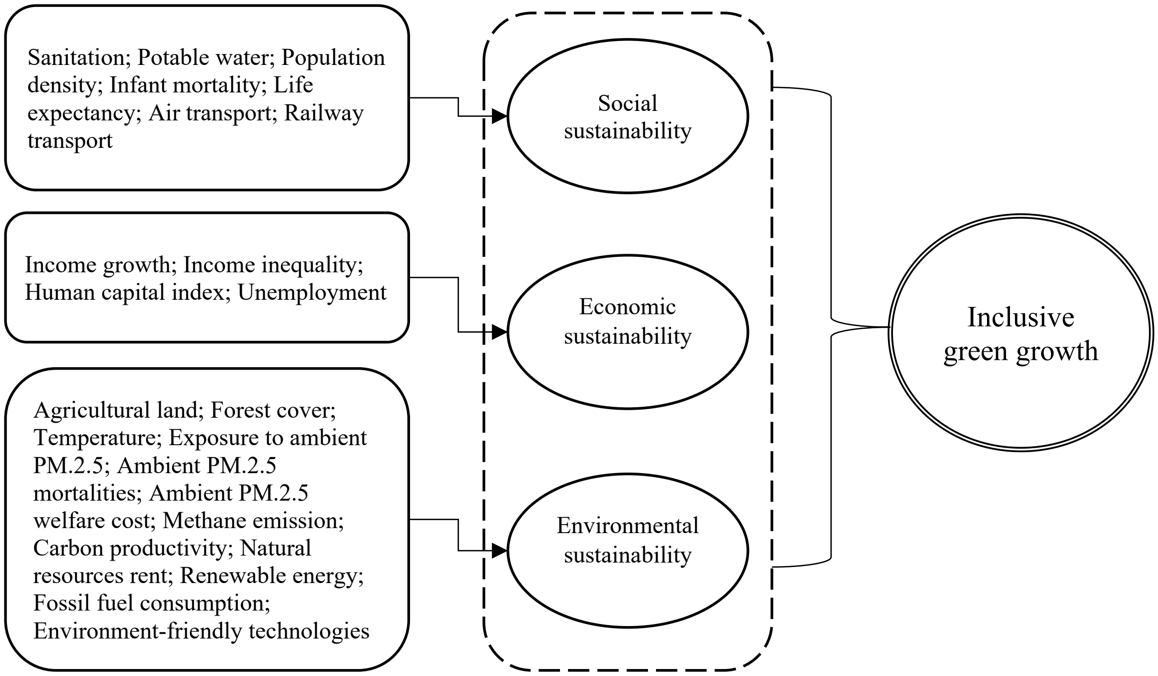
Source: Authors' construct; *Note*: Initial data retrieved from US Energy Information Association.

Figure 2. Mechanism of energy transition affecting IGG



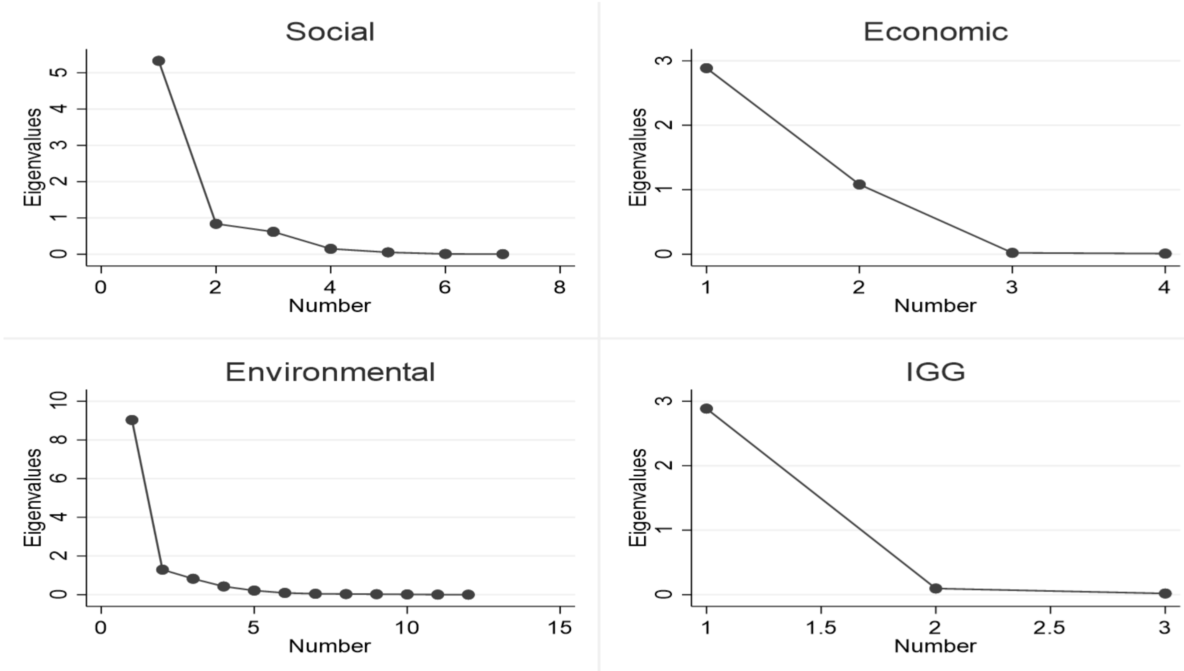
Source: Authors' construct.

Figure 3. Flow chart of obtaining IGG score



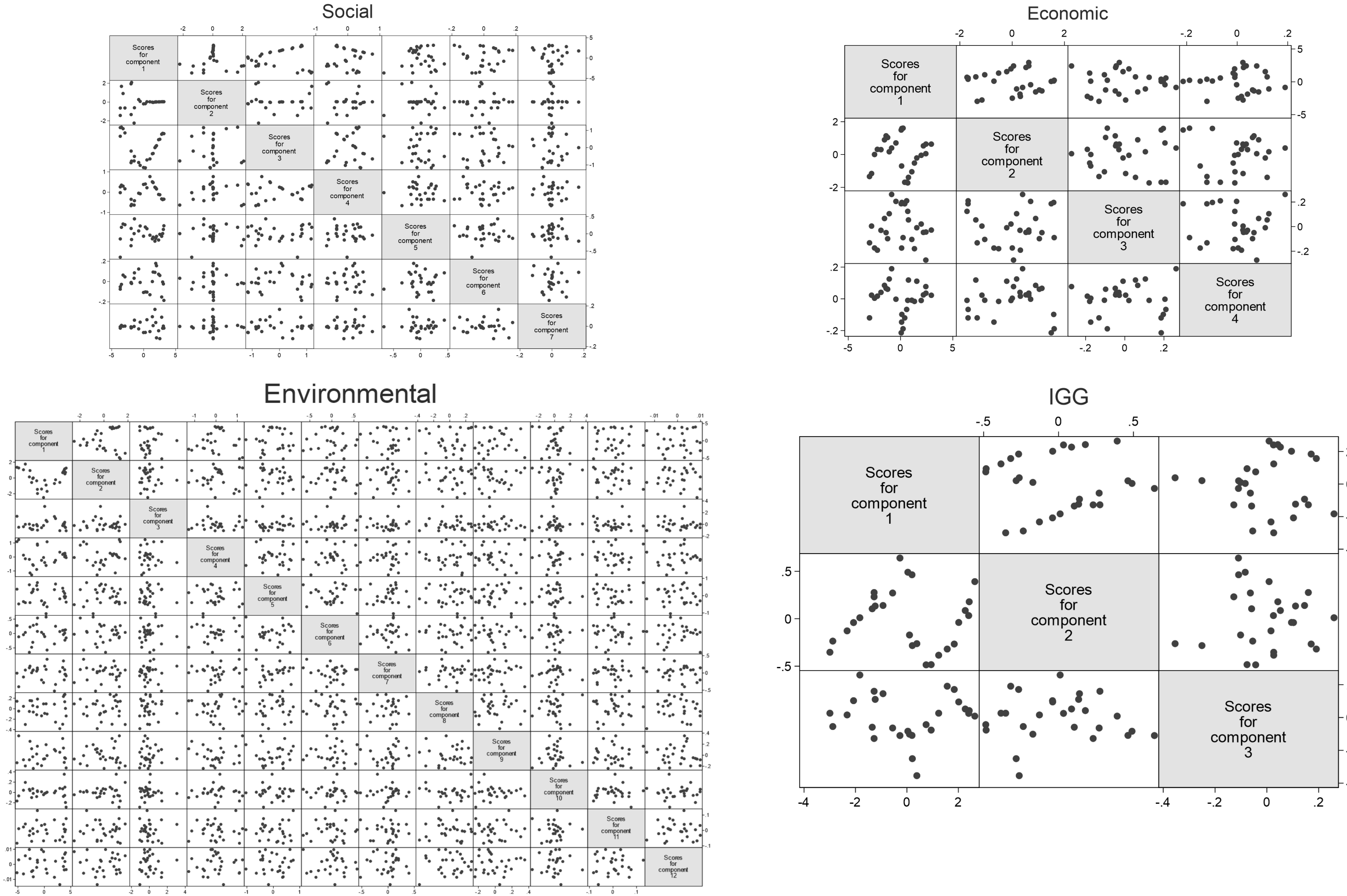
Source: Authors' construct.

Figure 4. Scree plot of components' eigenvalue



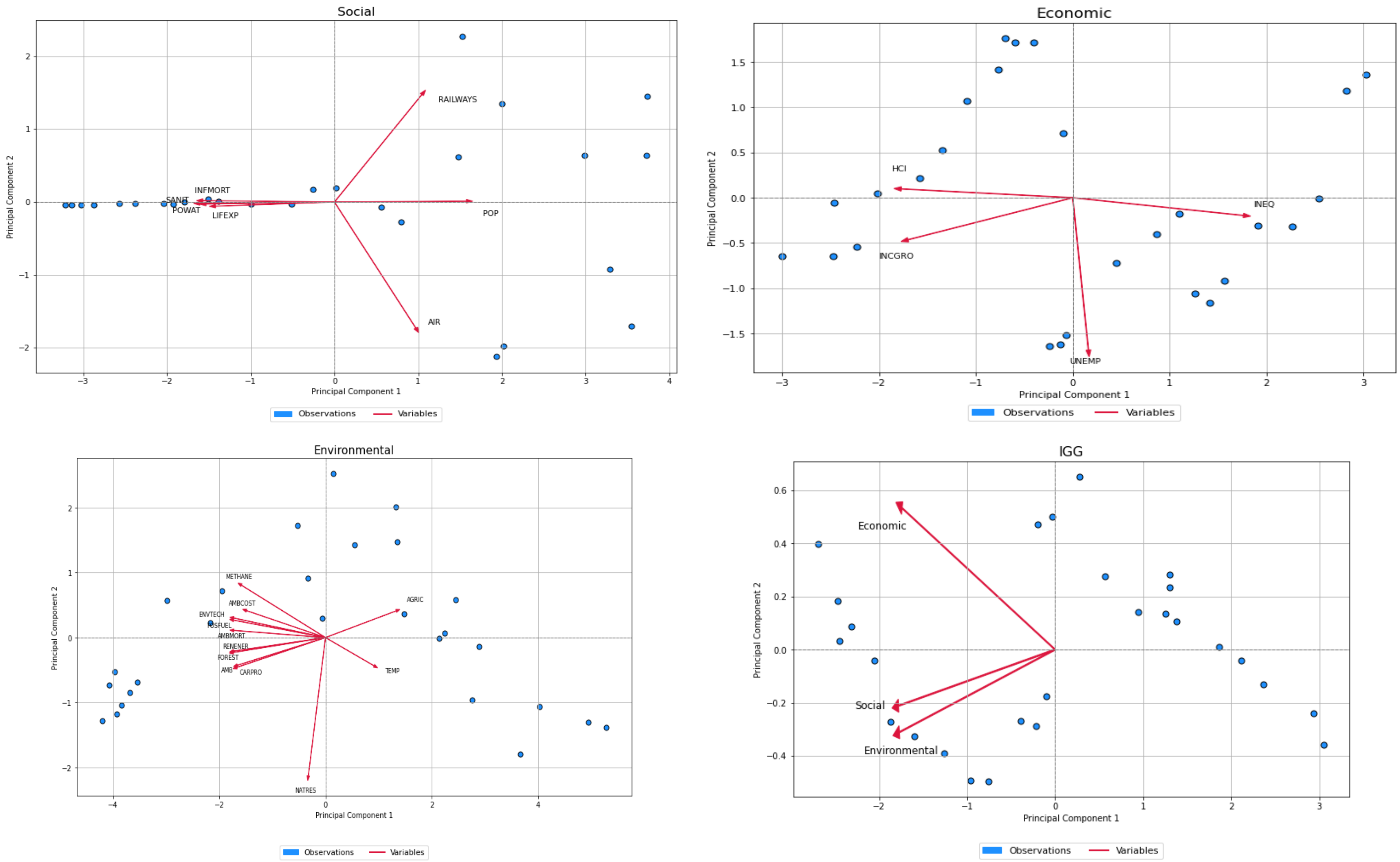
Source: Authors' construct.

Figure 5. Scatterplot of PCs of social, economic and environmental sustainability and IGG



Source: Authors' construct.

Figure 6. Biplot of social, economic, environmental and IGG indicators

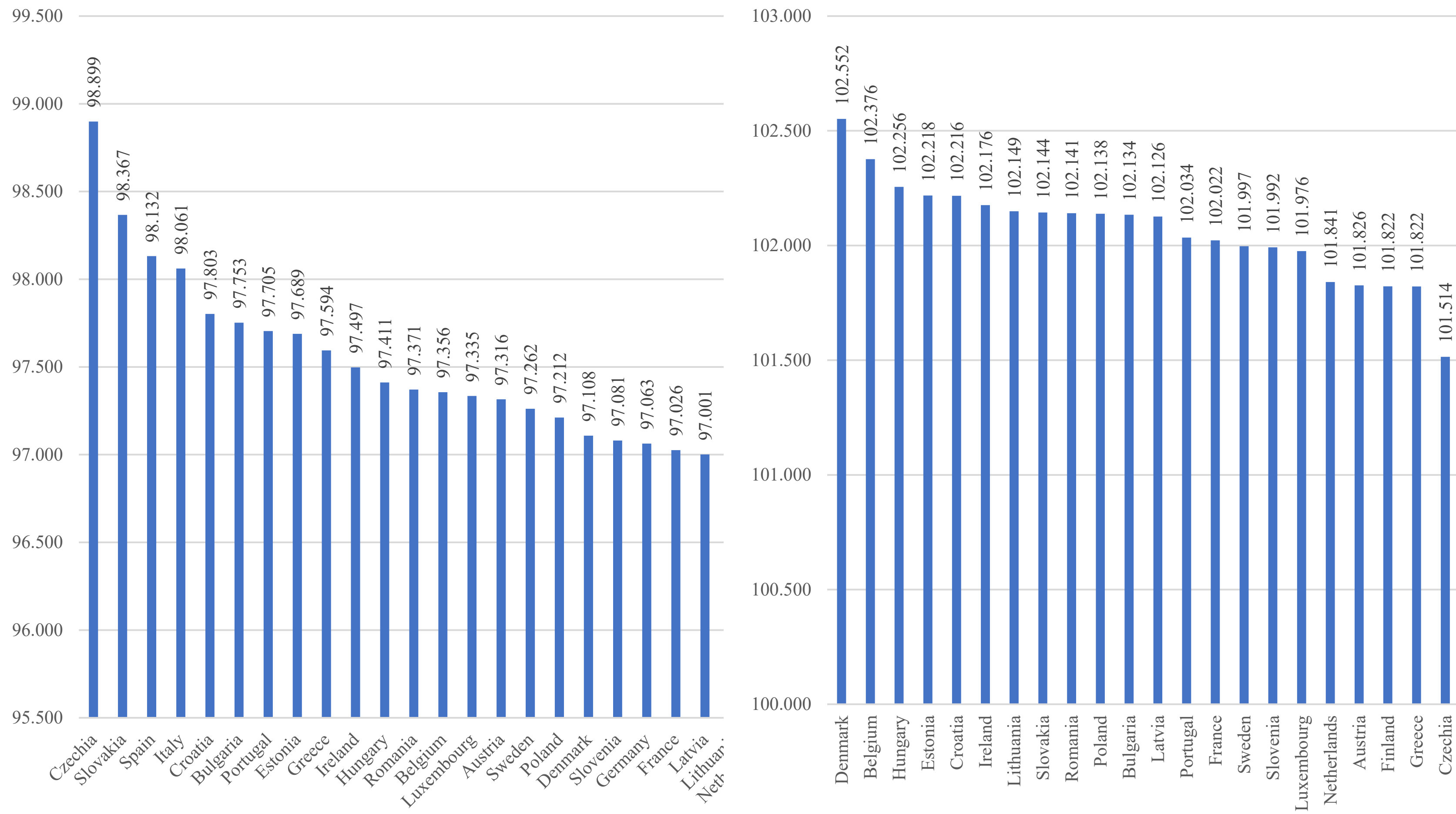


Source: Authors' construct.

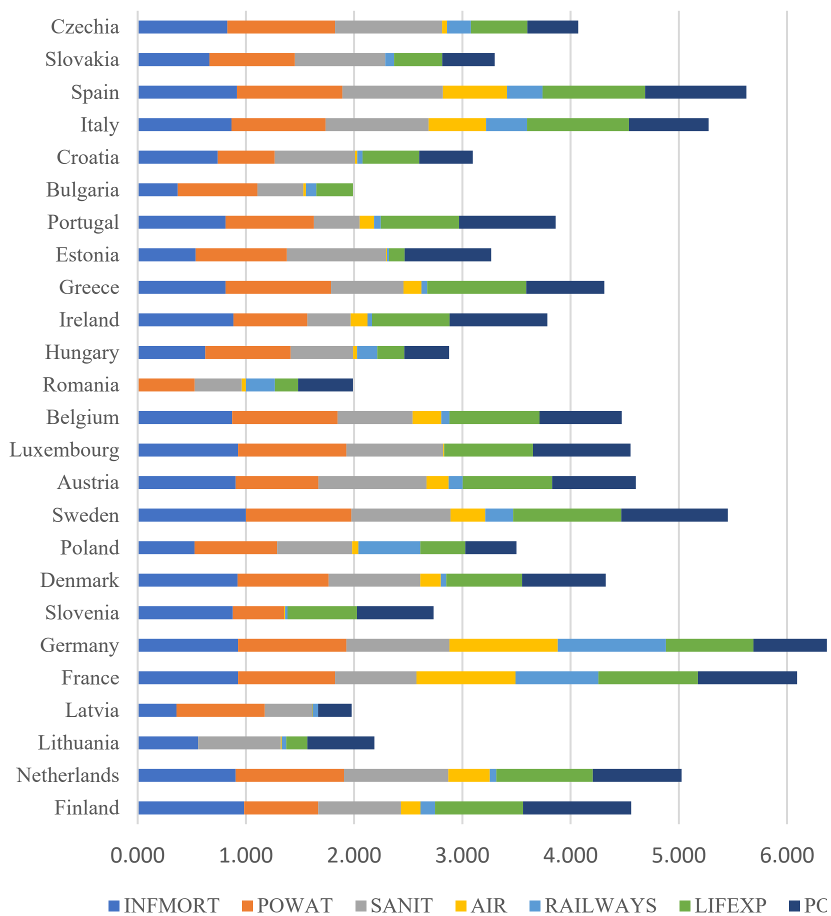
Figure 7. Countrywide IGG scores and its components: 1995 vs. 2021

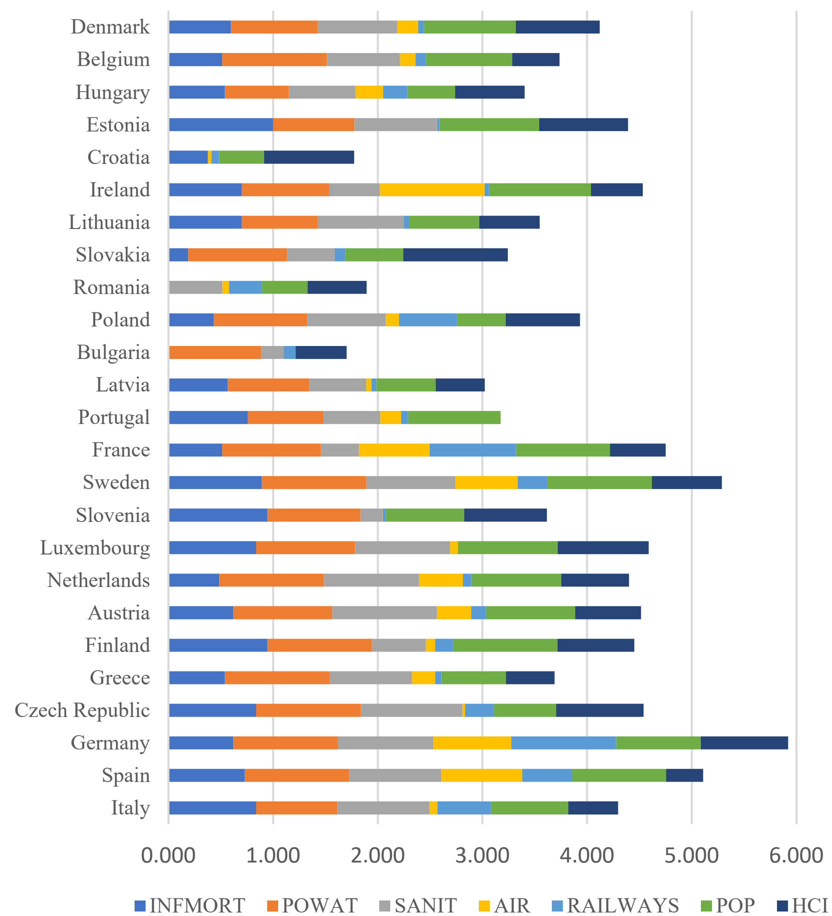
1995	2021

IGG scores

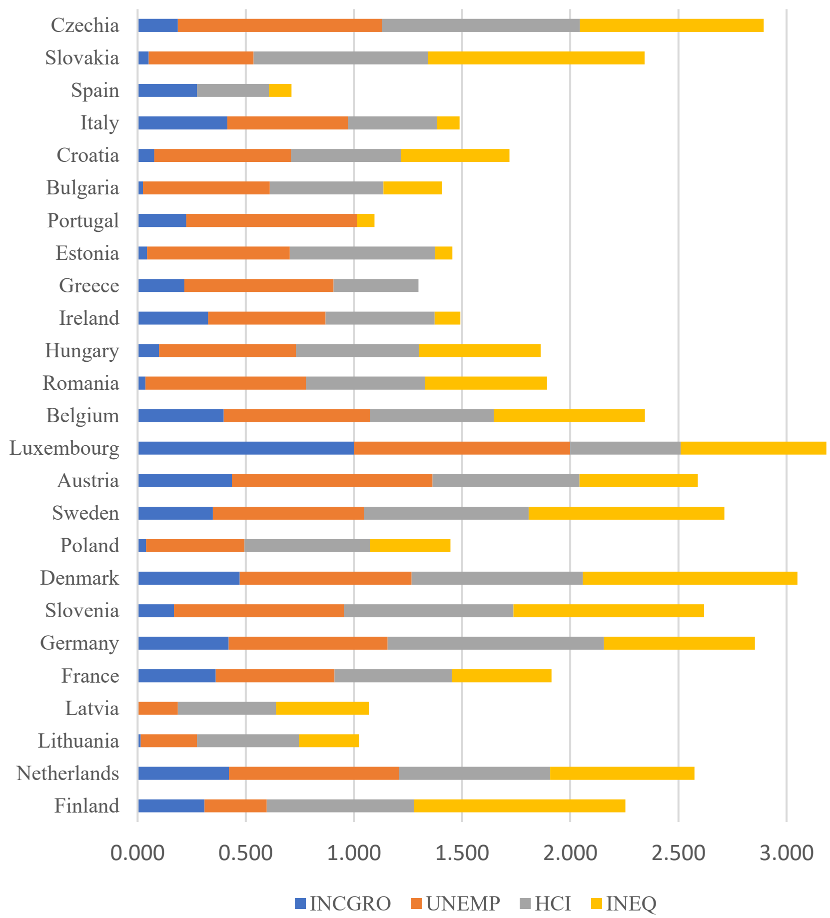


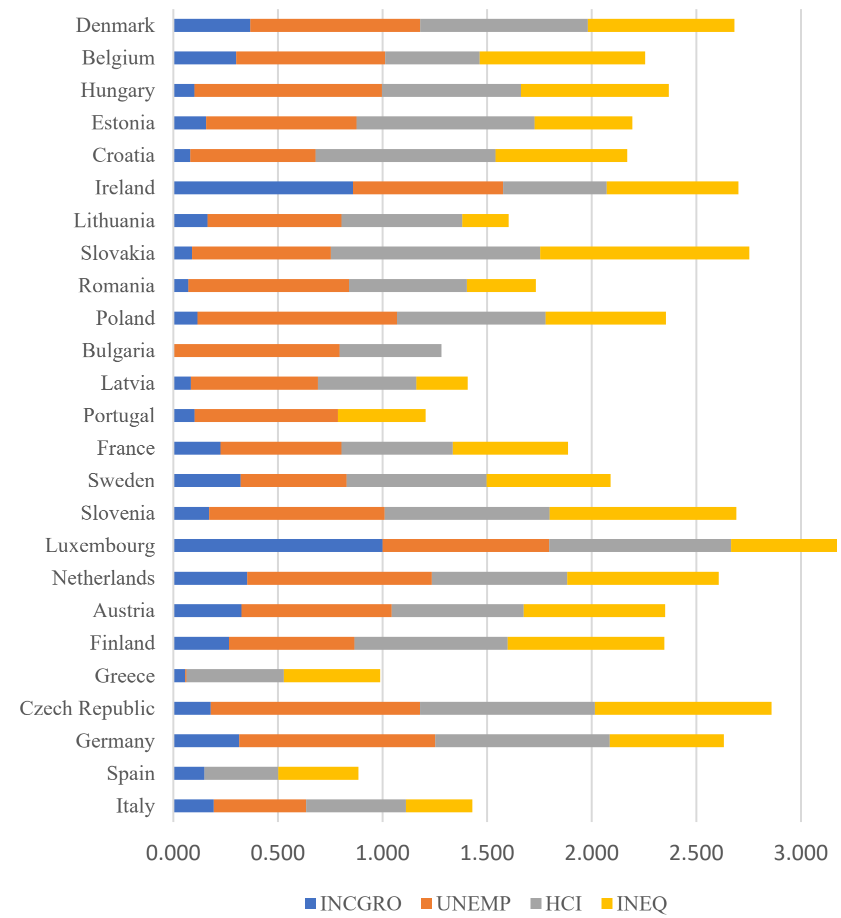
Social indicators



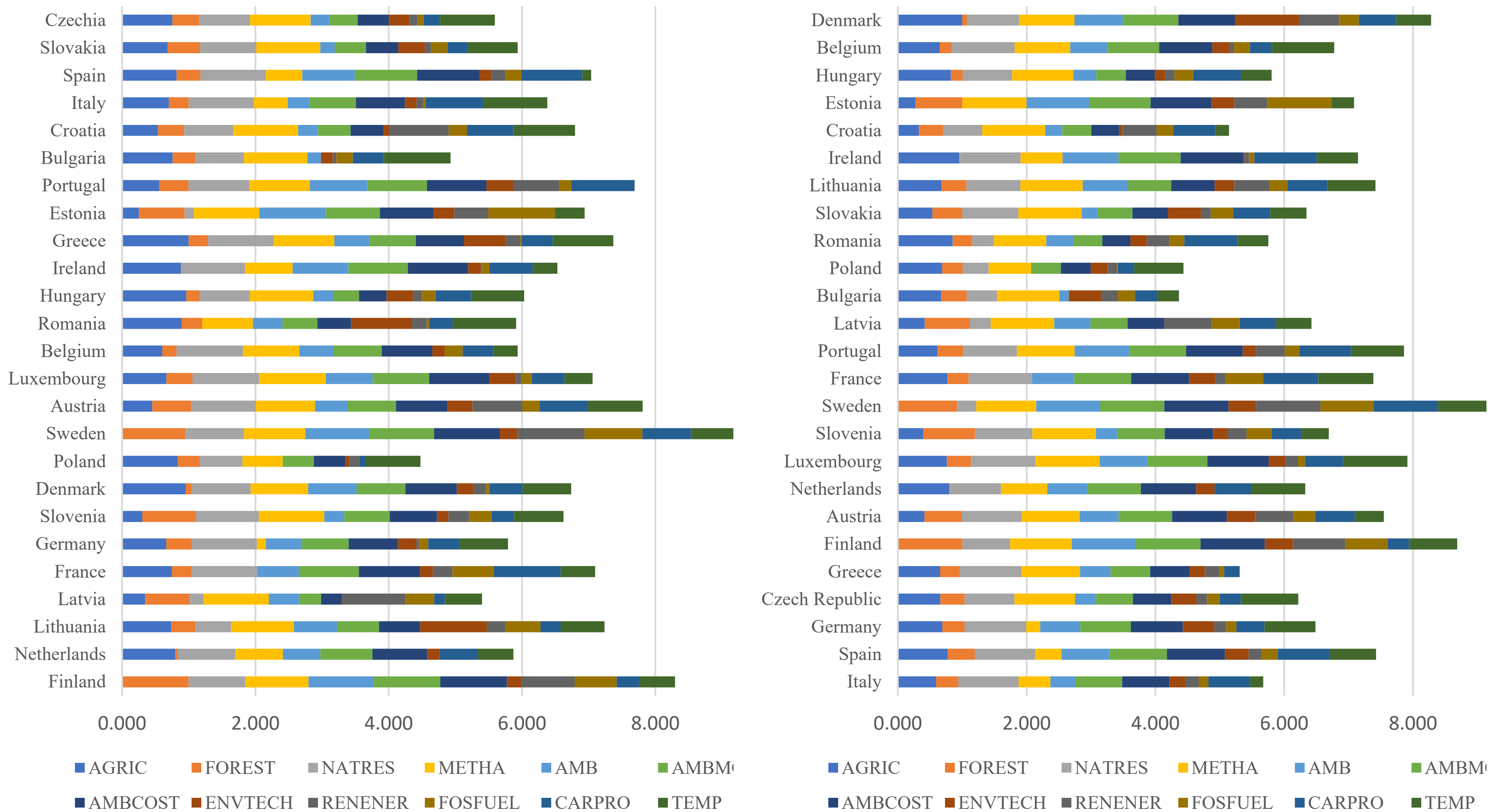


Economic indicators



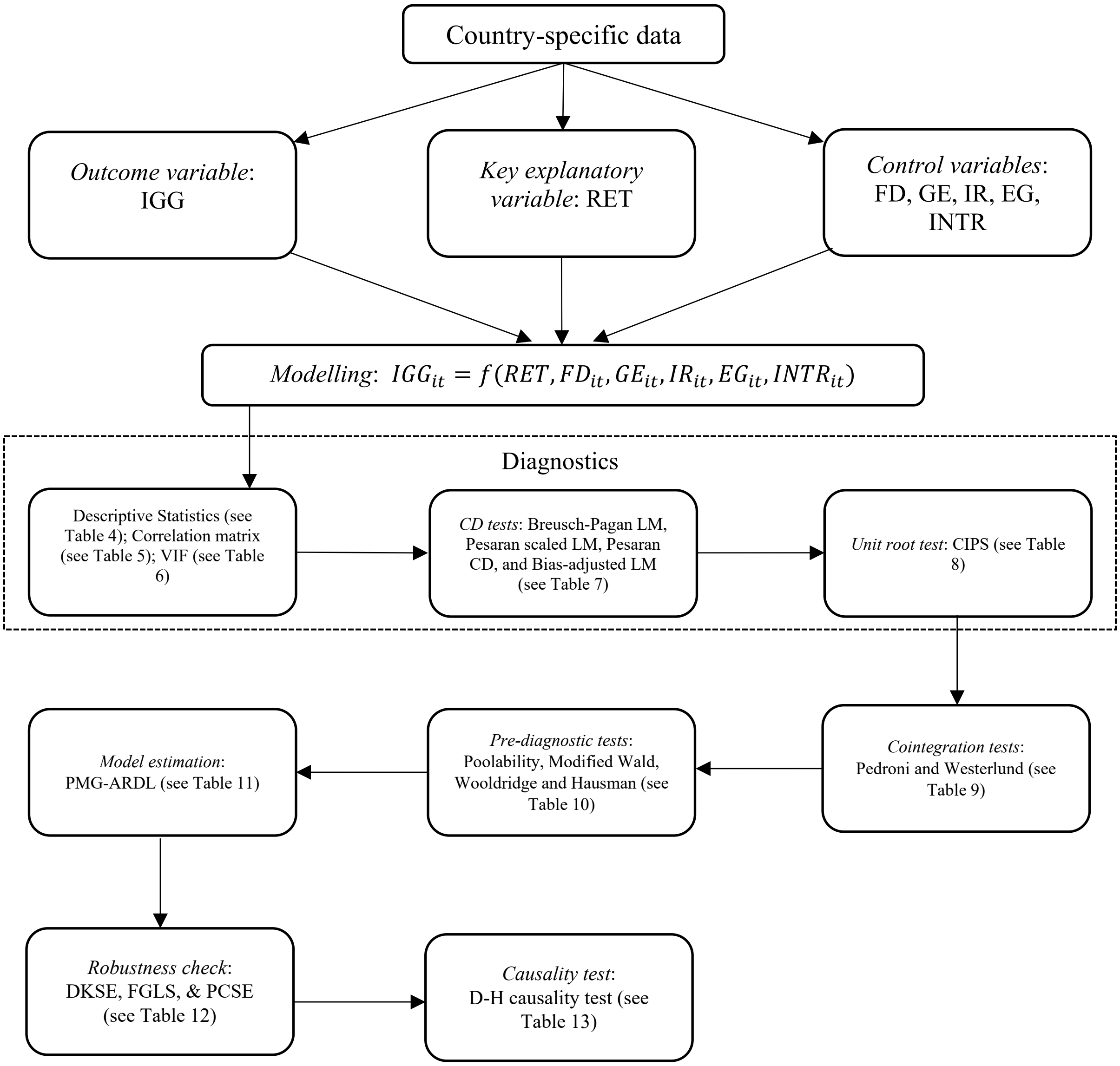


Environmental indicators



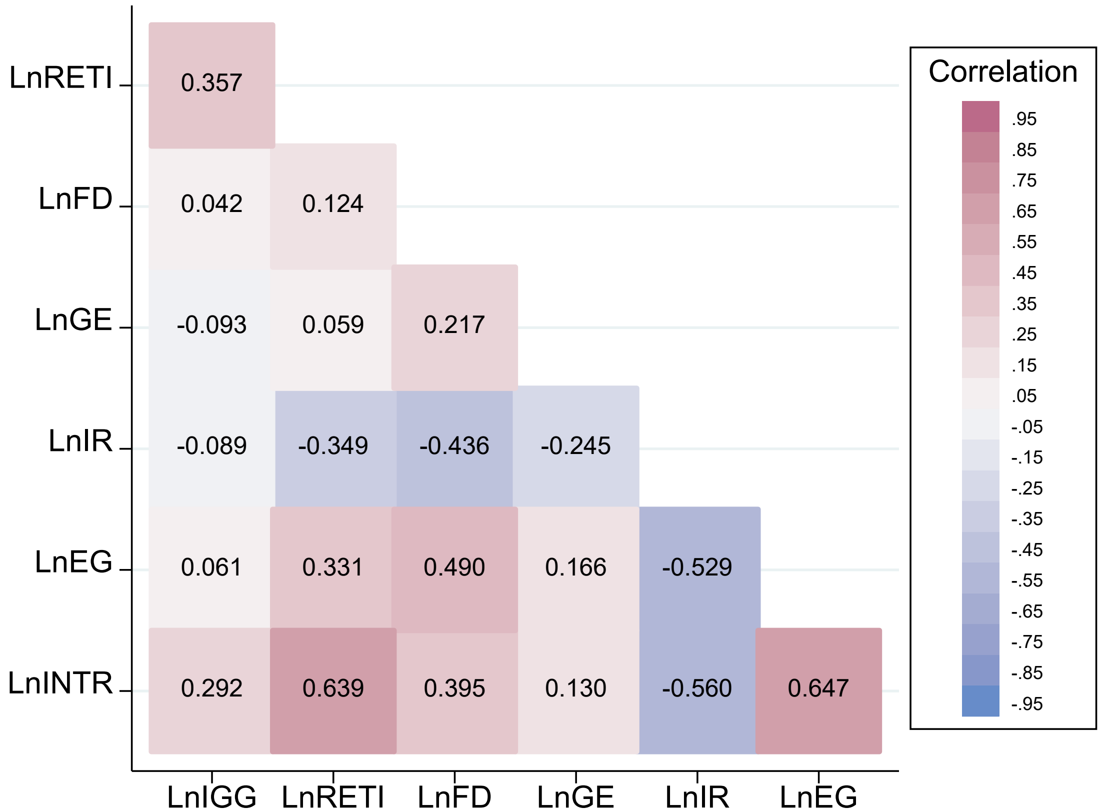
Source: Authors' construct.

Figure 8. Flowchart of steps involved



Source: Authors' construct; *Note*: IGG represents inclusive green growth; RET represents renewable energy transition; FD represents financial development; GE expenditure represents government expenditure; IR represents inflation rate; EG represents economic globalisation; INTR represents internet access; VIF represents variance inflation factors; CD represents cross-sectional dependence; LM represents Lagrange multiplier; CIPS represents cross-sectionally augmented Im-Pesaran-Shin; PMG-ARDL represents pooled mean group-autoregressive distributed lag; DKSE represents Driscoll-Kraay standard errors; FGLS represents feasible generalised least square; PCSE represents panel-corrected standard errors; D-H represents Dumitrescu-Harlin

Figure 9. Heat plot of the correlation matrix



Source: Authors' construct.