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Full Length Article

Analysis of European positioning on environmental sustainability: A review

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ABSTRACT

Extreme weather events are becoming more common, reflecting the rapid advance of climate change, which is primarily caused by human activity. Whereas some effects are irreversible, others can be mitigated through actions that seek to reduce greenhouse gas emissions, and thus limit global warming. In recent years, academia has been actively engaged in addressing this situation, as reflected in the volume of related scientific output. In this context, the objective of this research is to conduct a literature review of studies on environmental sustainability in the European Union (EU) published in the decade 2015–2024. The choice of the geographical scope of the study is based on the EU's strong commitment to climate neutrality. In order to identify the possible gaps in the literature and extract the main research directions, the PRISMA protocol is used together with an Rstudio library called bibliometrix. The results reveal an exponential growth in studies published in high-impact scientific journals, and a notable prevalence of international co-authorship. The analysis identifies three main lines of research. The first focuses on the structural foundations of sustainability, including circular economy, sustainable agriculture, and eco-innovation. The second addresses environmental policies promoted by the European Union and stands out as the most influential in terms of academic impact. The third explores energy efficiency in crisis contexts, with particular attention to the effects of the COVID-19 pandemic. Energy transition, circular economy, and the pursuit of efficiency and productivity are among the most studied topics within the scientific community.

Introduction

Climate change (CC) has become the major predicament facing twenty-first century society. Frequent heat waves followed by torrential rains and freezing temperatures are giving rise to uncontrolled forest fires and floods that affect large expanses of the planet. The economic and human costs associated with these severe meteorological effects are increasing as global warming worsens, creating a need for mitigation and adaptation measures to ease and even reverse this crisis (Abbass et al., 2022). The situation calls for a paradigm shift in which climate governance fosters the implementation of laws and strategies that engage all kinds of actors from the private and public sectors, ensuring that nobody is left behind regardless of status or wealth (IPCC, 2022). Humanity as a whole must collaborate by bringing about a shift in daily habits towards more environmentally-friendly practices, targeting efforts at energy and water savings, waste reduction, and the elimination of fossil fuel use (Liu-Lastres et al., 2025; Triantafyllidou & Zabaniotou, 2022).

The concepts of sustainable development (SD) and sustainability have emerged from this context. Ruggerio (2021) conducted a review of these two concepts, which are frequently applied interchangeably, concluding that the latter offers greater potential as long as the definition meets the following criteria: (1) it encompasses economic, ecological, social and political factors, (2) it accounts for intergenerational and intragenerational equity, and (3) it acknowledges the feedback between socioecological systems and their surroundings. The original definition of SD proposed by Brundtland (1987) described it as the ability to meet present needs without compromising those of future generations. It rests on three fundamental pillars: economic, social and environmental. However, the conceptualization of "*need*" and "*generation*" has sparked

Abbreviation: CC, climate change; EU, European Union; SD, sustainable development; ES, environmental sustainability; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses; GHG, greenhouse gases; MCA, multiple correspondence analysis; EE, energy efficiency.

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considerable controversy, resulting in substantial ambiguity in their application (Hajian & Kashani, 2021).

In contrast, the term sustainability has become more prominent in recent decades, with a marked increase in its application to all kinds of activities, including tourism (Li et al., 2024), agriculture (Muhie, 2022), business (Liu et al., 2024), technology (Wang & Lu, 2025) and even healthcare (Vishwakarma et al., 2023). Sustainability is an attribute of a system—understood as a set of elements related to each other—which is open to interactions with its external world (Gallopin, 2003). Although the flexibility of the term makes it easily applicable, this same flexibility also makes it difficult to assess, as it has been used loosely and sometimes inappropriately (Dogmus & Nielsen, 2021). In certain spheres, it has been used as a label to improve the positioning of a product or service, thereby obscuring the true meaning of the concept, squandering its intrinsic value, and consequently creating confusion among potential consumers (Sonntag et al., 2023).

Coming under the umbrella of both concepts, environmental sustainability (ES) is associated with the balance between natural reserves and human activities, aimed at guaranteeing the long-run availability of resources. The disconnect between environmental protection and people's actions is having a serious impact on the Earth (Edo et al., 2024). One of the most important initiatives driving ES is the United Nations Framework Convention on Climate Change created in 1994 and the subsequent adoption of the Kyoto Protocol in 1997, where more than 190 countries pledged to work together to curb CC, uniting in their efforts to improve the health of the climate (United Nations, 1997). Another major milestone was the Paris Agreement established at COP21, which was intended to replace the Kyoto Protocol by 2016. This agreement marked a turning point in international treaties, with signatories taking on a greater responsibility to protect the planet. The signatory countries have committed to reducing greenhouse gas (GHG) emissions to net zero by 2050, as well as limiting the temperature increase to less than 1.5ºC (United Nations, 2015). All this involves the need to help populations adapt to CC, a task of particular urgency in certain island or developing countries (Cassin et al., 2022; Opoku-Boateng et al., 2024).

The Paris Agreement has mobilized the European Union (EU) Member States to work towards an ecological transition that can boost competitiveness, while still focusing on social justice and the provision of financial aid to the most disadvantaged (European Commission, 2024; Sabato & Mandelli, 2024). In 2021, the EU took action on the climate by implementing a binding regulation, the European Climate Law, which writes into law the European Green Deal (EGD). The EGD sets the intermediate target of reducing net GHG emissions by at least 55 % by 2030, compared to 1990 levels (European Parliament, 2021; Fetting, 2020). In early 2025, the European Commission presented the Competitiveness Compass (European Commission, 2025). It is based on the European plan for sustainable prosperity and competitiveness, in turn built on the Draghi report, which revolves around three fundamental axes: closing the innovation gap; establishing a joint roadmap for decarbonization; and reducing dependencies and guaranteeing economic security (European Commission, 2025). However, there is a general lack of uniformity: the empirical results obtained to date show that European territories are making uneven progress in their fight against CC (Calafat-Marzal et al., 2025; Sanz-Torró et al., 2025).

The EU's firm commitment to everything related to ES has sparked great interest in the scientific community, giving rise to a critical mass of research encompassing multiple approaches, aimed at studying the different advances achieved and revealing possible paths forward. Given the volume of scientific output, it is not easy to compile the different academic approaches and ensure accurate results. A bibliometric approach is considered suitable, as it enables a systematic identification of prevailing themes, influential contributions, and potential gaps within literature. In this context, the aim of this research is to conduct a review of the related studies published over the last decade (2013–2024) in order to answer the following questions:

Q1. What aspects of ES are of the greatest concern to academia?
Q2. Are there any similarities among the published papers that point to common lines of research?

The sample was chosen following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) protocol, and the subsequent analysis was conducted using a library implemented in the free software RStudio called bibliometrix (Aria & Cuccurullo, 2017). The analysis focused on papers indexed in the prestigious Web of Science (WoS) database in order to ensure high quality evidence. There have recently been numerous bibliometric analyses of SD (Akudugu & Ogwu, 2024) and its relation to CC (Baidya & Saha, 2024), ecological knowledge management (Ulhaq et al., 2024), the EGD (Szpilko & Ejdys, 2022), the implications of financial innovation (Barua et al., 2025), ES in Asian countries (Mugoni et al., 2024), corporate governance (Enciso-Alfaro and García-Sánchez, 2023) and the supply chain (Rajendran et al., 2024). However, the present analysis goes further, focusing on the entire body of literature on ES as it relates to the EU. The geographical scope of the study is justified by the old continent's strong commitment to tackling CC and its proven pro-environmental attitude. The results shed light on the progress achieved and help identify the gaps remaining in the literature to guide researchers' future studies. They can also provide decision-makers with valuable information, allowing them to discern the aspects that require more attention and focus attention there.

The rest of the paper is structured as follows: the methodology and the sample used are presented in section 2; the results of the bibliometric review are analysed in section 3, along with a discussion of the existing paradigm; and, finally, the conclusions, contribution of the study and limitations are summarized in section 4.

Methodology

Among the high volume of scientific output generated annually, there have been numerous literature reviews on very specific issues, offering a synthesized overview of the evidence to date. In this research, we decided to apply the PRISMA protocol, which has been widely used in bibliometric analyses of ES. Notable examples of such studies include reviews of the position of the banking industry on climate criteria (Galletta et al., 2024), environmental entrepreneurship (Albhirat et al., 2024), agricultural adaptation strategies to CC (Takal et al., 2025), the impact of transportation (Delso-Vicente et al., 2025) and the link between blockchain technology and ES (Arshad et al., 2023). However, the aim of this paper is, on the one hand, to expand the field of research by analysing all the dimensions related to ES, and on the other, to limit the study to the EU Member States.

The advantages of the PRISMA procedure lie in its objectivity and efficient exploration of the sample (Moher et al., 2009), which enhances the transparency and accuracy of bibliometric studies (de Freitas Netto et al., 2020). The literature review is conducted by narrowing the sample through a meticulous, explicitly-stated process, which facilitates the examination of the implications drawn from a substantial body of publications, and the detection of possible thematic gaps (Liberati et al., 2009; Tranfield et al., 2003). In this research, we propose an adapted version of the flowchart suggested by Galletta et al. (2024), who establish a four-step sequence: (1) *identification*, a search is conducted to find the relevant studies on the chosen subject, within certain predefined criteria; (2) *screening*, the publications are screened on the basis of whether they meet the established inclusion and exclusion criteria; (3) *eligibility*, an assessment is made of the quality of the studies resulting from the screening phase; (4) *inclusion*, the information from the selected papers is analysed to synthesize the findings and answer the research questions posed (Fig. 1).

In the first phase, we extract from WoS all the papers that contain "Environmental sustainability" AND "European Union" in their keywords or their abstract, giving a total of 490 papers. For the *screening* phase, we establish specific criteria aimed at focusing the study on the

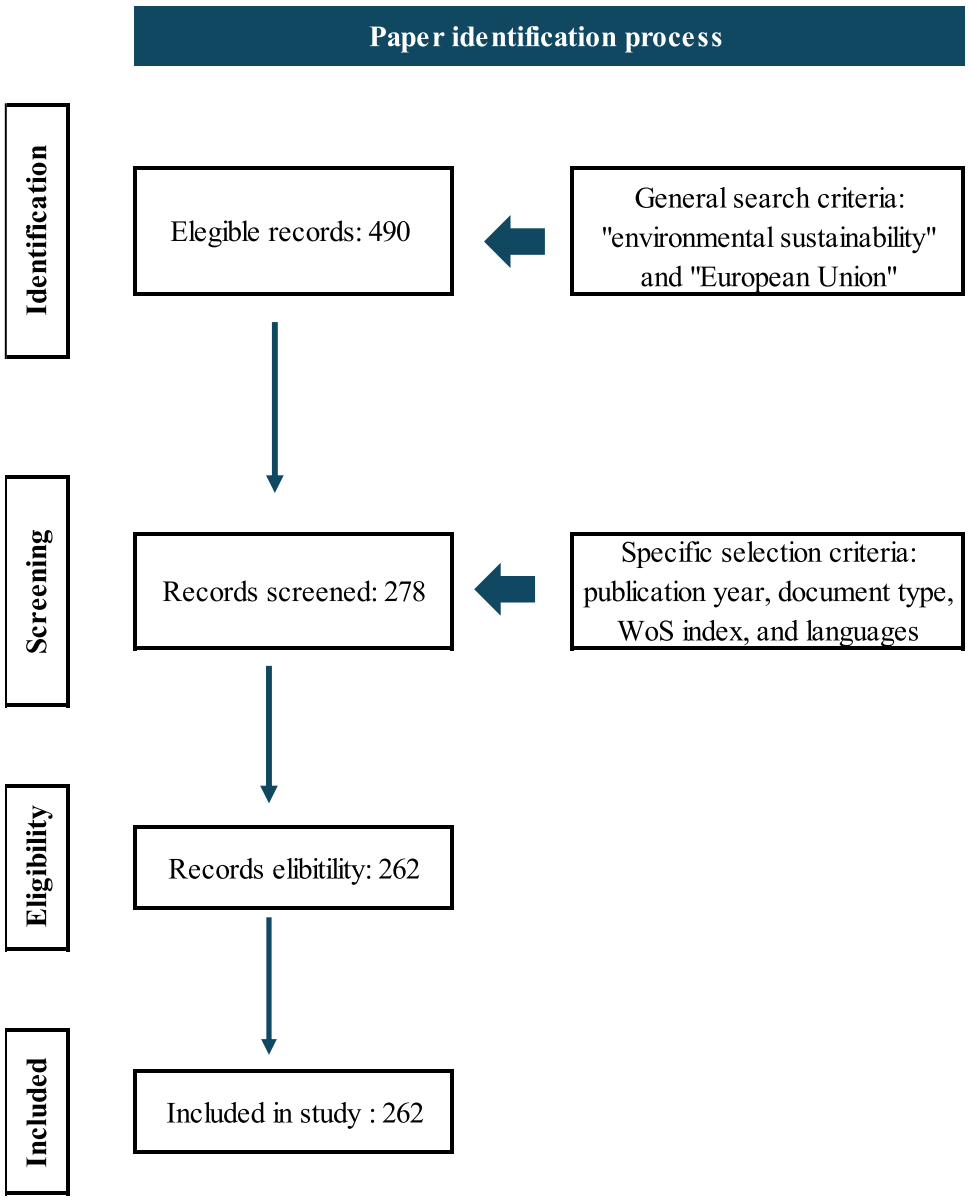

Fig. 1. PRISMA flow diagram.

topic of interest. Specifically, we narrow the analysis in relation to the following items: date of publication (2015–2024), document type (articles), WoS index (Science Citation Index Expanded, Social Sciences Citation Index, Emerging Sources Citation Index), and language (English). This time frame was selected to capture scientific production in the decade surrounding key EU environmental policy milestones, including the launch of Horizon 2020 (2014) and the adoption of the European Green Deal (2019). The result is a substantial reduction in the sample (to 278 papers). Then, in the *eligibility* phase, another 15 are excluded because they are proceedings or early access papers rather than definitive publications, as these types of documents often lack final peer review and may not reflect stable citation or indexing information. The 262 selected papers are then introduced into the bibliometrix library (version 4.3.2) to analyse them in accordance with the objectives of the study (*inclusion*). The bibliometric analysis included performance analysis, keyword co-occurrence mapping, and thematic clustering, which allowed the identification of research trends and conceptual structures within the selected literature. Table 1 summarizes the profile of the final sample, made up of the publications that meet the selection criteria.

The central research area has experienced remarkable growth over the last decade (32.14 %), going from 7 papers in 2015 to 87 in 2024 (Fig. 2). In addition, we see a large number of researchers involved (1038), and 36.82 % of the sample having an international co-authorship, reflecting the geographical range of the studies carried out. The mean number of citations per year is 24.23, which is an indication of the prestige and rigour of the studies carried out.

The Kyoto Protocol and the Paris Agreement have aroused the European scientific community's interest in studying ES. This is evidenced by the exponential increase in output in recent years, a period in which we see the EU strengthening its commitment to tackling CC. The European environmental strategies, which work on all fronts in an effort to protect natural habitats, are the Circular Economy Action Plan (European Commission, 2020a), the Biodiversity Strategy for 2030 (European Commission, 2020b), Farm to Fork (European Commission, 2020c), and the Zero Pollution Action Plan (European Commission, 2021). This action has been accompanied by growing academic interest, reflected in a large body of worthy publications. The literature review conducted here provides a more accurate understanding of the advances and approaches of the scientific community in support of European

Table 1
General description of the studies.

Main information	
Time span	2015–2024
Sources (Journals, Books, etc.)	157
Documents	278
Annual Growth Rate %	32.14
Average age of document	3.29
Average citations per doc	24.23
References	16,232
Document contents	
Keywords Plus (ID)	798
Author's Keywords (DE)	1120
Authors	
Authors	1038
Authors of single-authored docs	20
Author collaborations	
Single-authored docs	20
Co-Authors per Doc	4.05
International co-authorships %	36.82
Document types	
Article	262
Article; early access	11
Article; proceedings paper	4

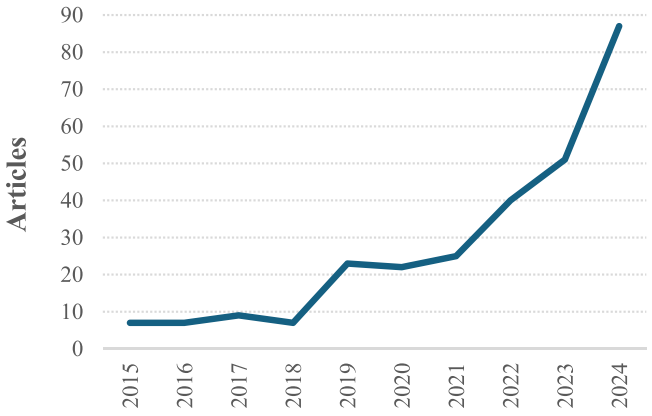

Fig. 2. The trend in scientific output in the decade 2015–2024.

environmental commitments.

Results and discussion

The bibliometrix library allows an in-depth, systematic review of the sample that we extracted from the WoS database using an adapted version of the PRISMA protocol. Specifically, the following items have been analysed: the most active journals and authors, the most cited studies, the ES-related terms that have been at the centre of this scientific output over the last decade, as well as the main lines of research. Table 2 shows the journals that account for the largest number of articles on ES and the EU, as well as the authors who have shown notable involvement in the field. As can be seen in this table, all the publications are indexed in the Science Citation Index Expanded and the Social Sciences Citation Index, mostly in the first quartile. They account for 91 of the 262 papers, reflecting the remarkable interest in the subject and the excellence of the studies carried out, hence their publication in high impact scientific journals. Regarding the authors, it should be noted that the 10 most active authors together account for 50 papers (19 %) and they all have a high Scopus h-index. This index, formulated by Hirsch (2005), provides a joint measure of the number of citations a researcher receives and the number of papers published; in other words, an average accounting for the quantity and quality of scientific output. On average, these researchers have achieved an h-index of 42, reflecting both the high level of research activity and the impact of its dissemination. The place of origin of the corresponding authors is very varied, as a consequence of the high level of co-authorship (4.05 % per document, Table 2).

Table 2
Most relevant sources and authors.

Journals	Journal Impact Factor (JIF)	Authors	Nº Papers	Scopus h-index	Country
Sustainability	Q3	Alola, A.A.	16	49	Norway
Journal of Cleaner Production	Q1	Adebayo, T. S.	5	71	Cyprus
Science of Total Environment	Q1	Bekun, F.V.	5	67	Turkey
Energies	Q3	Pata, U.K.	5	49	Azerbaijan
Environmental Science and Pollution Research	Q1	Aydin, M.	4	20	Turkey
Journal of Environmental Management	Q1	Adedoyin, F.F.	3	42	U.K.
Land Use Policy	Q1	Ahmed, Z.	3	48	South Korea
Renewable & Sustainable Energy Reviews	Q1	Matuszcak, A.	3	13	Poland
Sustainable Development	Q1	Medeiros, E.	3	21	Portugal
Energy Conversion and Management	Q1	Akadiri, S. S.	3	40	Turkey

The number of times a paper is cited is a reflection of the scientific community's recognition of the implications drawn from that paper. Table 3 presents the 10 studies that have had the greatest impact and their main conclusions, revealing a marked interest in renewable energy, economic growth and the circular economy, with recommendations focused on enhancing technological advances as a way to reduce emissions. For example, the paper by Alola et al. (2019a) has a total of 588 citations, with an annual average of 84. The authors examine the factors aimed at mitigating GHG emissions in the EU, demonstrating that the consumption of renewable energy improves ES. They advise the adoption of country-specific policies compatible with the Sustainable Development Goals, and point out the need to boost decarbonization and economic growth. In the same vein, Akadiri et al. (2019), with a total of 251 citations, analyse long-term sustainability in Europe, concluding that renewable energy sources must be harnessed to mitigate environmental pollution. For their part, Adedoyin et al. (2020), in third place, study the long-run and causal interaction between, renewable energy consumption, non-renewable energy consumption, and economic growth in an ecological footprint-income function. Their paper shows that R&D expenditure plays a key role in ensuring the ES of the planet.

Fig. 3, below, shows the keywords most frequently associated with ES in the EU. It can be seen that environmental strategies, the energy transition, the circular economy and GHG emissions are the issues on which the largest volume of analysed articles have centred, meaning they are the main focus of European concern (*Q1*). Some authors such as Bernstein et al. (2023), Schunz (2022) and Hametner (2022) analyse existing environmental policies, while others propose strategies aimed at promoting a green economy, in which environmental taxes play a relevant role (Adeshola et al., 2024; Gao & Fan, 2023; Medeiros et al., 2022). Regarding the energy transition, Ahmad et al. (2024) investigate the impact of climate technology together with the energy transition on CO2 emissions, advising EU countries to adopt green technologies and

Table 3
Contributions of the most cited studies.

Authors	Conclusions	Total Citations	TC per year	Normalized TC
Alola et al. (2019a)	An increase in real GDP and renewable energy consumption improves ES	588	84.00	7.97
Akadiri et al. (2019)	Positive link in the long term between ES, renewable energy and economic growth	251	35.86	3.40
Adedoyin et al. (2020)	R&D and renewable energy improves ES; there is an urgent need to diversify the energy portfolio	201	33.50	4.04
Amankwah-Amoah (2020)	Covid-19 was a challenge to ES initiatives such as upgrading to environmentally friendly aircraft and offsetting emission footprint	172	28.67	3.46
Hysa et al. (2020)	Strong positive correlation between the circular economy and economic growth	172	28.67	3.46
Adedoyin et al. (2021)	In some European regions, GDP per capita, energy consumption, tourism and economic complexity boost CO2 emissions	157	31.40	2.79
Alola et al. (2019b)	The consumption of renewable energies predicts a desirable decrease in environmental degradation	156	22.29	2.11
Khan et al. (2021)	Renewable energy, technological innovation and the carbon tax reduce emissions	147	29.40	2.61
Cucchiella et al. (2017)	Waste to Energy plants are a reasonable and sustainable alternative technology to landfill	142	15.78	3.54
Scown et al. (2020)	The results of the Common Agricultural Policy are unclear and there is a lack of effective monitoring indicators	134	22.33	2.69

implement environmental regulations, in line with the recommendations made by Chen et al. (2023). These implications are aligned with those drawn from the studies of Stanković et al. (2021), Niero (2023) and Mohsin et al. (2024), who suggest that strengthening the circular economy is a way to mitigate GHG emissions.

Lastly, in order to detect any underlying structures in the set of publications that make up the sample, we perform a multiple correspondence analysis (MCA). This method was originally proposed by Benzecri (1969) to identify associations between categorical or qualitative variables. MCA groups representative words according to these

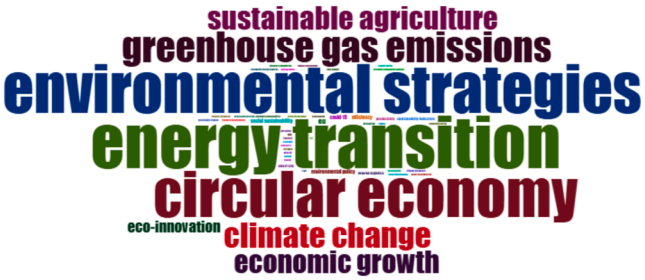

Fig. 3. WordCloud.

associations. Based on the results, we can distinguish three clusters, reflecting the lines of research followed by the scientific community. The dendrogram from the MCA is shown in Fig. 1A of the appendix. Each cluster contains a set of words that characterize the cohesion of the cluster (Table 4).

Cluster 1. Aspects of ES: This cluster is defined by 7 keywords (environmental sustainability, circular economy, sustainable agriculture, eco-innovation, social sustainability, and productivity). The most cited papers are in high-impact scientific journals, with their indexing in WoS and the h-index providing confirmation of the quality of the publication and the relevance of the lead authors, respectively. The mean number of citations per year is close to 15, and notable studies include those by Belletti et al. (2015), Hysa et al. (2020), Pauer et al. (2019): the first two alone have received more than 100 citations. This first cluster covers aspects related to the SD pillars (environmental, social and economic).

The circular economy is positioned as a crucial model to protect the environment without jeopardizing economic growth (Hysa et al. 2020), requiring life cycle assessments of all products and services in order to make the necessary improvements (Lo-Iacono-Ferreira et al. 2020; Niero, 2023; Notarnicola et al., 2017). Continuing with the ES-progress dilemma, Nadiri et al. (2024) reveal the potential offered by carbon taxes, eco-innovation, renewable energy and globalization to curb environmental deterioration, in a context of ongoing progress. Achieving a healthy environment must be compatible with social sustainability, and this can be facilitated by new technologies in large cities (Vogiatzaki et al., 2020). In rural areas, on the other hand, sustainability is determined by access to basic services, and an increase in productivity to overcome the risk of poverty and social exclusion (Widomski & Musz-Pomorska, 2023). Focusing on the agricultural sector, Grzelak et al. (2019) advise greater endowments of capital and lower labour intensity to improve ES. EU subsidies are facilitating the replacement of obsolete and polluting agricultural machinery with more modern, efficient and environmentally-friendly machinery (Lewandowska-Czarnecka et al., 2019).

Cluster 2. *Environmental Policies*: This is the most academically relevant cluster, with a yearly mean number of citations of 34. The authors Akadiri et al. (2019), Adedoyin (2020) and Amank-Amoah (2020) alone account for a total of 624; in addition, the research has been published in relevant scientific journals. Its includes 6 keywords (*environmental strategies, energy transition, European Union, greenhouse gas emissions, climate change,* and *smart city*), and the central axis around which all of them revolve is the European measures adopted. Mitigating CC requires an energy transition: fossil fuels must be replaced by renewable energies to achieve the much sought-after climate neutrality. Akadiri et al. (2019) recommend measures for commercializing and further developing these energies, the implementation of which will foster job creation, innovation and improved health. Furthermore, Adedoyin et al. (2020) note that the use of non-renewable energy and economic growth increase carbon emissions; it is thus necessary to promote a paradigm shift through R&D to orient humanity towards the consumption of modern, environmentally-friendly supplies.

The EGD is driving a package of initiatives aimed at enabling an

Table 4
Keywords, authors, journal (JIF) and annual mean citations.

	Keywords	Authors*	Journals (JIF, 2023)	Annual mean citations
Cluster 1	environmental sustainability, circular economy, sustainable agriculture, eco-innovation, social sustainability, productivity	Aydin et al. (2023), Bekun et al. (2021), Belleti et al. (2015), Gallego-Schmid et al. (2018), Grzelak et al. (2019), Hsueh (2019), Hysa et al. (2020), Notarnicola et al. (2017), Pauer et al. (2019), Šprajc et al. (2019)	Sustainability, Land Use Policy, Environmental Science & Pollution Research, Renewable and Sustainable Energy Reviews, Journal of Cleaner Production, Gondwana Research, Business Strategy and the Environment, Science of The Total Environment	14.7
Cluster 2	environmental strategies, energy transition, European Union, greenhouse gas emissions, climate change, smart city	Akadiri et al. (2019), Adedoyin (2020), Amankwah-Amoah (2020), Adedoyin (2021), Alola (2019b), Khan (2021), Ozgen et al. (2021), Sheraz et al. (2021), Sharma et al. (2021), Sala et al. (2020)	Energy Policy, Science of The Total Environment, Journal of Cleaner Production, Journal of Environmental Management, Environmental Science & Pollution Research, Renewable and Sustainable Energy Reviews	34.0
Cluster 3	Covid-19, energy efficiency	Ascione et al. (2022), Karakaya et al. (2024) Li et al. (2022), Özkan et al. (2023)	Frontiers in Energy Research, Sustainable Energy Technologies and Assessments, Journal of Cleaner Production, Energy Economics	16.8

* The 10 most cited authors, except in cluster 3, which includes all publications with more than 15 citations.

orderly ecological transition in order to achieve climate neutrality by 2050 (European Commission, 2019). This requires the continuous monitoring of economic activities to avoid undermining the EU's green objectives (Bernstein et al., 2023). These provisions should have an impact on all strata of society and the economy. According to Sessa et al. (2022), EGD policies should constitute a guide towards urban regeneration, thereby fostering SD, with companies committed to monitoring their carbon footprint and accelerating the transition by providing clean, affordable technologies. Marchesani and Masciarelli (2023) obtain evidence of the positive impact of tourism on cities' green transformation, enabling progress towards smart tourism aligned with the appropriate development of destinations. However, although many papers focus on proposed strategies and policy frameworks, relatively few directly assess the actual effectiveness or outcomes of the implemented environmental measures.

Cluster 3. *Energy efficiency in crisis situations*: This cluster contains a smaller volume of publications, emerging after the outbreak of COVID-19. However, the findings have had a major impact, as reflected by the average of 16.8 citations per year. It contains only two keywords (*Covid-19 and energy efficiency*), revealing the additional effect of the pandemic on the slow progress being made towards energy efficiency (EE). EE is closely linked to ES: it is critical to the effective management of the planet's resources. It involves optimizing the use of energy, that is, achieving maximum performance with minimal consumption, thereby minimizing GHG emissions at the same time. The EU has reinforced its commitment in this regard, setting a goal of reducing EU final energy consumption by 11.7 % by 2030, compared to the projected energy use for 2030 (European Parliament, 2023). The measures implemented by the EU are aimed at the sectors with the greatest potential for savings, such as industry, the public sector, construction and renovation of buildings, transport and supplies. According to the "Energy Efficiency First" principle, which complements the EU objectives of sustainability, neutrality and green growth, (1) only the energy that is strictly necessary should be produced, (2) investments in stranded assets should be avoided, and (3) demand for energy should be reduced and managed in a cost-effective way. The solution requires a transition from fossil fuels to renewable energies and EE (IPCC, 2022; IEA, 2021).

The pandemic underscored all the existing weaknesses, exacerbating the digital divide and energy poverty, and becoming an incontrovertible priority for government action (Carfora et al., 2022). The lockdown led to an increase in household energy demand that did not overshadow the reduction in energy demand in business and industry, where renewables gained ground (IEA, 2020). In this context, the residential sector is now on a one-way journey towards energy-efficient building stock (Ascione et al., 2022). The government stimulus provided to the construction sector is aimed at driving energy-efficient building production, which would help improve current figures: in Europe, the construction industry accounts for 40 % of primary energy consumption and 36 % of the carbon emitted (Li et al., 2022).

Karakaya et al. (2024) highlight the EE gap in the EU, associated with countries' level of development as a result of their greater capacity to invest in and improve processes. R&D and the regulatory framework could be behind these differences; policy-makers have to factor in countries' strengths and weaknesses to ensure the success of their energy strategies (Li et al., 2022). Özkan et al. (2023) have found evidence of the role played by non-renewable EE, renewable energy intensity and green technologies in mitigating GHG emissions.

This classification of the literature has revealed the main lines of academic research on ES in the EU over the last decade. In addition, there is a possible gap in the literature related to the assessment of the measures taken to mitigate CC and ensure ES (*Q2*).

Conclusions

ES is one of the three pillars of SD, together with social and economic sustainability. It is about raising people's awareness that the planet's natural resources are finite, and current practices, often abusive, are having significant harmful effects on those resources, with considerable monetary and human losses. Academia has shown a great deal of interest in finding environmentally-friendly solutions for curbing CC. In the last decade, the scientific studies relating to the terms sustainability and SD have numbered in the thousands, offering ideas that, despite the impact of papers, sometimes do not achieve the desired outcome.

The bibliometric review carried out has synthesized the evidence obtained in internationally influential studies of ES in the EU. The old continent's firm commitment to CC mitigation is reflected in the ongoing implementation of regulations and agreements that oblige the EU Member States to adapt their production strategies to ensure the protection of the environment. Based on the results of the study, we can distinguish three lines of research; the one dealing with the

environmental policies aimed at reducing emissions has had the greatest impact in the scientific community. The circular economy, energy transition, CC, economic growth and sustainable agriculture are the most studied items, due to the major role they play in every strata of production. Furthermore, despite the impact of environmental strategies, we find fewer studies aimed at assessing the effectiveness of the implemented measures. Following the right path towards neutrality requires continuous measurement of the suitability of the chosen instruments to achieve the objectives established. This will make it possible to avoid unwanted deviations or delays, providing decision-makers with valuable information that they can use to realign their instruments, if necessary. This study offers a comprehensive overview of the thematic evolution of EU-related environmental sustainability research over the last decade, providing a structured perspective that complements existing narrative reviews.

This research is not without its limitations. The fundamental bias of literature reviews lies in the keywords chosen to focus the study: even minor changes can sometimes substantially reduce the size of the sample under study. In our case, we sought to expand the range of the analysis by choosing only two concepts, ES and the EU, meaning we could include a larger number of studies.

CRediT authorship contribution statement

V. Sanz-Torro: Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **C. Calafat-Marzal:** Writing – review & editing, Visualization, Methodology, Investigation, Data curation. **J.M. Guaita-Martinez:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Formal analysis, Conceptualization. **V. Vega:** Writing – review & editing, Visualization, Supervision, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Appendix 1

Fig. A1.

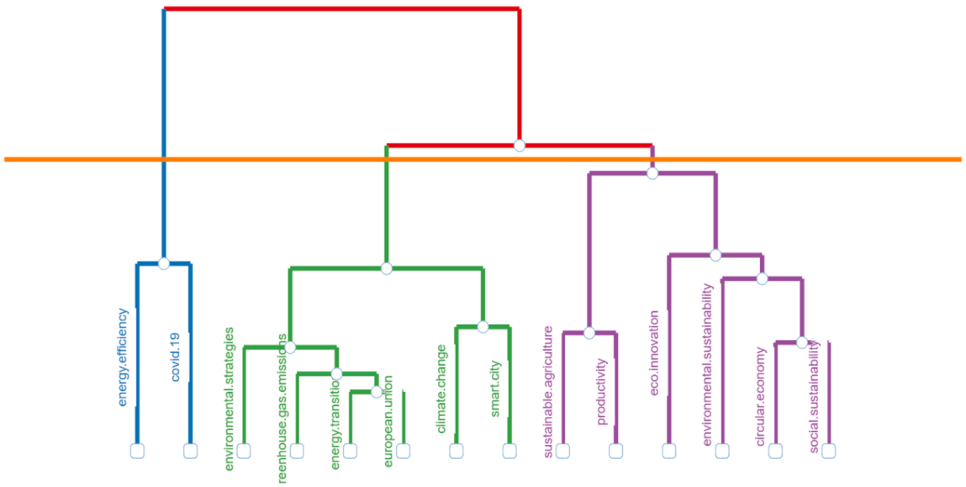

Fig. A1. Dendrogram from the MCA.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research, 29*, 42539–42559. https://doi.org/10.1007/s11356-022-19718-6

Adedoyin, F. F., Alola, A. A., & Bekun, F. V. (2020). An assessment of environmental sustainability corridor: The role of economic expansion and research and development in EU countries. *Science of The Total Environment, 713*, Article 136726. https://doi.org/10.1016/j.scitotenv.2020.136726. Article.

Adedoyin, F. F., Agboola, P. O., Ozturk, I., Bekun, F. V., & Agboola, M. O. (2021). Environmental consequences of economic complexities in the EU amidst a booming tourism industry: Accounting for the role of Brexit and other crisis events. *Journal of Cleaner Production, 305*, Article 127117. https://doi.org/10.1016/j.jclepro.2021.127117. Article.

Adeshola, I., Usman, O., Agoyi, M., Awosusi, A. A., & Adebayo, T. S. (2024). Digitalization and the environment: the role of information and communication technology and environmental taxes in European countries. *Natural Resources Forum, 48*(4), 1088–1108. https://doi.org/10.1111/1477-8947.12342

Ahmad, M., Ahmed, Z., Riaz, M., & Yang, X. (2024). Modeling the linkage between climate-tech, energy transition, and CO2 emissions: Do environmental regulations matter? *Gondwana Research, 127*, 131–143. https://doi.org/10.1016/j.gr.2023.04.003

Akadiri, S. S., Alola, A. A., Akadiri, A. C., & Alola, U. V. (2019). Renewable energy consumption in EU-28 countries: Policy toward pollution mitigation and economic sustainability. *Energy Policy, 132*, 803–810. https://doi.org/10.1016/j.enpol.2019.06.040

Akudugu, M. A., & Ogwu, M. C. (2024). Sustainable development policies and interventions: A bibliometric analysis of the contributions of the academic community. *Journal of Cleaner Production, 434*, Article 139919. https://doi.org/10.1016/j.jclepro.2023.139919. Article.

Albhirat, M. M., Rashid, A., Rasheed, R., Rasool, S., Zulkiffli, S. N. A., Zia-ul-Haq, H. M., & Mohammad, A. M. (2024). The PRISMA statement in enviropreneurship study: A systematic literature and a research agenda. *Cleaner Engineering and Technology, 18*, Article 100721. https://doi.org/10.1016/j.clet.2024.100721. Article.

Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019a). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Science of The Total Environment, 685*, 702–709. https://doi.org/10.1016/j.scitotenv.2019.05.139

Alola, A. A., Yalçiner, K., Alola, U. V., & Akadiri, S. S. (2019b). The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe largest states. *Science of The Total Environment, 674*, 307–315. https://doi.org/10.1016/j.scitotenv.2019.04.163

Amankwah-Amoah, J. (2020). Stepping up and stepping out of COVID-19: New challenges for environmental sustainability policies in the global airline industry. *Journal of Cleaner Production, 271*, Article 123000. https://doi.org/10.1016/j.jclepro.2020.123000. Article.

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Arshad, A., Shahzad, F., Rehman, I. U., & Sergi, B. S. (2023). A systematic literature review of blockchain technology and environmental sustainability: Status quo and future research. *International Review of Economics & Finance, 88*, 1602–1622. https://doi.org/10.1016/j.iref.2023.07.044

Ascione, F., De Masi, R. F., Mastellone, M., Ruggiero, S., & Vanoli, G. P. (2022). Improving the building stock sustainability in European countries: A focus on the Italian case. *Journal of Cleaner Production, 365*, Article 132699. https://doi.org/10.1016/j.jclepro.2022.132699. Article.

Aydin, M., Degirmenci, T., Gurdal, T., & Yavuz, H. (2023). The role of green innovation in achieving environmental sustainability in European Union countries: Testing the environmental Kuznets curve hypothesis. *Gondwana Research, 118*, 105–116. https://doi.org/10.1016/j.gr.2023.01.013

Baidya, A., & Saha, A. K. (2024). Exploring the research trends in climate change and sustainable development: A bibliometric study. *Cleaner Engineering and Technology, 18*, Article 100720. https://doi.org/10.1016/j.clet.2023.100720. Article.

Barua, S., Golder, U., Chowdhury, R. S., & Sharmeen, K. (2025). Implications of NFT as a sustainable fintech innovation for sustainable development and entrepreneurship. *Sustainable Technology and Entrepreneurship, 4*(2), Article 100099. https://doi.org/10.1016/j.stae.2025.100099. Article.

Benzecri, J. P. (1969). Statistical analysis as a tool to make patterns emerge from data. In S. Watanabe (Ed.), *Methodologies of pattern recognition* (pp. 35–74). Academic Press. https://doi.org/10.1016/B978-1-4832-3093-1.50009-2.

Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Yaw, S. S. (2021). The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. *Environmental Science & Pollution Research, 28*, 51137–51148. https://doi.org/10.1007/s11356-021-14251-4

Belletti, G., Marescotti, A., Sanz-Cañada, J., & Vakoufaris, H. (2015). Linking protection of geographical indications to the environment: Evidence from the European Union olive-oil sector. *Land Use Policy, 48*, 94–106. https://doi.org/10.1016/j.landusepol.2015.05.003

Bernstein, M. J., Franssen, T., Smith, R. D. J., & Wilde, M. (2023). The European commission's green deal is an opportunity to rethink harmful practices of research and innovation policy. *Ambio, 52*, 508–517. https://doi.org/10.1007/s13280-022-01802-3

Brundtland, G. H. (1987). *Our common future. Report of the world commission on environment and development*. United Nations.

Calafat-Marzal, C., Vega, V., Sanz-Torro, V., & Puertas, R. (2025). Assessment of the resilience factors associated with European green efficiency. *Science of The Total Environment, 966*, Article 178643. https://doi.org/10.1016/j.scitotenv.2025.178643. Article.

Carfora, A., Scandurra, G., & Thomas, A. (2022). Forecasting the COVID-19 effects on energy poverty across EU member states. *Energy Policy, 161*, Article 112597. https://doi.org/10.1016/j.enpol.2021.112597. Article.

Cassin, L., Melindi-Ghidi, P., & Prieur, F. (2022). Confronting climate change: Adaptation vs. migration in small island developing states. *Resource and Energy Economics, 69*, Article 101301. https://doi.org/10.1016/j.reseneeco.2022.101301. Article.

Chen, J., Huang, S., & Kamran, H. W. (2023). Empowering sustainability practices through energy transition for sustainable development goal 7: The role of energy patents and natural resources among European Union economies through advanced panel. *Energy Policy, 176*, Article 113499. https://doi.org/10.1016/j.enpol.2023.113499. Article.

Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2017). Sustainable waste management: Waste to energy plant as an alternative to landfill. *Energy Conversion and Management, 131*, 18–31. https://doi.org/10.1016/j.enconman.2016.11.012

de Freitas Netto, S. V., Sobral, M. F. F., Ribeiro, A. R. B., & da Luz Soares, G. R. (2020). Concepts and forms of greenwashing: A systematic review. *Environmental Sciences Europe, 32*, 19. https://doi.org/10.1186/s12302-020-0300-3. Article.

Delso-Vicente, A. T., Camperos, M. C., & Almonacid-Durán, M. (2025). The evolution of electric and hybrid vehicles and their influence on sustainable transport: A review and future research lines. *Sustainable Technology and Entrepreneurship, 4*(2), Article 100100. https://doi.org/10.1016/j.stae.2025.100100. Article.

Dogmus, Ö. C., & Nielsen, J.Ø. (2021). Defining sustainability? Insights from a small village in Bosnia and Herzegovina. *GeoJournal, 86*, 2165–2181. https://doi.org/10.1007/s10708-020-10181-9

Edo, G. I., Lilian Itoje-akpokiniovo, O., Obasohan, P., Ikpekoro, V. O., Samuel, P. O., Jikah, A. N., Nosu, L. C., Ekokotu, H. A., Ugbune, U., Oghroro, E. E. A., Emakpor, O. L., Ainyanbhor, E. I., Mohammed, W. A. S., Akpoghelie, P. O., Owheruo, J. O., & Agbo, J. J. (2024). Impact of environmental pollution from human activities on water, air quality and climate change. *Ecological Frontiers, 44*(5), 874–889. https://doi.org/10.1016/j.ecofro.2024.02.014

Enciso-Alfaro, S.-Y., & García-Sánchez, I.-M. (2023). Corporate governance and environmental sustainability: Addressing the dual theme from a bibliometric approach. *Corporate Social Responsibility and Environmental Management, 30*(3), 1025–1041. https://doi.org/10.1002/csr.2403

European Commission. (2019). *What is the european green deal*. Retrieved from https://ec.europa.eu/commission/presscorner/api/files/attachment/859152/What_is_the_European_Green_Deal_en.pdf.

European Commission. (2020a). *A new circular economy action plan*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM%3A2020%3A98%3AFIN.

European Commission. (2020b). *EU biodiversity strategy for 2030. Retrieved from* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380.

European Commission. (2020c). *A Farm to Fork Strategy*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0381.

European Commission. (2021). *EU action plan: 'Towards zero pollution for air, water and soil'*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021DC0400.

European Commission. (2024). *Consistency of financial flows with the Paris agreement objectives – the Eu navigating the transition towards climate neutrality and resilience*. Directorate-General for CLIMATE ACTION. Retrieved from https://climate.ec.europa.eu/document/download/54f56844-a283-4e99-adeb-81989ab6b95e_en?filename=swd_21c_en.pdf.

European Commission. (2025). *A competitiveness compass for the Eu*. Retrieved from https://commission.europa.eu/document/download/10017eb1-4722-4333-add2-e0ed18105a34_en.

European Parliament. (2021). *Regulation (EU) 2021/1119 of the European parliament and of the council of 30June 2021establishing the framework for achieving climate neutrality and amending regulations (EC) no 401/2009 and (EU) 2018/1999 ('European climate law')*. Retrieved from http://data.europa.eu/eli/reg/2021/1119/oj.

European Parliament. (2023). *Directive (EU) 2023/1791 of the european parliament and of the council of13 september 2023on energy efficiency and amending regulation (EU) 2023/955*. Retrieved from https://eur-lex.europa.eu/eli/dir/2023/1791/oj.

Fetting, C. (2020). *The european green deal. esdn report*. Vienna: ESDN Office. https://www.esdn.eu/fileadmin/ESDN_Reports/ESDN_Report_2_2020.pdf.

Gallego-Schmid, A., Mendoza, J. M. F., & Azapagic, A. (2018). Improving the environmental sustainability of reusable food containers in Europe. *Science of The Total Environment, 628–629*, 979–989. https://doi.org/10.1016/j.scitotenv.2018.02.128

Galletta, S., Mazzù, S., Naciti, V., & Paltrinieri, A. (2024). A PRISMA systematic review of greenwashing in the banking industry: A call for action. *Research in International Business and Finance, 69*, Article 102262. https://doi.org/10.1016/j.ribaf.2024.102262. Article.

Gallopin, G. (2003). A systems approach to sustainability and sustainable development. ECLAC/Government of The Netherlands project NET/00/063 "Sustainability assessment in Latin America and the Caribbean".

Gao, X., & Fan, M. (2023). Environmental taxes, eco-innovation, and environmental sustainability in EU member countries. *Environmental Science and Pollution Research, 30*, 101637–101652. https://doi.org/10.1007/s11356-023-29361-4

Grzelak, A., Guth, M., Matuszczak, A., Czyżewski, B., & Brelik, A. (2019). Approaching the environmental sustainable value in agriculture: How factor endowments foster the eco-efficiency. *Journal of Cleaner Production, 241*, Article 118304. https://doi.org/10.1016/j.jclepro.2019.118304. Article.

Hametner, M. (2022). Economics without ecology: How the SDGs fail to align socioeconomic development with environmental sustainability. *Ecological Economics, 199*, Article 107490. https://doi.org/10.1016/j.ecolecon.2022.107490. Article.

Hajian, M., & Kashani, S. J. (2021). 1 - Evolution of the concept of sustainability. From Brundtland Report to sustainable development goals. In C. Mustansar Hussain, & J. F. Velasco-Muñoz (Eds.), *Sustainable resource management* (pp. 1–24). Elsevier. https://doi.org/10.1016/B978-0-12-824342-8.00018-3.

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceeding of the National Academy of Sciences, 102*, 16.569.16572.

Hsueh, L. (2019). Opening up the firm: what explains participation and effort in voluntary carbon disclosure by global businesses? An analysis of internal firm factors and dynamics. *Business Strategy and the Environment, 28*, 1302–1322. https://doi.org/10.1002/bse.2317

Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. *Sustainability, 12*, 4831. https://doi.org/10.3390/su12124831. Article.

IEA. (2020). *The covid-19 crisis and clean energy progress*. Paris: IEA. Retrieved from https://www.iea.org/reports/the-covid-19-crisis-and-clean-energy-progress.

IEA. (2021). *Greenhouse gas emissions from energy data explorer*. Retrieved from https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer.

IPCC. (2022). *Climate change 2022. Mitigation of climate change. Working group iii contribution to the sixth assessment report of the intergovernmental panel on climate change*. Retrieved from https://www.ipcc.ch/.

Karakaya, E., Alataş, S., Erkara, E., Mert, B., Akdoğan, T., & Hiçyılmaz, B. (2024). The rebound effect of material and energy efficiency for the EU and its major trading partners. *Energy Economics, 134*, Article 107623. https://doi.org/10.1016/j.eneco.2024.107623. Article.

Khan, S. A. R., Ponce, P., & Yu, Z. (2021). Technological innovation and environmental taxes toward a carbon-free economy: An empirical study in the context of COP-21. *Journal of Environmental Management, 298*, Article 113418. https://doi.org/10.1016/j.jenvman.2021.113418. Article.

Lewandowska-Czarnecka, A., Buller, L. S., Nienartowicz, A., & Piernik, A. (2019). Energy and emergy analysis for assessing changes in Polish agriculture since the accession to the European Union. *Ecological Modelling, 412*, Article 108819. https://doi.org/10.1016/j.ecolmodel.2019.108819. Article.

Li, J., Coca-Stefaniak, J. A., Nguyen, T. H. H., & Morrison, A. M. (2024). Sustainable tourist behavior: A systematic literature review and research agenda. *Sustainable Development, 32*(4), 3356–3374. https://doi.org/10.1002/sd.2859

Li, M., Peng, M. Y. P., Nazar, R., Adeleye, B. N., Shang, M., & Waqas, M. (2022). How does energy efficiency mitigate carbon emissions without reducing economic growth in post COVID-19 ERA. *Frontiers in Energy Research, 10*. https://doi.org/10.3389/fenrg.2022.832189

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement

for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ, 339*(b2700). https://doi.org/10.1136/bmj.b2700

Liu, M., Tang, J., Walton, S., Zhang, Y., & Zhao, X. (2024). Auditor sustainability focus and client sustainability reporting. *Accounting, Organizations and Society, 113*, Article 101512. https://doi.org/10.1016/j.aos.2023.101512. Article.

Liu-Lastres, B., Bao, H., & Cecil, A. (2025). Exploring gaps in young generations' sustainable travel behavior: A mixed-methods study. *Journal of Sustainable Tourism*, 1–16. https://doi.org/10.1080/09669582.2025.2453693

Lo-Iacono-Ferreira, V. G., Viñoles-Cebolla, R., Bastante-Ceca, M. J., & Capuz-Rizo, S. F. (2020). Transport of Spanish fruit and vegetables in cardboard boxes: A carbon footprint analysis. *Journal of Cleaner Production, 244*, Article 118784. https://doi.org/10.1016/j.jclepro.2019.118784. Article.

Marchesani, F., & Masciarelli, F. (2023). Does tourism flow in cities drive green practices in the current smart city trajectories? Empirical evidence from Italy. *International Journal of Tourism Cities, 9*(3), 559–571. https://doi.org/10.1108/IJTC-04-2023-0071

Medeiros, E., Valente, B., Gonçalves, V., & Castro, P. (2022). How impactful are public policies on environmental sustainability? Debating the Portuguese case of PO SEUR 2014–2020. *Sustainability, 14*(13), 7917. https://doi.org/10.3390/su14137917. Article.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group, T. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine, 151*(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-0013

Mohsin, A. K. M., Gerschberger, M., Plasch, M., Ahmed, S. F., Rahman, A., & Rashed, M. (2024). Examining the synergy of green supply chain practices, circular economy, and economic growth in mitigating carbon emissions: evidence from EU countries. *Journal of Environmental Management, 371*, Article 123109. https://doi.org/10.1016/j.jenvman.2024.123109. Article.

Mugoni, E., Kanyepe, J., & Tukuta, M. (2024). Sustainable supply chain management practices (SSCMPS) and environmental performance: A systematic review. *Sustainable Technology and Entrepreneurship, 3*(1), Article 100050. https://doi.org/10.1016/j.stae.2023.100050. Article.

Muhie, S. H. (2022). Novel approaches and practices to sustainable agriculture. *Journal of Agriculture and Food Research, 10*, Article 100446. https://doi.org/10.1016/j.jafr.2022.100446. Article.

Nadiri, A., Gündüz, V., & Adebayo, T. S. (2024). The role of financial and trade globalization in enhancing environmental sustainability: evaluating the effectiveness of carbon taxation and renewable energy in EU member countries. *Borsa Istanbul Review, 24*(2), 235–247. https://doi.org/10.1016/j.bir.2024.01.004

Niero, M. (2023). Implementation of the European Unionś packaging and packaging waste regulation: A decision support framework combining quantitative environmental sustainability assessment methods and socio-technical approaches. *Cleaner Waste Systems, 6*, Article 100112. https://doi.org/10.1016/j.clwas.2023.100112. Article.

Notarnicola, B., Tassielli, G., Renzulli, P. A., & Monforti, F. (2017). Energy flows and greenhouses gases of EU (European Union) national breads using an LCA (Life Cycle Assessment) approach. *Journal of Cleaner Production, 140*(Part 2), 455–469. https://doi.org/10.1016/j.jclepro.2016.05.150

Opoku-Boateng, E., Agyei, F., Osei Asibey, M., & Mintah, F. (2024). Climate change resilience and social capital: insights from informal urban neighbourhoods in Kumasi, Ghana. *Cities (London, England), 152*, Article 105234. https://doi.org/10.1016/j.cities.2024.105234. Article.

Ozgen, S., Cernuschi, & Caserini, S. (2021). An overview of nitrogen oxides emissions from biomass combustion for domestic heat production. *Renewable and Sustainable Energy Reviews, 135*, Article 110113. https://doi.org/10.1016/j.rser.2020.110113. Article.

Özkan, O., Alola, A. A., & Adebayo, T. S. (2023). Environmental benefits of nonrenewable energy efficiency and renewable energy intensity in the USA and EU: examining the role of clean technologies. *Sustainable Energy Technologies and Assessments, 58*, Article 103315. https://doi.org/10.1016/j.seta.2023.103315. Article.

Pauer, E., Wohner, B., Heinrich, V., & Tacker, M. (2019). Assessing the environmental sustainability of food packaging: an extended life cycle assessment including packaging-related food losses and waste and circularity assessment. *Sustainability, 11*(3), 925. https://doi.org/10.3390/su11030925. Article.

Rajendran, B., Babu, M., Tripathy, N., & Anandhabalaji, V. (2024). A bibliometric exploration of environmental sustainability in supply chain research. In *Supply Chain Analytics, 8*, Article 100086. https://doi.org/10.1016/j.sca.2024.100086. Article.

Ruggerio, C. A. (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of The Total Environment, 786*, Article 147481. https://doi.org/10.1016/j.scitotenv.2021.147481. Article.

Sabato, S., & Mandelli, M. (2024). Towards an EU framework for a just transition: welfare policies and politics for the socio-ecological transition. *European Political Science, 23*, 14–26. https://doi.org/10.1057/s41304-023-00458-1

Sala, S., Crenna, E., Secchi, M., & Sanyé-Mengual, E. (2020). Environmental sustainability of European production and consumption assessed against planetary boundaries. *Journal of Environmental Management, 269*, Article 110686. https://doi.org/10.1016/j.jenvman.2020.110686. Article.

Sanz-Torró, V., Calafat-Marzal, C., Guaita-Martinez, J. M., & Vega, V. (2025). Assessment of European countries' national circular economy policies. *Journal of Environmental Management, 373*, Article 123835. https://doi.org/10.1016/j.jenvman.2024.123835. Article.

Schunz, S. (2022). The 'European Green Deal' – a paradigm shift? Transformations in the European Union's sustainability meta-discourse. *Political Research Exchange, 4*(1). https://doi.org/10.1080/2474736X.2022.2085121

Scown, M. W., Brady, M., & Nicholas, K. A. (2020). Billions in misspent EU agricultural subsidies could support the Sustainable Development Goals. *One Earth, 3*(2), 237–250. https://doi.org/10.1016/j.oneear.2020.07.011

Sessa, M. R., Russo, A., & Sica, F. (2022). Opinion paper on green deal for the urban regeneration of industrial brownfield land in Europe. *Land Use Policy, 119*, Article 106198. https://doi.org/10.1016/j.landusepol.2022.106198

Sharma, G. D., Tiwari, A. K., Erkut, B., & Mundi, H. S. (2021). Exploring the nexus between non-renewable and renewable energy consumptions and economic development: evidence from panel estimations. *Renewable and Sustainable Energy Reviews, 146*, Article 111152. https://doi.org/10.1016/j.rser.2021.111152. Article.

Sheraz, M., Deyi, X., Ahmed, J., Ullah, S., & Ullah, A. (2021). Moderating the effect of globalization on financial development, energy consumption, human capital, and carbon emissions: evidence from G20 countries. *Environmental Science and Pollution Research, 28*, 35126–35144. https://doi.org/10.1007/s11356-021-13116-0

Sonntag, W. I., Lemken, D., Spiller, A., & Schulze, M. (2023). Welcome to the (label) jungle? Analyzing how consumers deal with intra-sustainability label trade-offs on food. *Food Quality and Preference, 104*, Article 104746. https://doi.org/10.1016/j.foodqual.2022.104746. Article.

Šprajc, P., Bjegović, M., & Vasić, B. (2019). Energy security in decision making and governance - methodological analysis of energy trilemma index. *Renewable and Sustainable Energy Reviews, 114*, Article 109341. https://doi.org/10.1016/j.rser.2019.109341. Article.

Stanković, J. J., Janković-Milić, V., Marjanović, I., & Janjić, J. (2021). An integrated approach of PCA and PROMETHEE in spatial assessment of circular economy indicators. *Waste Management, 128*, 154–166. https://doi.org/10.1016/j.wasman.2021.04.057

Szpilko, D., & Ejdys, J. (2022). European Green Deal–research directions. A systematic literature review. *Ekonomia i Środowisko*, (2), 8–38. https://doi.org/10.34659/eis.2022.81.2.455

Takal, S. U., Tahiru, A. W., Fattah, I. R., Cobbina, S. J., Asare, W., & Abanyie, S. K. (2025). Enhancing resilience to climate change: A comprehensive PRISMA review of agricultural and non-agricultural adaptation strategies for Ghana. *Cogent Social Sciences, 11*(1). https://doi.org/10.1080/23311886.2025.2453905

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management, 14*, 207–222. https://doi.org/10.1111/1467-8551.00375

Triantafyllidou, E., & Zabaniotou, A. (2022). From theory to praxis: 'Go Sustainable living' survey for exploring individuals consciousness level of decision-making and action-taking in daily life towards a green citizenship. *Circular Economy and Sustainability, 2*, 113–139. https://doi.org/10.1007/s43615-021-00046-9

Ulhaq, I., Nayak, R., George, M., Nguyen, H., & Quang, H. (2024). Green knowledge management: A bibliometric analysis, research trends and future directions. *VINE Journal of Information and Knowledge Management Systems*. https://doi.org/10.1108/VJIKMS-02-2024-0069. Vol. ahead-of-print No. ahead-of-print.

United Nations. (1997). *Kyoto protocol to the united nations framework convention on climate change. Conference of the parties.* FCCC/CP/1997/L.7/Add.1.

United Nations. (2015). *Paris agreement*. Retrieved from https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Vishwakarma, L. P., Singh, R. K., Mishra, R., & Kumari, A. (2023). Application of artificial intelligence for resilient and sustainable healthcare system: Systematic literature review and future research directions. *International Journal of Production Research, 63*(2), 822–844. https://doi.org/10.1080/00207543.2023.2188101

Vogiatzaki, M., Zerefos, S., & Hoque Tania, M. (2020). Enhancing city sustainability through smart technologies: A framework for automatic pre-emptive action to promote safety and security using lighting and ICT-based surveillance. *Sustainability, 12*(15), 6142. https://doi.org/10.3390/su12156142. Article.

Wang, K. H., & Lu, W. C. (2025). AI-induced job impact: complementary or substitution? Empirical insights and sustainable technology considerations. *Sustainable Technology and Entrepreneurship, 4*(1), Article 100085. https://doi.org/10.1016/j.stae.2024.100085. Article.

Widomski, M. K., & Musz-Pomorska, A. (2023). Sustainable development of rural areas in Poland since 2004 in the light of sustainability indicators. *Land, 12*(2), 508. https://doi.org/10.3390/land12020508. Article.