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REVIEW ARTICLE

Mapping trends and knowledge structure of energy efficiency research: what we know and where we are going

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Abstract

Energy efficiency (EE) is an evolving research aspect for researchers, businesses, and policymakers for its undeniable role in meeting increasing energy demand, reducing CO_2 emissions, and tackling climate change. This paper provides a review of the current state of EE research by mapping the research landscape in business and economics to understand the socioeconomic dimensions within these research areas. To identify key information, we examine the trends and characteristics of 2935 relevant scientific publications over a 30-year period from 1990 to 2019 in the Social Science Citation Index of the Web of Science database using bibliometric analysis with a R language package called 'bibliometrix'. Our analysis shows an increasing trend in publications from 2006 onwards; the period remarkably coincides with the implementation phase of the Kyoto protocol in 2005. Accordingly, we observe that EE research has a strong association with issues like CO_2 emissions, climate change, sustainability, and the growing importance of these issues in recent years. Thus, our findings provide crucial understandings by incorporating a wide array of scientific outputs in response to calls for greater theoretical clarification of EE research. These findings provide insights into the current state of the art of, and identify crucial areas for future, research. Hence, our research assists in formulating environmentally sustainable policies to tackle the adverse effects of CO_2 emissions and related climate change through providing critical grasps on the scholarly development related to EE.

Keywords Energy efficiency · Energy Policy · Climate change · Carbon emissions · Energy sustainability · Bibliometric analysis

Introduction

Economies are heavily dependent on energy consumption in order to maintain sustainable economic growth, which, in turn, increases the world's demand for energy (Benromdhane 2015; Mahi et al. 2020). However, increasing energy consumption causes a sizable rise in carbon emissions, which negatively impacts the environment (Alola and Joshua 2020; Gu et al. 2019). This scenario presents a major dilemma for countries worldwide since they need to consume energy to maintain economic development. At the same time, they must reduce the adverse environmental impact of energy

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consumption. This twofold challenge can be met if they can improve the ratio of the usable energy output to input; in other words, by enhancing energy efficiency (EE)[1] (Nishant et al. 2014; Pan et al. 2020). The current energy supply is based on limited fossil fuel resources (Streimikiene et al. 2007) and the consumption of fossil fuels is accountable for more than 80% of total carbon dioxide (CO_2) emissions (Nishant et al. 2014). Hence, decreasing energy consumption appears to be the best way to manage emissions and related climate deteriorations (Javid and Khan 2020; Soytas and Sari 2009).

Considering the effective means of CO_2 emission mitigation, there is no single universally and effectively applicable policy instrument for environmental protection and sustainable development (Hájek et al. 2019). Among the available measures, EE improvement is endorsed as the most cost-effective approach in addressing energy-related issues and the 'first fuel' of energy transitions to deal with growing energy demand and reducing energy-related emissions (IEA 2014, 2018). Besides EE, the governments have taken other policy initiatives to reduce CO_2 emissions over the years. A more direct and widely used mechanism is exercising carbon tax[2] to internalize the negative externalities from the firms' business activities (Oikonomou et al. 2008). However, some argue that imposing carbon taxes can instigate inequality in business competition among the firms located in different regions—between those with taxes and without taxes (Dorsey-Palmateer and Niu 2020). Also, at the macro-level, inefficient tax policy may excessively burden the poor if the government fails to efficiently distribute tax revenue among the affected parties (Fremstad and Paul 2019). Besides, taxation on carbon emission is predominantly a regulatory initiative imposed on the firms, thus adding cost to the carbon-emitting firms. In comparison, EE improvement initiatives are taken by the firms voluntarily too. Firms often see energy efficiency improvement initiatives to convey their environmental concerns and long-term commitments (Dangelico and Pontrandolfo 2015) because the benefits realized from an increased efficiency can be extended to the environment and society at large (Testa and Vigolo 2015).

Moreover, EE is a critical element for the cleaner production pathway to facilitate the efficient use of resources to prevent environmental pollution from industrial activities. The Resource Efficient and Cleaner Production (RECP) program[3] considers EE attainment one of the critical targets in eliminating or minimizing waste and emissions to the environment, thus making industrial production more sustainable. Therefore, the implementation of adequate EE measures promotes cleaner production by reducing fossil-based energy and delivering benefits of energy security (Dhar et al. 2018). Moreover, the United Nations (UN) emphasized global energy efficiency improvement as one of the three major objectives of their Sustainable Energy for All (SE4ALL) initiative (UN 2020). Ensuring universal access to modern energy services along with doubling the global rate of improvement in energy efficiency and substantial enhancement of renewable energy in the global energy mix by 2030 are the key pathways to achieving sustainable development goals (Anton and Nucu 2020; UN 2020). Particularly, attaining efficiency in utilizing energy alone can save up to 35% of the cumulative CO_2 emissions (holding the global demand for energy steady until 2050) (IEA, 2018). This target is required to keep the rise in temperature within the 2°C scenario of global warming by 2050 and 1.5°C by 2100, considering the rapid economic and population growth (Esmeijer et al. 2018; Rogelj et al. 2018). The critical roles of EE highlight the need for countries to implement policies to reduce their reliance on fossil fuels and lessen the adverse impacts on the environment (Al-Mulali et al. 2016). Hence, the multifaceted benefits offered by EE improvement at both micro- and macro-level in reducing the CO_2 emission tackling climate deterioration, and improving energy security make it a reasonably superior measure to keep economies on the sustainable development path..

To support this idea and provide an implementation framework, the Kyoto Protocol in 1997 was signed to reduce CO_2 and other greenhouse gases (GHG) emissions (Obradović and Lojanica 2017). Consequently, at the Paris Climate Conference (COP21) in 2015, for the very first time, 195 countries, including the USA, agreed on a universal global climate deal (Shahbaz et al. 2018). However, in a recent report, the International Energy Agency (IEA) stresses that the worldwide energy intensity level has been weakening each year (IEA 2018). The IEA (2018) report finds that the rate of energy efficiency improvement is 1.2% in 2018, which is well below the average 3% improvement target in line with the IEA's Efficient World Strategy.[4] This discrepancy between expectation and reality poses major concerns in attaining EE goals to combat the adverse effects of climate change for governments, policymakers, and the research community. Therefore, identifying the knowledge structure of EE can reveal how research has advanced in this field so far. This

[1] The concept of EE is popularly understood as 'doing more with less,' that is, lowering the energy requirements for a given level of economic activity (Hanley et al. 2009).

[2] A carbon tax is an excise tax imposed on the carbon content of fossil fuels to control CO_2 emissions by the firms (Hájek et al. 2019; Oikonomou et al. 2008).

[3] RECP is a joint initiative the United Nations Industrial Development Organization (UNIDO) and the United Nations Environment Programme (UNEP) in response to countries' growing demand for help with the delivery of Resource Efficient and Cleaner Production services to industries through different stakeholders in over 60 developing and transition economies.

[4] Efficient World Strategy by IEA identifies where the efficiency opportunities exist and sets out the policies required to be put in place to capture them. It offers a blueprint to governments to improve their economies and lower their emissions. It also maps out how to meet key elements of the UN's Sustainable Development Goals relating to energy.

understanding is essential to gain insights into the research concentration of the existing literature and identify potential areas to explore in supporting governments, policymakers, and other stakeholders in reaching necessary EE goals. Accordingly, our study primarily aims to answer the following research questions: what is the global trend of scientific publications on EE? What information is revealed from the existing stream of publications? What other themes are linked to EE research? How have these themes evolved over time? To answer these questions, we review the existing literature using bibliometric methods to understand the current knowledge structure of EE research and highlight the future direction of research in this field.

We use bibliometric analysis since it allows ascertaining necessary information about a specific area of research (Casadesus-Masanell and Ricart 2011; Secinaro et al. 2020). Compared to other methods of literature review, such as narrative or systematic literature reviews, bibliometric is a methodical, straightforward, and reproducible process that minimizes the intrinsic subjectivity (Della Corte et al. 2019). From the standpoint of research breadth, bibliometric analysis can comprehensively review all the existing studies; at the same time, it offers a quantitative approach in investigating the significantly expanding literature in each field (Feng et al. 2017). This method organizes the data available in the databases (i.e., WoS or Scopus) and transforms them into comprehensible information, thus assist in enhancing knowledge in a particular area of study. Essentially, the bibliometric method maps an overview of a particular field of research based on a wide range of indicators (Valenzuela Fernandez et al. 2019), incorporates an overview of a specific area of research, and the analysis of leading investigators (Bjork et al. 2014). The bibliometric analysis also evaluates advances in knowledge of a particular subject and assesses the scientific value (Albort-Morant and Ribeiro-Soriano 2016) and presents a broader picture of the research field over the past years (Bonilla et al. 2015). Correspondingly, the method helps organize information in a precise thematic field (Merigó et al. 2015), thus assessing the trends and future research (Ji et al. 2018). Hence, with our aim to provide a systematic overview, a historical context, and distinguish future directions in research on energy efficiency, this method allows us to provide a quantitative analysis in terms of output and impact (Dominko and Verbič 2019). Furthermore, visualizing the bibliographic information through mapping helps scholars to understand research trends broadly and intuitively by highlighting the boundaries of the existing relevant intellectual territory and knowledge structure (Cobo et al. 2011; Huang et al. 2020).

Our study obtains Web of Science (WoS) data from 1990 to 2019 to analyze the bibliographic information, particularly in the areas of business, finance, economics, and management (BFEM). Outlooks from these perspectives are essential to complement science-based research as the market mechanisms and business models play a significant role in achieving energy efficiency improvements. Potential market imperfections on both the demand and supply side of the market can lead to underinvestment in energy efficiency (Jaffe et al. 2004). Accordingly, research in these areas seeks to conceptualize energy efficiency decision-making, identify the degree to which market or behavioral failures may present an opportunity for net-beneficial policy interventions, and evaluate the realized effectiveness and cost of actual policies (Gillingham et al. 2009). Hence, our specific focus on EE from the perspectives of BFEM enables us to focus on the socioeconomic and related policy aspects more specifically. We have chosen a 30-year window for analysis since it covers some crucial global events, such as the signing and implementation of the Kyoto protocol and COP21, which have considerable influences on EE research and policy formulation. To analyze the sample data, we have used a recently developed R language package called ‘bibliometrix’ and its ‘biblioshiny’ extension to visualize the outputs (Aria and Cuccurullo 2017).

Our results show an increasing trend in the overall publications over time, along with an accelerated upward shift from 2006 onwards. Further, the results reveal that the USA has been the most productive and influential country in the field of EE research in terms of total publications (TP) and total citations (TC) received, together with multi-country publications (MCP) outputs. Also, at the institutional level, the University of California, Berkeley, has contributed the most in this area of research. As a source of publications, Energy Policy journal has come out as a great patron of publications related to different aspects of EE in these BFEM disciplines and has published more than 50% of total publications during the period of analysis. The analysis of author keywords shows that the keyword ‘energy efficiency’ fluctuates at different points of time and links to other keywords, including ‘sustainability,’ ‘CO2 emissions,’ and ‘global warming,’ gaining more attention in recent publications.

While identifying the main keywords provides a general overview of the research focus in BFEM, we further present the trends and dynamic changes of keywords at different years under analysis. This enables us to see the changes in research interest and orientation from the past to the present. Moreover, our study provides a more in-depth insight by analyzing ideas and mapping the temporal structure of different research concepts through the association of the keywords. Through the segregation of ideas in different clusters, we demonstrate the diversity, breadth, and intellectual thrust of the work undertaken in these areas of research in a novel way. We further identify seven major research themes based on the co-word analysis. Among the themes, ‘energy efficiency’ is positioned as the primary and most important theme. We also find that ‘climate change’ is an important and specialized research theme. Besides, ‘carbon dioxide emissions’-related studies represent an emerging area of research, while ‘energy consumption’ and ‘sustainable development’ research streams constitute specialized themes. Moreover, we find that substantial changes have taken place in the research interest in the fields of BFEM. The initial focus of energy- and policy-related concerns has merged into areas such as climate change or sustainable development. This shifting trend indicates the growing interest and importance of EE to combat emission reduction along with lessening the undesirable impact of climate change.

Our paper contributes to the existing body of knowledge in several ways. First, we contribute to the literature by offering an essential overview of EE research by exploring critical aspects in BFEM. Second, our study contributes to understanding diverse characteristics of existing research for a sufficiently long period, which covers some key events that are directly influential to EE research- and policy-related issues. Third, our analysis has gone some way towards enhancing the understanding of the underlying knowledge structure through clustering and thematic mapping, which are the unique approaches within the bibliometric analysis to uncover the historical research orientations in these fields of research. Our study adds further novelty by identifying and illustrating the changes in research trends at different points of time, which will aid the future researcher to recognize research issues more efficiently and accelerate the required research. These, in turn, expect to assist industry players and policymakers with crucial breakthroughs in achieving energy-related sustainable development goals. Finally, we employ a newly developed and comprehensive R package (bibliometrix) which, to the best of our knowledge, is the first study to analyze EE research using this powerful tool which is increasingly gaining popularity in other areas for its comprehensiveness in bibliometric analysis.

The remainder of the paper is set out as follows: the “Analytical framework” section discusses the analytical framework of the study, which discusses the fundamentals of the bibliometric analysis and methodologies to evaluate the scientific outputs. Additionally, this section provides the rationale for employing the chosen data sources and analytic tools. The “Results” section presents and discusses the main bibliographic indicators to understand the scientific output in this area of research. The “Conclusion, policy implications, and future research directions” section concludes the study by summarizing the findings and suggesting future areas of research.

Analytical framework

Bibliometric methods and indicators

A number of methods are used in the literature to analyze bibliometric information. The conventional and conceivably the most utilized method is citation analysis. This method serves as an approximate measure of scientific quality, particularly in the case of individual researchers, university rankings, and institutions (Frandsen and Rousseau 2005). Citation analysis is also useful for evaluating the impact of publications (Waltman et al. 2012) or merely as a measure of academic influence (Ellegaard and Wallin 2015). The underlying notion is that if a publication or author achieves a high number of citations, the publication or author is believed to have an impact in the field (Feng et al. 2017). An alternative and certainly crucial indicator which also considers citation count is the h-index. The index indicates that ‘h’ number of articles published by an author is cited at least ‘h’ times each (Hirsch 2010). Unlike total citation counts, the distinctiveness and strength of the h-index stems from the combined estimation of two metrics—the total number of research carried out (i.e., the number of publications) and the consistency (i.e., the number of citations in publications) on a single number (Sharma et al. 2013). Hence, the h-index is used to measure the productivity as well as the impact of authors, thus advantageous for assessing a scholar’s research achievement in terms of both quality and quantity (Hirsch 2010; Hou et al. 2015).

Then again, the degree of similarity between two different publications can be detected using co-citation analysis. This method analyzes the bibliographic information of scientific documents that share one or more of the same references (Walter and Ribière 2013). When other researchers frequently cite a group of authors’ articles at the same time, it indicates that the cited authors have studied similar topics. Hence, this approach is widely used to provide information about links between different groups in the scientific community (Ellegaard and Wallin 2015). Another popular bibliometric analysis is the co-author analysis, which examines the authors and their affiliations to analyze the social structure and collaboration networks (Glänzel 2001).

Furthermore, to identify the focus of research in a particular field, analysis of keywords is used in bibliometric studies. Identifying and analyzing relevant keywords in publications helps to construct a semantic field map for a specific area of research (Zupic and Čater 2015). This, in turn, scientifically discovers subfield linkages and tracks the research phenomenon (Feng et al. 2017). Similarly, co-word analysis extracts scientific maps of a field using keywords based on the high frequencies of words that appear in the publications. This analysis helps researchers to use the actual content of a text directly to capture co-occurrence interactions in constructing the framework (Feng et al. 2017). Furthermore, thematic

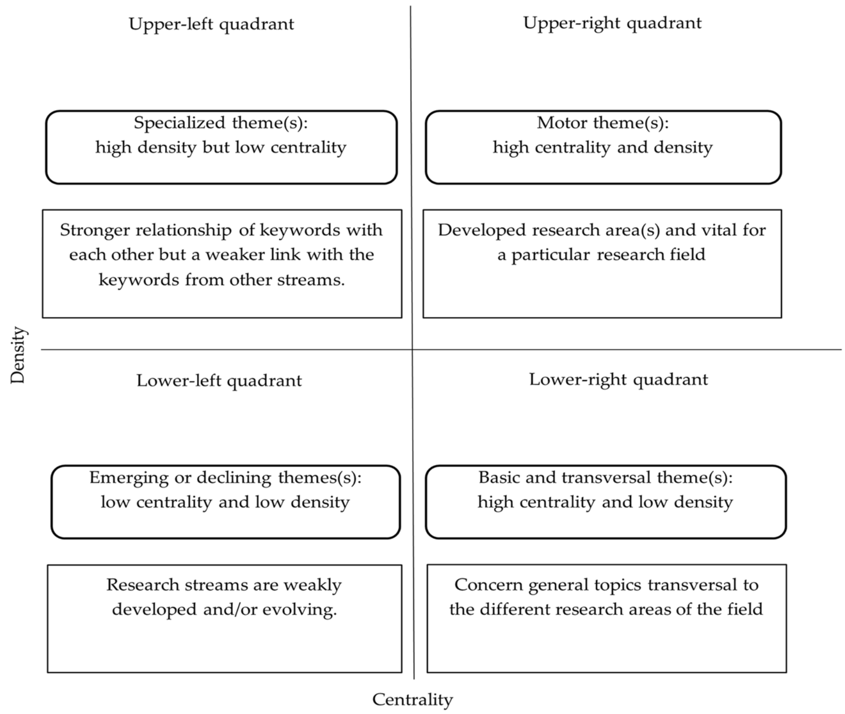


Fig. 1 Thematic map (source: authors' illustration; adapted from Della Corte et al. (2019))

mapping of keywords provides the research topics, important expressions, and the relationships between them. The degree of the relation among different topics is termed as the centrality of a theme, while density indicates the level of advancement of a particular theme (Esfahani et al. 2019). Four typologies of themes can be defined according to the quadrant in which they are placed (Della Corte et al. 2019). Figure 1 below illustrates the thematic map and highlights the characteristics of each quadrant.

Bibliometric data and analysis strategy

To create a broad dataset that contains research on EE, we considered the scientific publications listed in the Social Science Citation Index (SSCI) of the WoS database. The WoS is a well-known database and incorporates information of more than 161 million records across 254 subject areas.[5] The database gives access to articles from scientific journals, books, and other academic documents in all disciplines within the scholarly community. Though WoS does not essentially index the largest number of journals in all the different fields compared to other databases like Scopus (Li et al. 2010), it is believed to provide an adequate amount of high-quality literature (Ellegaard and Wallin 2015).

We particularly considered the publications that are indexed on the SSCI. Essentially, SSCI is the most important source of information for wide-ranging bibliometric analyses of the social sciences (van Leeuwen 2006). Besides, it covers the domain of economics and related research areas like business and finance (van Leeuwen and Medina 2012). Hence, the consideration of publications in other WoS indexes (i.e., SCI or AHCI) may dilute the focus of the study with a too large sample and the presence of the publications that are not reasonably related to BFEM areas. Accordingly, SSCI can be considered the most suitable index in analyzing the publication trends and knowledge structure of the EE publications in these fields of research. Figure 2 below illustrates the workflow of our bibliometric analysis from the keywords search to analysis and visualization.

In order to create a representative set of documents for analysis and to avoid the risks of distorting the results, the best option is to search for specific content, which is done through the following search string:

TOPIC: ("Energy efficiency" OR "Energy-efficiency" OR "Energy effici" OR "Energy-effici*")*

As our focus is on the BFEM fields, we refine the search results in WoS categories and retain the results for the categories that include 'business,' 'business finance,' 'social sciences interdisciplinary,' 'economics,' and 'management.' With the dataset obtained, this study analyzes a broad set of scientific output amounting to 2935 documents, including articles, book chapters, proceeding papers, and the like over a period of 30 years from 1990 to 2019. The starting year 1990 was chosen as the EE-related publications in BFEM were relatively low (i.e., less than 7) before 1990. Additionally, the 30-year research period

[5] Clarivate Analytics Company (Web of Science Group) Website: https://clarivate.com/webofsciencegroup/solutions/web-of-science/; accessed on 2020 February 14

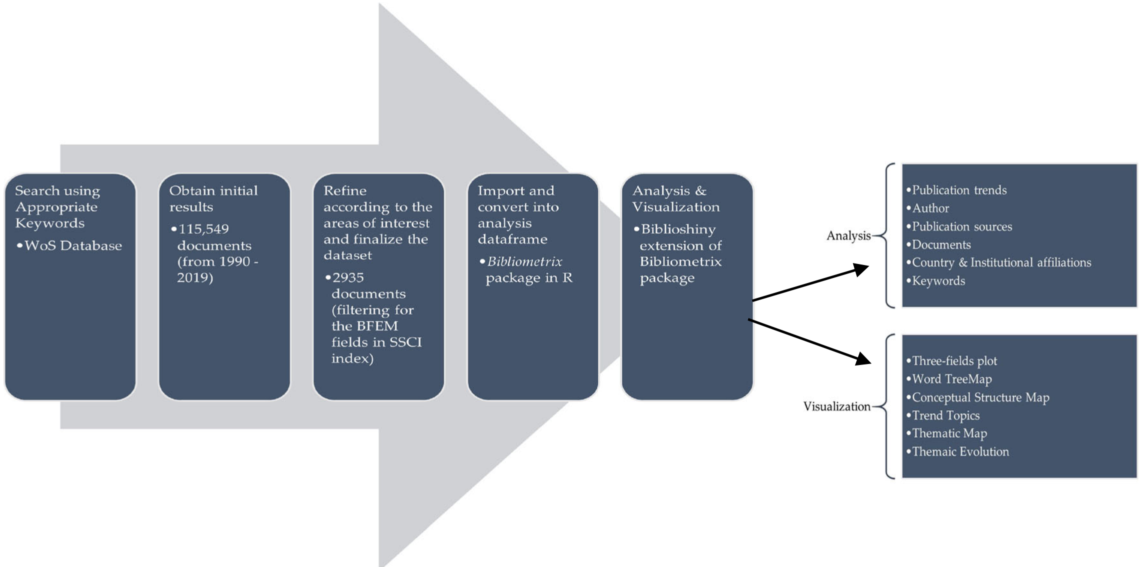


Fig. 2 Bibliometric analysis workflow (source: authors' illustration)

from 1990 to 2019 provides a sufficiently long period for analysis. The summary of the search results is presented in Table 1.

From Table 1, the largest share of scientific outputs is in the form of 'Article' (2739 articles), which is 93.32% of the total records during the analysis period, followed by proceedings paper (2.93%). Other types of publications accounted for the rest, including book chapter, book review, editorial material, review, and the like. From the aspect of the number of authorships, the number of single-authored publications is almost a quarter compared to collaborative publications.

Table 1 Summary of the search results

Description	Results
Period	1990–2019
Sources (journals, books, etc.)	272
Documents	2935
Authors	5621
Single-authored publications	591
Multiple-authored publications	2344
Total citations received by all publications	81,871
Average citations per publication	27.89
Keywords plus	2853
Author's keywords	5654
Document types	
Article	2739
Book chapter	6
Proceedings paper	85
Book review	9
Correction	4
Correction, addition	1
Editorial material	39
Letter	3
Meeting abstract	1
Note	10
Review	37
Review; book chapter	1

Analysis tools

This paper adopts the open-source statistical application called R to perform the bibliometric analysis. Particularly, the 'Bibliometrix' package (http://www.bibliometrix.org) (Aria and Cuccurullo 2017) is used to analyze the dataset obtained through search queries from the WoS database. We have used the 'biblioshiny' extension of the specified package to tabulate and visualize results. Bibliometrix is, by far, the most popular R package and is used in a growing number of publications having functions that allow for descriptive analyses (Linnenluecke et al. 2020).

Bibliometrix package is a suite of tools for accurate publication data processing such as file conversion, term extraction, duplicate matching and merging, descriptive analysis, matrix building, and similarity normalization for network analysis (Aria and Cuccurullo 2017). The package has gained popularity in bibliometric analysis, and several studies have used the bibliometrix tool for their specific research fields, recently (Alonso et al. 2018; Firdaus et al. 2019; Linnenluecke et al. 2020). Hence, we use the bibliometrix package to extract bibliographic data of EE-related papers in the field of BFEM into R language analytical frame, as well as to analyze and visualize the information to understand the knowledge structure of publications through different bibliometric indicators.

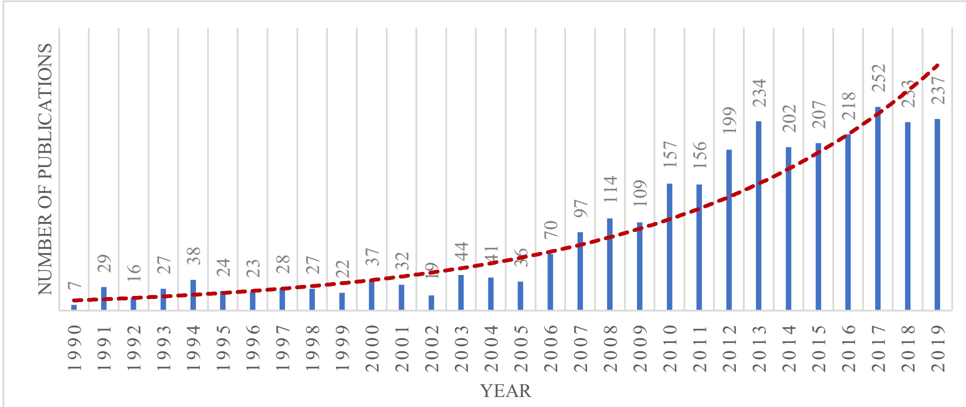


Fig. 3 Trends in EE publications from 1990 to 2019

Results

Characteristics of scientific output

Publication trends related to EE in the field of BFEM research are presented in Fig. 3.

Figure 3 shows that annual publications have increased over the year. This result may be explained by the increasing global concerns regarding energy consumptions, related carbon emissions, and its effect on climate change. The problem has caught the attention of the academic community as well as the policymakers, which is depicted through the increasing number of publications (NP). Specially, a rapid shift in the publication trend is observed in 2006 when the number of documents has almost doubled (NP=70) compared to the preceding year (NP=36). Consequently, we notice an overall upward trend since 2006, which has experienced a slight fluctuation in recent years, however, continued rising. One possible reason could be the implementation of the Kyoto protocol on 16 February 2005 (which was adopted back in 1997). Since then, the number of publications has increased significantly until today, and the growth rate of publications is 12.91% per annum over this 30-year period.

Top contributing authors

The contribution of the most prolific authors in EE research is evaluated. A total of 5621 authors contributed to the 2935 publications during the period of study. Interestingly, only 136 authors (2.42%) have produced five or more publications among these authors. The results revealed that a few highly productive authors contributed to most of the publications. Table 2 presents a list of the top 20 researchers with their PYS, NP, TC, and h-index.

From Table 2, we observe a mixed result for the leading authors. Taking the number of publications into account, Bo Q. Lin (Lin BQ) is the most prolific author with a total of 23 publications. In comparison, Ning Zhang (Zhang N) appears in the second position with 20 publications during the period of study. However, the ranking changes when TC is considered. Steve Sorrell (Sorrell S) has the highest citations for his publications. Lin BQ again holds the position of the most influential author when h-index is considered having a score of 16. Interestingly, Ernst Worrell (Worrell E) occupies the second position in terms of h-index (score 15), having a comparatively smaller number of publications (NP 16) to his peer authors.

Furthermore, Fig. 4 illustrates the publication timeline of the top twenty authors. Among them, Lin BQ, Zhang N, and Zhou P have started publications much more recently

Table 2 Top twenty most publishing and prominent authors

Rank	Authors	PYS	NP	TC	h-index
1	Lin BQ	2010	23	922	16
2	Zhang N	2011	20	926	12
3	Zhou P	2007	19	1488	14
4	Schipper L	1991	18	508	12
5	Schleich J	2008	18	697	11
6	Blok K	1993	17	594	13
7	Wu Y	2009	17	579	13
8	Worrell E	1993	16	822	15
9	Sorrell S	2003	15	1732	13
10	Ang BW	1996	14	1173	12
11	Kok N	2011	13	846	11
12	Turner K	2007	13	426	8
13	Sanstad AH	1994	12	390	10
14	Sueyoshi T	2010	12	705	11
15	Wei YM	2007	12	718	9
16	Zhou N	2008	12	772	10
17	Choi Y	2011	11	643	8
18	Sovacool BK	2007	11	293	9
19	Streimikiene D	2007	11	175	6
20	Bertoldi P	2003	10	306	9

[1] NP: number of publications. [2] PYS: publication year start. [3] TC: total citations

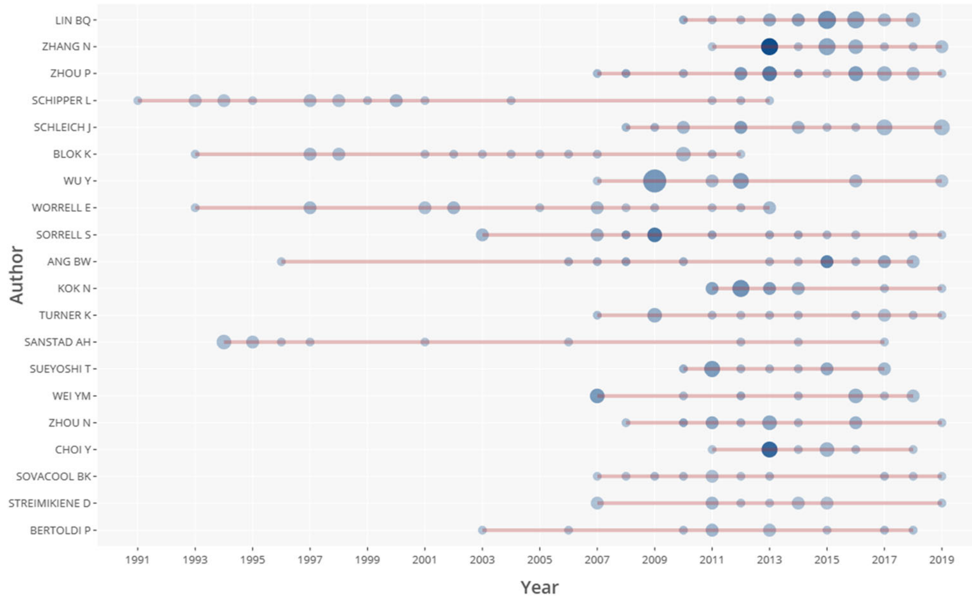


Fig. 4 Top authors' publications from 1990 to 2019

compared to other top published peer authors, such as Schipper L, Blok K, and Worrell E, while Schipper L, Blok K, Worrell E, Ang BW, Sanstad AH, Schipper L, and Bertoldi P are among the top authors who have contributed to EE publications over a more extended phase compared to other authors.

Top contributing journals and publications

This section provides the information of the most contributing publications and publication venues of EE-related research in BFEM fields. Table 3 lists down the top twenty core journals that published the highest number of articles on EE since their

Table 3 Top twenty most publishing and influential sources

Rank	Authors	PYS	NP	TC	h-index
1	Energy Policy	1990	1617	50,809	98
2	Energy Economics	1990	267	8079	54
3	Ecological Economics	1994	94	3536	29
4	Energy Journal	1994	78	1487	24
5	Technological Forecasting and Social Change	1997	44	837	18
6	Transportation Research Part A-Policy and Practice	1993	35	739	13
7	Resource and Energy Economics	1994	27	990	12
8	Environmental & Resource Economics	2000	25	884	11
9	Journal of Environmental Economics and Management	2004	25	787	14
10	International Journal of Consumer Studies	2007	22	259	10
11	Applied Economics	1990	20	133	8
12	Economic Modelling	2003	20	614	11
13	Economics of Energy & Environmental Policy	2012	18	113	5
14	Transportation Research Part B-Methodological	2014	17	584	13
15	European Journal of Operational Research	1995	14	466	8
16	Business Strategy and The Environment	2009	12	302	6
17	Omega-International Journal of Management Science	1994	12	200	6
18	China Economic Review	2012	11	305	6
19	Transport Policy	2012	11	123	6
20	American Economic Review	2002	9	668	9

[1] NP: number of publications. [2] PYS: publication year start. [3] TC: total citations

publication year start (PYS), total citations (TC) received, and h-index of the journals. The results show that a significant proportion (2378 out of 2935) is published in the top twenty journals, which accounts for 81% of total publications during the analysis period. Notably, 'Energy Policy' has published the most articles compared to its peer journals. The journal published around 55% of total publications and almost six times more than 'Energy Economics,' which is ranked second in the list.

Moreover, we evaluate the information of the 2935 publications, among which 591 are single-authored documents, while more than one author produces the rest. Besides, a total of 81,871 citations were received by 2935 publications in our analysis. Of that, 159 publications (5.41%) have received 100 or more citations, while 228 publications (7.77%) have not received any citations as of 2019 December 31. Based on the number of global citations[6] received, we have identified the twenty most impactful publications within the BFEM aspects of EE. The top-cited publication is a review paper titled 'Energy efficiency and consumption—the rebound effect—a survey.' This publication is co-authored by Greening et al. (2000) and published in Energy Policy. The second- and third-placed papers are also published in Energy Policy. However, the second-placed publication 'Total-factor energy efficiency of regions in China' which is authored by Hu and Wang (2006) is more recent one compared to the third most cited publication 'The energy-efficiency gap - what does it mean?' by Jaffe and Stavins (1994). Also, the publication by Hu and Wang (2006) comes second in terms of average citations per year (ACPY). Similarly, in terms of ACPY, the publication titled 'Empirical estimates of the direct rebound effect: a review' authored by Sorrell et al. (2009) is ranked third in the top-ranked publication list. The list of the top ten publications with relevant information is provided in the Appendix Table 5.

Geographic and institutional dissemination of publications

In this section, we analyze the geographic distribution of publications considering authors' affiliated institutions and countries. Table 4 shows the most prolific institutions and countries in terms of total publications. Additionally, it summarizes the collaborative nature of the scientific outputs along with the impact of their publications in terms of total citations (TC), multi-country publications (MCP), and multi-country publication ratio (MCPR).

From the institutional level, the University of California, Berkeley contributed 112 publications (3.82%) of the total number of publications, followed by the National University of Singapore with 52 publications during the period of analysis. At a macro-level, the USA is the most productive country in terms of scientific output in EE-related research, having 680 publications which is more than double what China has published (NP=329) during the period, followed by the UK (NP = 275). Germany, the Netherlands, and Sweden are the other three countries with more than 100 publications in this area on research. However, the country ranking changes when the collaborative output ratio is considered. Though the USA has the highest number of MCP (MCP=185), Australia tops the list with the highest MCPR having 34 MCP compared to 42 single country publications (SCP), 44.74% of total publications by the Australian authors. Canada and France are not far behind in this ranking, having an MCPR of 43.86%t and 37.37%, respectively. Also, the list indicates that Greece, Singapore, and Denmark are among the countries with the highest collaborative publications event. However, they have published less compared to other countries on the list.

In addition, Fig. 5 depicts each of the country's collaborations worldwide, showing blue color as an indication of the existence of the country's scientific output. The darker the blue, the more productive the country is in terms of EE publications. The red lines indicate the collaboration networks of the publishing countries. From Fig. 5, the countries that actively collaborate with others are the USA, the UK, China, and Australia. The map indicates that the USA is the country that collaborates the most by engaging with almost all active countries in publishing research in EE, followed by China and a few countries in Europe, including the UK, Germany, the Netherlands, Sweden, and France.

Furthermore, we encapsulate the top twenty prolific countries and institutions with top twenty publishing sources through a three-field plot in Fig. 6. This illustration provides us with the idea of the relative contributions of the institutions in a country's overall research output. For the USA and China, the country's scientific productions are predominantly contributed by the top listed institutions. For the USA, University of California, Berkeley, constitutes the most considerable portion of the country's overall scientific outputs, followed by Stanford University, University of Maryland, Harvard University, Lawrence Berkeley National Laboratory, and Duke University. Similarly, for China, the most participating institutions to overall country scientific publications are Xiamen University, Tsinghua University, Tianjin University, and Nanjing University of Aeronautics and Astronautics. Also, the UK publications show a similar composition, having participated mainly by the University of Sussex, University of Oxford, University of Cambridge, and Leeds University. However, contributions are less concentrated in the top-ranked institutions in the other top-producing countries. Then again, from the publication sources perspective, the highest publishing sources, Energy Policy, are mainly contributed by the authors from China, the USA, and the UK,

[6] Global citations measure the number of citations a publication receives from the records contained in an entire database (i.e, the WoS database for the current study) (Yao et al. 2014)

Table 4 Twenty most cited publications (1990–2019)

Rank	Paper title	Author (publication year)	Source	TC	ACPY
1.	Energy efficiency and consumption - the rebound effect - a survey	Greening, LA; Greene, DL; Difiglio, C (2000)	Energy Policy	815	38.8095
2.	Total-factor energy efficiency of regions in China	Hu, JL; Wang, SC (2006)	Energy Policy	563	37.5333
3.	The energy-efficiency gap - what does it mean	Jaffe, AB; Stavins, RN (1994)	Energy Policy	548	20.2963
4.	Induced innovation and energy prices	Popp, D (2002)	American Economic Review	429	22.5789
5.	What is energy efficiency? Concepts, indicators and methodological issues	Patterson, MG (1996)	Energy Policy	404	16.16
6.	Empirical estimates of the direct rebound effect: a review	Sorrell, S; Dimitropoulos, J;Sommerville, M (2009)	Energy Policy	397	33.0833
7.	Environmental policy and technological change	Jaffe, AB; Newell, RG; Stavins, RN (2002)	Environmental & Resource Economics	354	18.6316
8.	Moving to greener pastures? Multinationals and the pollution haven hypothesis	Eskeland, GS;Harrison, AE (2003)	Journal of Development Economics	353	19.6111
9.	The rebound effect: microeconomic definitions, limitations and extensions	Sorrell, S; Dimitropoulos, J (2008)	Ecological Economics	341	26.2308
10.	The induced innovation hypothesis and energy-saving technological change	Newell, RG; Jaffe, AB; Stavins, RN (1999)	Quarterly Journal of Economics	328	14.9091

[1] TC: total citations. [2] ACPY: average citations per year

followed by Germany, Spain, Italy, and Sweden. Specifically, for the UK, Spain, Italy, and Sweden, the more significant part of overall country scientific documents is published in Energy Policy, as illustrated in Fig. 6. Publications in other sources are distributed randomly among different top publishing countries.

Conceptual structure of literature

Analysis of conceptual structure is crucial as it discovers the hidden and dynamic pattern of a research field to identify the trends and major themes in literature. Also, it helps to understand the connection between various concepts in the existing

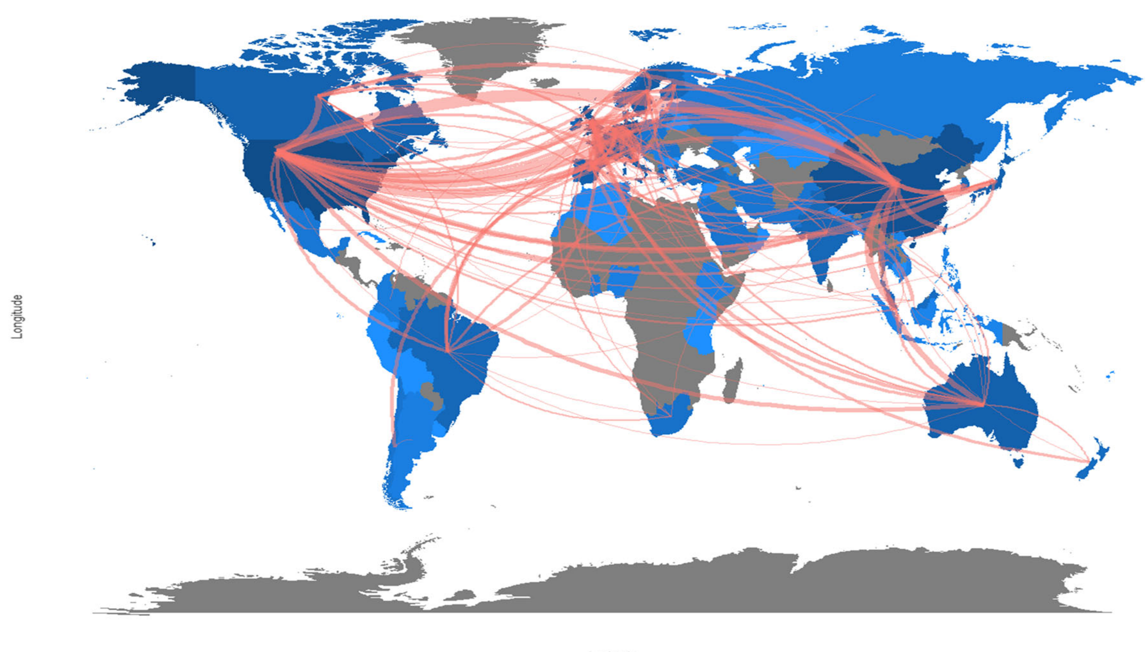


Fig. 5 Collaboration world map

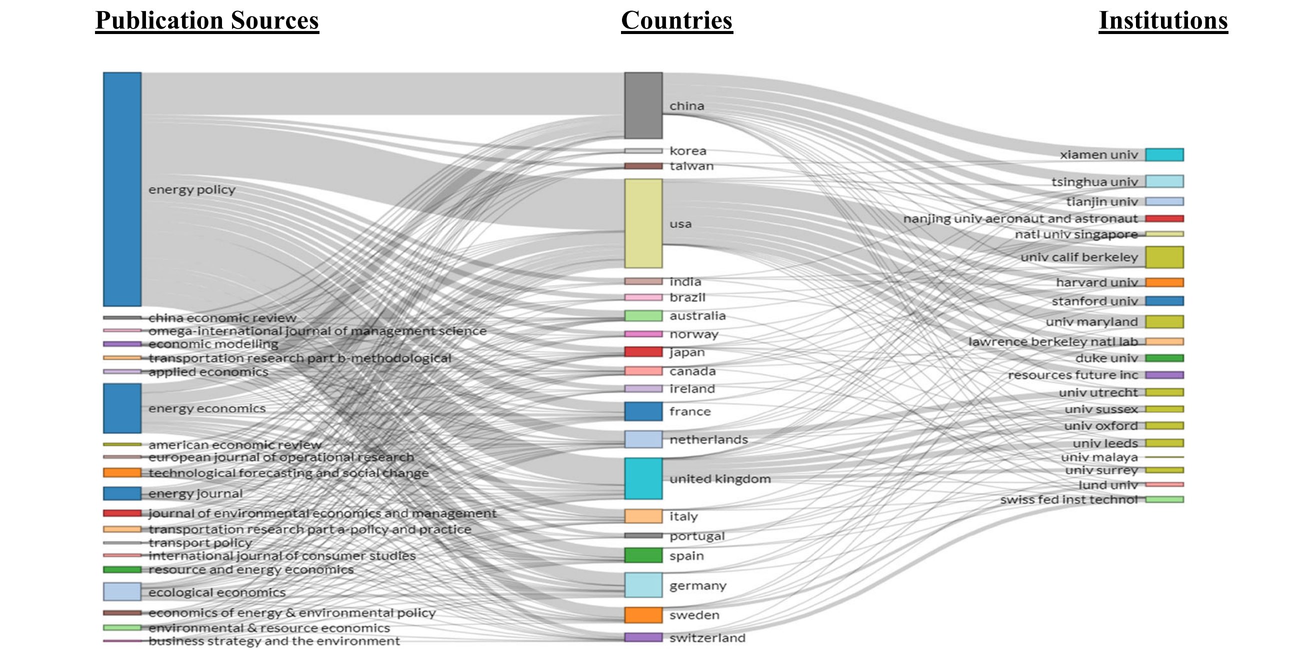


Fig. 6 Three-fields plot (top twenty journals, countries, and institutional affiliations)

literature that leads towards identifying future research agenda. We analyzed the conceptual structure of EE research mainly in two ways. Firstly, the analysis of keywords and trends and, secondly, the major themes are illustrated using co-word analysis. Additionally, we divide the thematic development at different points of time to understand the changes and the latest development of the research.

Analysis of keywords

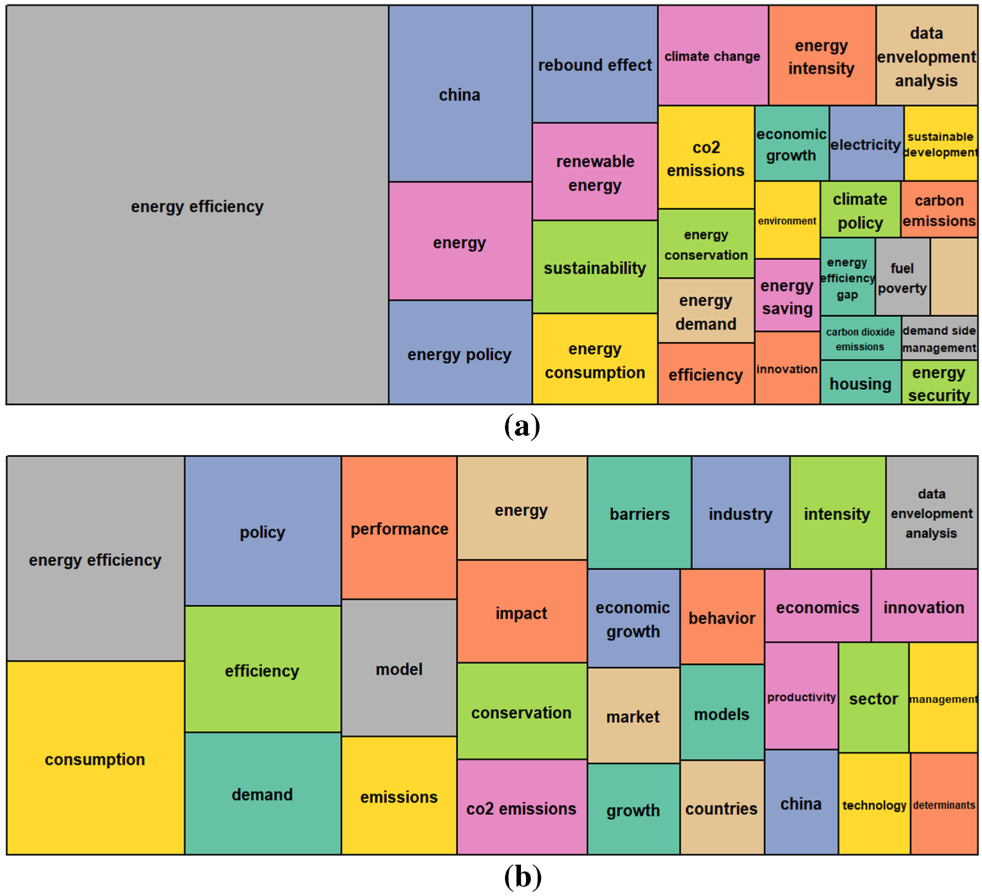
This section provides the research keywords used by the authors in EE research over time. Statistical analysis of author keywords, keywords plus, and title words can be used to identify directions in research, which can be a useful way to explore the development of scientific outputs (Du et al. 2013). In Fig. 7, we have illustrated the top thirty keywords based on authors' keywords as well as keywords plus. Author keywords are those provided by the original authors. In contrast, keywords plus are the words or phrases that frequently appear in the titles of an article's reference and are extracted by Thomson Reuters through an automatic computer algorithm (Zhang et al. 2016).

In both panels in Fig. 8, the most frequently used keyword is 'Energy Efficiency,' given that we have focused on this particular keyword, to begin with. 'Consumption' is the second most used keyword based on the keyword plus criterion. In comparison, authors have used 'China' as a keyword for their research, which indicates that a substantial amount of research has been concentrated on China's EE-related issues. Besides, a significant amount of research focused on the consumption, conservation, and efficiency aspects of energy. Again, CO_2 emissions, climate problems, and impact analysis are the common areas explored by the researchers, while the impact of energy on economic growth and performance remained as crucial issues as well. We particularly observe the research focus on renewable energy by the authors. In meeting increased energy demand and reducing climate pollution, renewable energy is becoming increasingly important in the global energy mix besides achieving energy efficiency (Anton and Nucu 2020; Ozturk et al. 2019). This, in turn, provides synergic benefits in meeting energy and related environmental challenges, and thus served as the 'twin pillars' of sustainable energy policy (Prindle et al. 2007). Moreover, we notice a prevalent methodological orientation in this area of research; to measure EE, data envelopment analysis has widely been used since it is one of the most popular tools in measuring efficiency (Lin et al. 2019).

We further analyze the association of the keywords used to understand the topics covered by scholars. Figure 8 visualizes the temporal structure in a two-dimensional plot of the research concentration from 1990 to 2019 based on multiple correspondence analysis (MCA)[7] of author keywords. The graph indicates that the keywords used in scientific outputs are organized into five primary clusters. A comprehensive review of the content of these five clusters is not included due to the word limit and brevity of the discussion; a few illustrative examples demonstrate the diversity, breadth, and intellectual thrust of the work undertaken in each cluster.

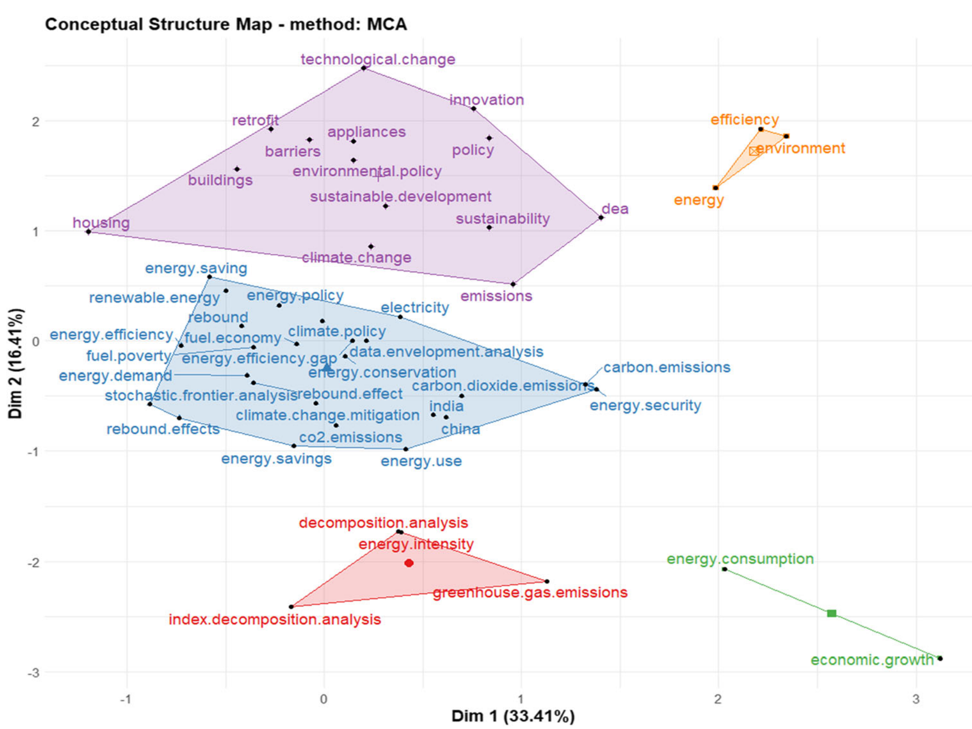
[7] Multiple correspondence analysis or MCA geometrically displays data in rows and clumns in a low dimensional space, so that the proximity in the space indicates the similarities (Le Roux and Rouanet 2010). Hence, the analysis draws a conceptual structure of the field and K-means clustering to identify clusters of documents which express common concepts (Aria and Cuccurullo 2017).

Fig. 7 Most frequently used keywords in research: **a** word treemap by author keywords; **b** word treemap by keywords plus



In Fig. 8, the first cluster (color: violet) contains a total of 14 keywords associated with articles that emphasize the sustainability aspects of EE research, which is related to technological change, housing, buildings, retrofit, appliances, and

Fig. 8 Conceptual research structure based on author keywords



innovation. The association indicates that a substantial amount of research has focused on the EE of buildings and constructions. Besides, the essential aspects explored as the related fields of research are policy and environmental policy connected with the EE in buildings and building retrofits. The second cluster (color: blue) is comprised of 25 keywords associated with articles that address the EE issues more directly. The cluster shows the different energy-related aspects that have a close intellectual association with EE, like energy use, energy-saving, energy conservation, energy demand, energy security, and energy policy. A significant amount of emission- and climate-related research concentrations are observed in this cluster which provides a notable aspect of EE research. The intensity implies the importance given by the research community to find the critical ties between energy and climate concerns.

Comparable research focusing on energy-related efficiency is observed in cluster 3 (color: yellow), where research is revolved around energy, efficiency, and environment. Similarly, cluster 4 (color: red) emphasizes energy intensity and greenhouse gas emissions. Moreover, in this cluster, methodological attention has a distinctive significance. Notably, many studies have employed decomposition analysis or index decomposition analysis, which in turn reveals the relatedness of emission and environmental aspects in EE-related studies since the decomposition model is a conventional method to analyze the dominating factors of carbon emissions (Zhang et al. 2018). Finally, cluster 5 (color: green) shows a decent amount of research; presumably, economics has concentrated on the nexus between energy consumption and economic growth.

Our preceding analyses provide the overall idea about the keywords used by the researcher. We further illustrate the year-to-year growth of author keywords in Fig. 9 to complement our previous findings by demonstrating the most used keywords in different periods.

Figure 9 shows that the keywords predominantly used by the researchers over the periods are ‘energy efficiency’: but in different frequencies at various points of time and in several ways. In the earlier years, we notice that the research is focusing on the energy efficiency indicators back in 1997 and domestic energy efficiency in 2003. The usage of these keywords became more prominent during 2006 as it appears in higher frequency and reaches the peak around 2013. Besides, we notice a significant rise in research focusing on efficiency in building retrofits during 2009 and 2013. However, in recent times, the topics that cut more attention to the research community are associated with climate and sustainability, which is noticeable through the surge of the usage of keywords like ‘Sustainability’ or ‘CO_2 Emissions,’ which started emerging during 2007 as we observe the high frequency use of keyword ‘global warming.’ Besides, we notice a significant increase in methodological concentrations in EE studies in recent times, which are depicted by the dominance of keywords like ‘Data Envelopment Analysis,’ ‘Stochastic Frontier Analysis,’ and ‘LMDI (Logarithmic Mean Divisia Index).’

Thematic mapping of EE research

Our thematic analysis identifies that the scientific outputs of EE in the fields of BFEM are concentrated around seven major areas which are presented in Fig. 10.

The upper right quadrant of Fig. 10, which represents the motor theme of a research area, does not show the dominance of any particular theme. However, we notice that the ‘energy efficiency’ and ‘climate change’ themes are apparently positioned in this quadrant. The ‘energy efficiency’ theme is also placed in the lower right quadrant of the graph, while the ‘climate change’ is in the upper left quadrant. The theme indicates that ‘energy efficiency’ itself represents a basic as well as the critical area of research having an association with other streams of research. Besides ‘energy efficiency,’ two different themes are located in the lower right quadrant, namely, ‘China’ and ‘energy.’ However, compared to ‘energy efficiency,’ these themes have a lower level of density and centrality, which indicates that even though these themes are important, but they are not as well-developed.

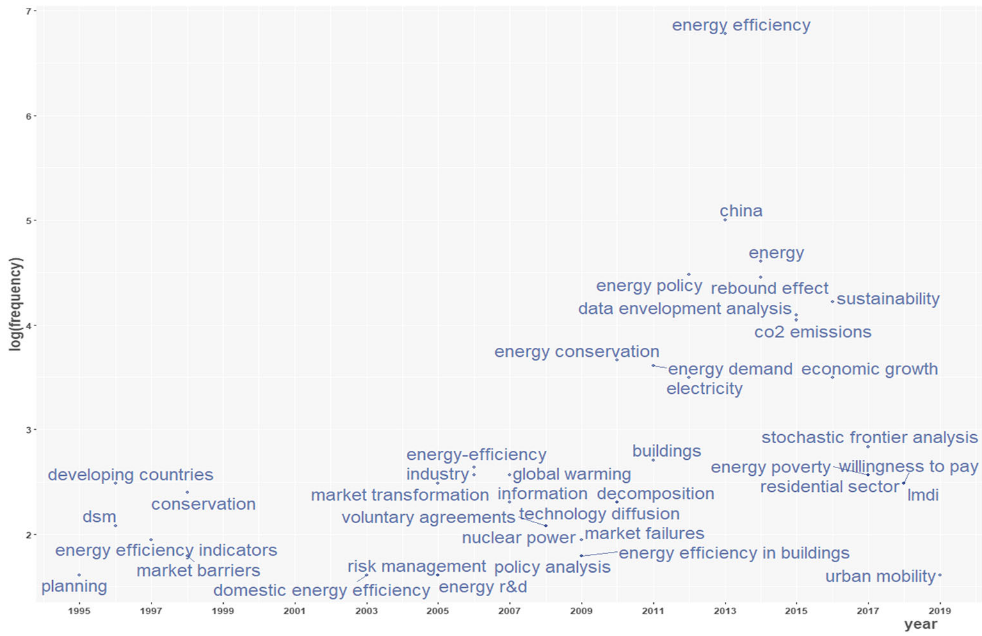
On the other hand, the simultaneous presence of ‘climate change’ in two quadrants indicates that this research stream is a crucial and specialized aspect in EE research. The other two specialized themes located in the upper left quadrant are ‘energy consumption’ and ‘sustainable development.’ This indicates that research related to energy consumption and sustainable aspects of development are very specialized aspects of EE research. Finally, the lower-left quadrant contains the ‘carbon dioxide emissions’ theme, representing an underdeveloped but emerging research theme in EE research. Such emerging research themes indicate the specific importance given by the research community to EE in dealing with CO_2 emissions.

Thematic evolution of EE research

While the thematic map in the previous section depicts the overall composition of research areas, we further analyze the changes of themes at different periods. This helps us identify what and how the research streams have evolved and merged over time. Also, the analysis allows us to distinguish the most recent issues related to EE. We have used the inclusion index weighted by word occurrences with each cluster containing 250 author keywords. Figure 11 illustrates the three-time slices; each slice encompasses the development of research in each decade.

In the first time slice (1990–1999), the focus of research evolved around energy in general with a higher concentration

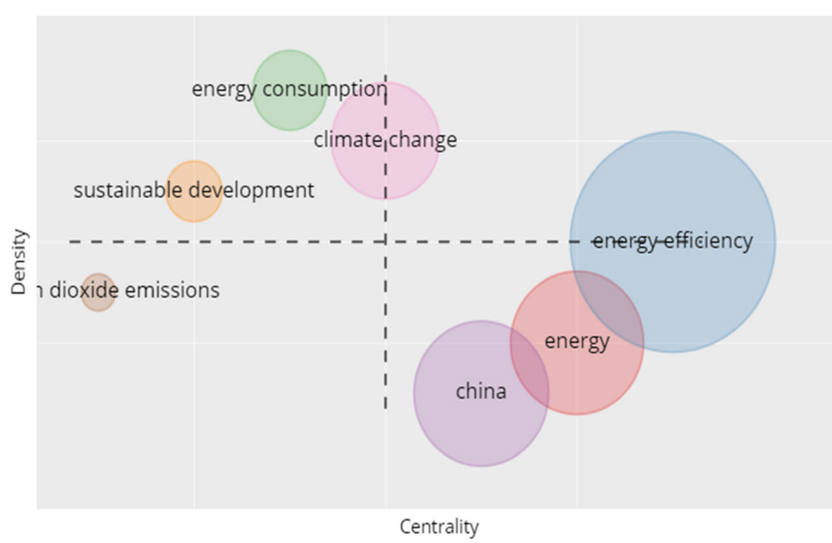
Fig. 9 Trends of author keywords from 1990 to 2019



on energy conservation, EE, and energy policy. The research on overall energy issues emphasizing energy conservation progressed in the latter decade (2000–2009) in China. The integration might pertain to the critical changes experienced by the Chinese energy sector in the late 1990s. Some of the significant changes include the establishment of State Power and Corporations together with the initiation of a four-step restructuring framework for the electric power industry in 1997 and the approval of independent operations of national oil corporations in 1998 (Lam 2005). These might have spurred the interest in the research community on Chinese energy-linked topics. Chinese energy research further diversifies into EE during 2010–2019. The trend indicates the importance of EE-related issues in recent years, considering China is the largest energy-consuming country and accounts for more than 20% of global energy demand (Jiang et al. 2020).

Likewise, we note significant importance on energy policy research along with EE during 1990–1999. These two research streams were conjoined with the EE research themes in the latter decade (2000–2009), which continued its dominance as a key research area in the recent decade (2010–2019). EE research in recent decades has gained a significant association with climate change research which started to get more importance during the first decade (2000–2009) of the twenty-first century. The more considerable emphasis on EE might have been prompted by the signing of the Kyoto Protocol in 1997, which underwent

Fig. 10 Thematic map of EE research



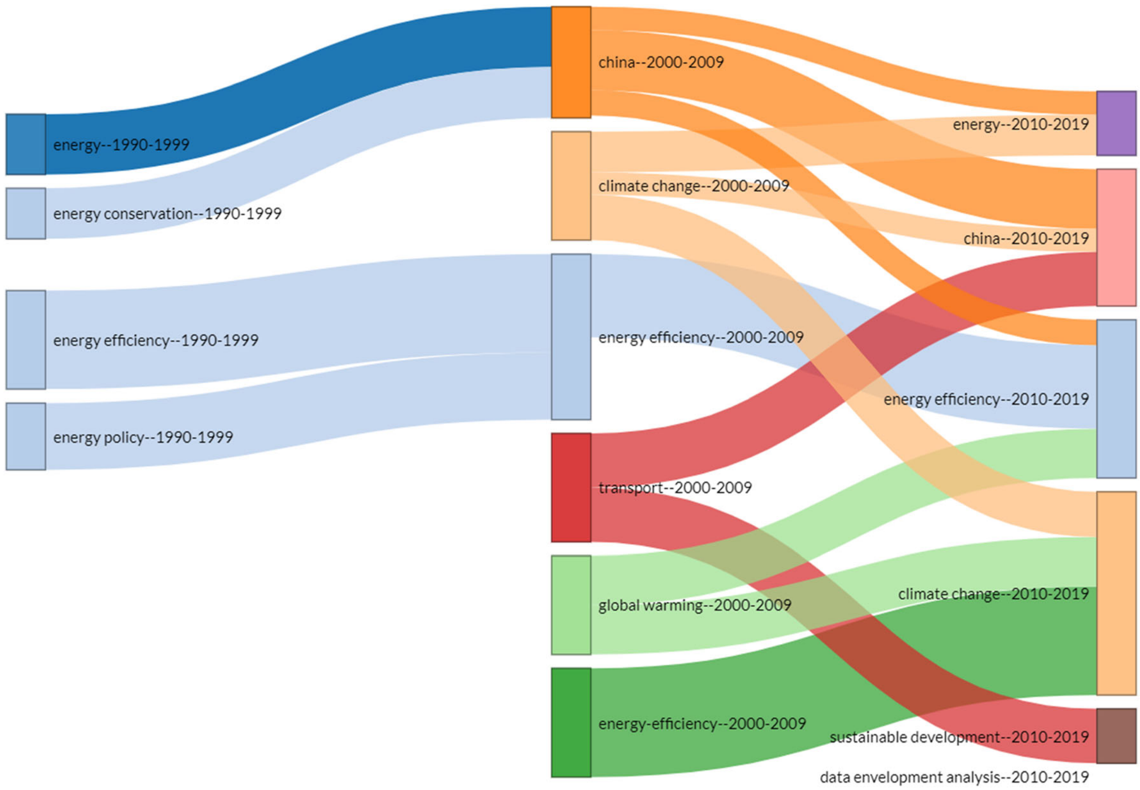


Fig. 11 Thematic evolution of EE in research in each decade between 1990 and 2019

the implementation by the signatory countries in 2005 onwards. To combat climate change and to keep the temperature increment within the 2°C scenario of global warming by 2050, the role of EE is emphasized by the research community along with different agencies, organizations, and governments (IEA, 2018; Shahbaz et al. 2018; Soytas and Sari 2009).

We observe some noticeable changes in research interest compared to the beginning period of our analysis. During the initial years, EE research was accompanied by energy conservation or energy policy. On the contrary, topics like global warming, climate change, and sustainable development gained more importance in recent years. Interestingly, we notice a distinct stream of transportation-related research having a strong tie with sustainable development issues and China. This brings forward a similar research interest regarding the energy consumption and EE aspect of transportation. Transport is one of the biggest consumers of global energy, which is responsible for 24% of direct CO_2 emissions (IEA 2020). Also, the attention can be understood from the emission statistics outlined by IEA in the same report, which emphasizes that global transport emissions increased by only 0.6% in 2018 compared to 1.6% annually in the preceding decade due to efficiency improvements. Therefore, future research in EE is expected to revolve around climate change and emission accompanied by environmental and sustainability aspects.

Conclusion, policy implications, and future research directions

In this study, we conducted a bibliometric analysis to understand better the intellectual base in EE's field with a specific focus in the areas of BFEM. We reviewed 2935 scientific publications over the last three decades spanning from 1990 to 2019 (Table 5), which are indexed in SSCI of the WoS database. Our analysis has reported major aspects of research in this field, including most influential publications, journals, authors, institutional affiliations, and publications' geographic diversity. We have further analyzed the most relevant keywords in this area of research and their conceptual construction, together with the research dynamics over the time to comprehend historical evolution to the most recent development.

Accordingly, we are able to answer the research questions posed at the beginning of the current study.

What is the global trend of scientific publications on EE?

Results from the descriptive analysis show a rapid increase in the number of publications leading to the overall growth of the intellectual base. Interestingly, we notice a rapid shift in publication trend from the year 2006 onwards. The increasing trend in scientific publications coincides with policy issues pertinent to the implementation of the Kyoto protocol in

2005. This evidently explains the importance given to energy efficiency by the scholarly community, which goes hand in hand with environmental and climate change-related policies.

What information is revealed from the existing stream of publications?

Further investigation of the publications indicates that the USA has been the most productive country and the most influential country based on the TC received. The USA has published the most collaborative research in terms of the total number of multi-country publications; however, considering the multi-country publication ratio (MCPR), Australia is the top country in collaborative publications. We have also visualized the collaboration network among different countries, which signifies the dominance of the USA, followed by China. Correspondingly, the University of California, Berkeley, produced the most scientific outputs, followed by the National University of Singapore and Xiamen University within this timeframe. Geographic and institutional dimensions imply the research interest from diverse parts of the world. In terms of publication sources, Energy Policy has been the most productive journal in publishing research from authors worldwide who have studied EE in the field of BFEM. Moreover, the journal has published seven of the twenty top-cited articles, including the most cited article authored by Greening et al. (2000). The top three influential authors based on the h-index are Lin BQ, Worrell E, and Zhou P, having an h-index score of 16, 15, and 14, respectively.

Based on an analysis of the association of keywords used in the research, five EE research clusters are documented. A major segment of the research during the analysis period focused on diverse energy issues. Some researchers focus on micro aspects, including energy-saving of housing, buildings, retrofit, appliances, and the related technology changes (i.e., conventional lighting vs. energy-saving lighting like light-emitting diode or LED). In contrast, some research looks into EE from macro perspectives like energy conservation, energy demand, and energy security, which are also related to studies on energy policy. Not only that but a significant number of studies also focused on the link between economic growth and development.

What other themes are linked to EE research?

The dominant research theme of energy efficiency has close associations with other themes of research. Notably, climate change has been positioned as a dominant theme related to energy efficiency research. Similarly, research that is focused on sustainable development represents a specialized research theme along with energy consumption. This thematic representation indicates the importance given to the efficient consumption of energy in attaining sustainable development. Besides, studies on CO_2 emissions formulate a separate and emerging theme in the existing research on EE. This finding remarkably signifies the critical role of EE recognized in the scholarly arena. Moreover, studies on EE linked with China dominate a significant proportion in the existing literature, as evidence by presenting a distinctive theme in the thematic map.

How have these themes evolved over time?

We find that the focus on EE research has evolved noticeably in the last three decades. The results of our thematic evolution analysis in each decade highlight that in the earlier period (1990–1999), studies concentrate more on energy conservation, energy policy, or energy in general. However, research in this area has generated more connection with environmental facets, considering the fundamental role of EE to tackle greenhouse gas emissions and related climate change in the recent decade (2010–2019). However, these issues started to develop in the earlier decade (2000–2009) and have established themselves as inseparable parts of research related to EE. Hence, research on EE has greater significance in dealing with environment- and climate-related aspects in the areas of BFEM, which is likely to accelerate more in the future.

The shift of research focus also brings forward the policy issues regarding EE. More funding from government and agencies could unearth new aspects of EE policy formulation, implementation, and performance evaluation at both macro- and micro-levels. Such an inclusive approach is essential to tackle energy-related challenges and environmental degradation. In doing so, stable regulatory frameworks are critical for developing, achieving, and maintaining the countries' energy efficiency goals. Besides, we notice that the research community has made a significant contribution from the developed countries that predominantly focus on issues related to those countries. However, it is also crucial to promote more research in achieving energy efficiency in developing countries. In particular, the countries' urban areas are likely to significantly increase the population in the coming decades. Furthermore, suitable policies should be devised to boost the research collaboration among countries, which would help to promote cross-directional research. Prudent policies can accelerate the necessary research to support developing low-carbon economies by exchanging information, expertise, and experiences among the research community.

Some knowledge gaps are uncovered from the overall analysis that enables us to sketch future research developments. One of the crucial areas that future research can focus on is the performance appraisal of EE attainments at both micro- and macro-levels. EE implementations have been taking place for quite a while by governments, agencies, and the business sectors. Evaluation of the EE performance at the macro-level could offer better understanding of the strengths and weaknesses and possibilities of energy-related policies. Firm-level EE assessment could benefit businesses to appreciate the significance of the implementation of EE measures in operations and related environmental and financial performances. In turn, performance evaluations may help mitigate the EE gap by indicating the critical performance aspects. In doing so, one area that future research should put more emphasis on is in developing the appropriate measurement of energy efficiency, especially in the fields of BFEM. The most widely used indication, energy intensity, as a proxy measure of energy efficiency in the literature remains questionable (see, e.g., Proskuryakova and Kovalev (2015)). Hence, to measure energy efficiency performance at both macro and micro and provide appropriate policy direction, researchers need to come out with more comprehensive measurement(s) of energy efficiency. Furthermore, the investigation into energy audit and energy financing issues could help to keep pace with emission reduction goals worldwide to tackle the adverse climate change. From our analysis, there is no evidence of considerable research in these areas. The conclusions should be substantiated with further investigations; therefore, we suggest that future research focus on filling these pinpointed gaps.

Overall, the findings of the current study may help researchers understand the trend, structure, and latest development in EE-related research in the field of BFEM from across the world and suggest directions for further research. However, this study is limited to only the SSCI indexed publications under the WoS database. While the research methodology aimed to be as inclusive as possible, it is acknowledged that it may not have captured all scientific publications on the EE in this process. Future research may endeavor to examine scientific output appearing in other databases, such as Scopus. Despite its limitations, the study certainly helps to understand crucial aspects related to EE research and publications. Further analysis would substantiate the finding of the study and provide a broader picture for the researchers in this area.

Appendix

Table 5 Most productive institutions, country affiliations, and citations (top twenty)

Institutional affiliations			Country affiliations				Most cited countries	
Rank	Affiliated institutions	NP	Country	NP	MCP	MCPR	Country	TC
1	Univ Calif Berkeley	112	USA	680	185	0.2721	USA	20,708
2	Natl Univ Singapore	52	China	329	91	0.2766	China	10,611
3	Xiamen Univ	49	UK	275	77	0.28	UK	8820
4	Tsinghua Univ	48	Germany	150	42	0.28	Germany	3694
5	Univ Utrecht	37	Netherlands	110	32	0.2909	Netherlands	3677
6	Stanford Univ	34	Sweden	107	22	0.2056	Sweden	3622
7	Univ Sussex	33	France	99	37	0.3737	Switzerland	2219
8	Univ Maryland	30	Spain	79	23	0.2911	Taiwan	1919
9	Harvard Univ	29	Australia	76	34	0.4474	France	1903
10	Lawrence Berkeley Natl Lab	29	Italy	73	20	0.274	Singapore	1707
11	Tianjin Univ	29	Japan	61	19	0.3115	Japan	1668
12	Univ Oxford	29	Canada	57	25	0.4386	Spain	1659
13	Duke Univ	27	Switzerland	55	18	0.3273	Italy	1453
14	Swiss Fed Inst Technol	26	Taiwan	45	13	0.2889	Australia	1439
15	Nanjing Univ Aeronaut and Astronaut	24	Norway	42	11	0.2619	Korea	1254
16	Univ Surrey	24	India	40	3	0.075	Mexico	1121
17	Lund Univ	23	Ireland	39	11	0.2821	Ireland	1080
18	Resources Future Inc	22	Greece	36	11	0.3056	New Zealand	1044
19	Univ Cambridge	22	Singapore	36	13	0.3611	India	1039
20	Univ Leeds	22	Denmark	33	11	0.3333	Canada	992

[1] NP: number of publications. [2] TC: total citations. [3] TC: total citations. [4] MCP: multiple country publications; [5] MCPR: multi-country publication ratio

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Authors' contribution Conceptualization, M.M., S.W.P. and I.I.; methodology, M.M. and S.W.P; software, M.M. and S.W.P.; validation, S.W.P. and I.I.; formal analysis, M.M.; data curation, M.M.; writing - original draft preparation, M.M.; writing—review and editing, I.I. and S.W.P.; visualization, M.M..; supervision, I.I. and S.W.P.; project administration, C.R.I. and I.I; funding acquisition, C.R.I., I.I. and S.W.P.

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Declarations

Conflict of interest The authors declare no competing interests.

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