

“Research trends on development of energy efficiency and renewable energy in households: A bibliometric analysis”

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RESEARCH TRENDS ON DEVELOPMENT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY IN HOUSEHOLDS: A BIBLIOMETRIC ANALYSIS

Abstract

Households are responsible for more than one-third of global energy consumption and exert a significant environmental impact. Therefore, energy efficiency and renewable energy issues have been a top theme in the literature, with numerous studies examining different facets of residential power consumption, green energy transition, decarbonization, and energy conservation. Despite extensive attention, these research trends and frontiers remain largely uncharacterized and poorly understood. This study aims to provide clear insights into the evolution and latest trends of household energy efficiency and renewable energy studies, reveal significant contributing countries, institutions, and authors of published papers, as well as directions of international collaboration. The method of bibliometric analysis with two supporting instruments (the SciVal platform and Scopus "Analyze search results" tool) was used to investigate an array of 3,761 research items on renewable energy and 4,474 items on energy efficiency in homes formed from the Scopus database. The studied period includes papers published during 1978–2023. The systematic review indicated that the United States, the United Kingdom, and China are primarily contributing countries with strong international collaboration in this field. The top journals include Energy Policy, Energy Efficiency, Energies, and Sustainability, while highly cited researchers investigate environmental, economic, and social effects and management mechanisms for introducing innovative energy-efficient and renewable energy technologies in households like smart meters and grids or the Internet of Things. The research frontier might encompass emerging and pioneering studies on home decarbonization strategies, behavioral interventions, energy saving, prosumerism, and optimization of energy consumption.

Keywords

energy efficiency, green energy, household, bibliometric analysis, decarbonization, trend, Scopus database, sustainable development

JEL Classification

D12, D14, Q40, Q56

INTRODUCTION

The energy efficiency and renewable energy issues have become widely relevant among scientists and practitioners in the last two decades due to fossil fuel depletion and climate change, which can be mitigated by green power and rational energy use (Trypolska, 2020; Samusevych et al., 2021). Moreover, the world economy is still based primarily on fossil fuels, unevenly distributed across countries and continents. Therefore, many states need more and more energy resources. It makes the transition to energy-efficient and green power technologies especially relevant for them, thereby eliminating dependence on imported fossil fuels.

Initially, energy-efficient and renewable energy technologies were primarily applied in the business sector since they required essential capital investments that might be problematic for households. Moreover,

enterprises involve large power volumes, and even a tiny percentage of energy savings or its replacement with green power affect significantly due to the scale effect. Later, as technologies developed and became cheaper, their use spread to households.

Today, the world's residential sector consumes about 40% of energy and remains among the leaders in CO₂ emissions. Therefore, its role in decarbonization and mitigating climate change is critical (Wang et al., 2023; Tu et al., 2022a). The developed countries have accumulated considerable experience in energy efficiency and renewable energy deployment in the residential sector. They created the mechanisms allowing the formation of the ecological and social responsibility of the population for rational energy consumption and environmentally friendly life patterns (Tu et al., 2022b). These results are valuable for studying and applying in developing and emerging economies, where increasing energy efficiency and switching to green power sources for homes are crucial and sometimes become matters of survival (Trypolska & Rosner, 2022).

Therefore, it is essential to investigate the world trends in energy efficiency and renewable energy development and analyze, select, and implement the best practices. New approaches considering the revealed trends will enable complex strategy development to update and extend the countries' energy infrastructure for the household sector on an innovative and sustainable basis, reaching decarbonization targets, strengthening national energy independence, and saving money on utilities for homes while increasing life quality.

1. LITERATURE REVIEW

The growing annual number of publications on energy efficiency and renewable energy in households has recently demonstrated an increasing interest of scholars and practitioners in this topic. The existing literature provides insights into energy efficiency and green power dimensions, including technological advancements, social, economic, and environmental issues.

Many research papers consider the technical aspects of energy efficiency and renewable energy in the residential sector. They study mainly heating (Hong et al., 2006, 2009), cooling (Novak et al., 2023; Kumari et al., 2022), and lighting topics (Azevedo et al., 2009; Byun et al., 2013). As for renewable energy specifically, there are papers devoted primarily to wind (Jahangir et al., 2020; Wang & Teah, 2017), solar (Hassan, 2021; Kumari et al., 2022), and bioenergy (Hensgen et al., 2011; Tonini et al., 2014) technologies used in homes.

Another research layer considers social issues of energy efficiency and green power in households. The key directions here are social acceptance of energy-efficient and renewable energy technologies (Eon et al., 2018; Chen et al., 2017; Jensen et al., 2018), home energy consumer behavior

(Trotta, 2018; Andor & Fels, 2018; Paone & Bacher, 2018), and energy justice (Milchram et al., 2018; Sovacool, 2015).

Economic issues present the following research direction in the field. They cover publications on energy efficiency and green energy policy and its efficiency in the residential sector (Strielkowski et al., 2019; Kurbatova et al., 2020; Koilo et al., 2022), power markets transformations (Kostyrko et al., 2021; Mengelkamp et al., 2018), household energy consumption patterns and their changes under economic incentives (Brounen et al., 2012; Makarenko et al., 2023), energy prices (da Silva & Cerqueira, 2017; Schreiber et al., 2015; Mukarati et al., 2023), investment support (Trotta, 2018; Versal & Sholoiko, 2022; Sala et al., 2023), and energy poverty (Streimikiene et al., 2021; Li et al., 2022). Closely connected to economic issues, organizational and management studies investigate energy security (Melnyk et al., 2022; Sovacool, 2015), energy labeling, audit and standards (Mahlia et al., 2002; Mills & Schleich, 2012), smart metering for homes (Carroll et al., 2014; Kumar et al., 2023), energy monitoring and forecasting (Daniel et al., 2019; Foulds et al., 2017).

Environmental research on energy efficiency and renewable energy in homes considers sustainable development goals and ways of their achievement.

It covers the ecological effects of implementing energy-efficient and green power technologies (Bastida et al., 2019; Liu et al., 2017) and decarbonization issues (Vélez-Henao & García-Mazo, 2022; Goldstein et al., 2020).

Another group of studies examines new trends in household energy efficiency and renewable energy. They include publications on smart grids (Milchram et al., 2018; Mengelkamp et al., 2018) and smart homes (Sovacool et al., 2020; Wilson et al., 2017), the Internet of Things (Sardianos et al., 2021; Casado-Mansilla et al., 2018), hybrid renewable energy systems (Babatunde et al., 2019; Pop et al., 2023), prosumers (Park et al., 2018; Kulapin et al., 2022), electric vehicles (Nishanthi et al., 2023; Chen et al., 2016), and home energy storage systems (Ahmad et al., 2017; Vieira et al., 2017).

The distinctive feature of research papers is their interdisciplinary character, which allows for combining social, technical, economic, and other aspects of energy efficiency and green power and filling the knowledge gaps while complicating the systematization of research results. Publications on bibliometric analysis could help, but there are a few of them considering energy efficiency and renewable energy aspects in the residential sector. For example, Dolšák (2023) provided the historical evolution of key energy-efficient retrofit determinants for homes over the past three decades. The study divided the determinants into information and policy measures, economic factors, socioeconomic characteristics of households, technical and building characteristics, and behavioral factors. It was suggested to apply a mix of approaches to promote energy-efficient retrofits in households. Zhang et al. (2021) identified five research streams in the green power field: energy transition, clean energy, and carbon emission policy, the impact of oil price on alternative energy stocks, clean energy and economics, and venture capital investments in clean energy. They indicated the growing research attention to energy-efficient improvements by applying clean energy technologies and forming policies for green power transition.

Han and Wei (2021), Ramnath and Harikrishnan (2021), and Ma et al. (2020) provided bibliometric analysis of household energy consumption. Han and Wei (2021) reviewed the literature on

energy conservation, energy poverty, and energy efficiency in homes. Using a bibliometric and network analysis, they noted behavioral interventions, energy conservation, and energy poverty connected to climate and electricity consumption as pioneering research directions. Ramnath and Harikrishnan (2021) analyzed household electricity consumption patterns, factors affecting energy consumption, and occupants' behavioral aspects of purchasing appliances and their use. Ma et al. (2020) investigated the evolution of residential energy consumption research during 1970–2018. They concluded that micro-factors, regional energy consumption issues, and energy consumption of rural households should be the directions for future works.

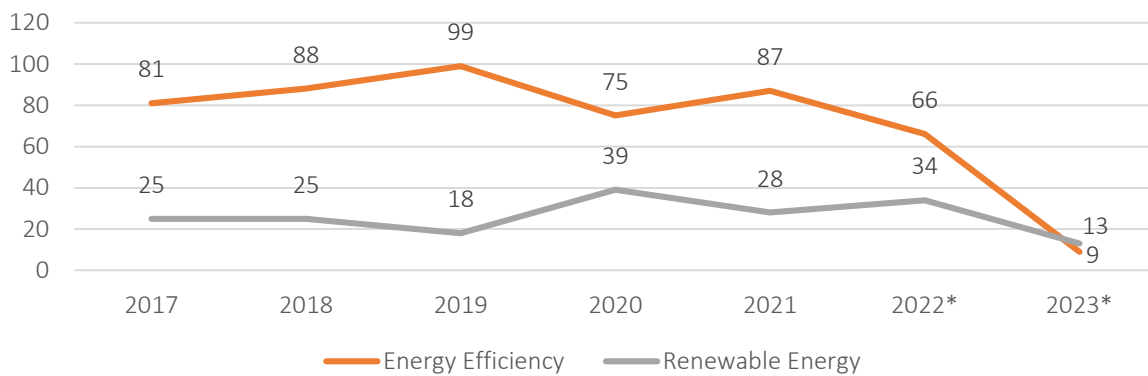
A significant limitation of these studies is their specific focus and absence of bibliometric analysis regarding the diversified role of energy efficiency and green power in households. The latter necessitates further consideration of current scientific results, popular topics, gaps, and future research opportunities. Applying bibliometric analysis tools will enable identifying trends and reliable sources, as well as prominent authors and research groups actively engaged in the field. Investigating the international scholarly groundwork of energy efficiency and green power will enhance further development and policy implications for countries and regions.

Given the above, the study aims to analyze world research trends in energy efficiency and renewable energy deployment in households and identify the perspectives for further consideration to improve national energy policies in the residential sector. The primary research method is bibliometric analysis, based on publications from the Scopus database and performed using the SciVal platform and Scopus "Analyze search results" tool (Matvieieva et al., 2023; Vakulenko & Lieonov, 2022; Saher et al., 2022).

2. METHODS

Publications on energy efficiency and renewable energy in households from the Scopus database as of June 12, 2023, formed the initial information for the study. The array of papers to analyze was

Source: The SciVal (www.scival.com); and Scopus databases (as of June 12, 2023).



Note: * – Incomplete year.

Figure 3. The scholarly output for research key phrases, T.5214 Household Energy; Energy; Smart Meters in SciVal, by year

99th percentile by worldwide Topic Prominence in 2017–2022. The topic array includes 2,793 papers with a field-weighted citation impact of 1.12 and contains both “energy efficiency” and “renewable energy” keyphrases (Figure 2). They are present in 639 papers (2.29% of the total) for the period 2017–2023, including 505 (1.8%) publications on energy efficiency issues and 182 articles (0.65%) on renewable energy in the residential sector. As SciVal considers 2022 and 2023 incomplete years, the number of publications on both topics in 2017–2021 demonstrates an overall growing tendency (Figure 3).

It should be noted that for 2012–2022, topic T.5214 did not include the key phrase “renewable energy,” while the latter is present for the analyzed period of 2017–2022. It indicates that research on renewable energy in homes started to develop actively only in recent years. On the contrary, the energy efficiency topic for the residential sector was investigated for a longer time than renewable energy. It is confirmed by the relevance size of the key

phrases in Figure 2. Table 1 shows the percentage of publications in the top 10% journal percentiles by SiteScore Percentile and the number of citations per publication for energy efficiency and renewable energy key phrases. Tables 2 and 3 present the most active contributors to topic T.5214 for the selected key phrases.

On average, 47.5% of publications on energy efficiency belonged to the top 10% of journals, while 42% of papers on green power were published in such journals. It again confirms that renewable energy for homes is a relatively new theme gaining popularity among scholars and practitioners, with 10.4 citations per publication compared to 11 citations for energy efficiency. Most researchers published their results on energy efficiency and green power in households in *Energies* (18 and 9 articles correspondingly), *Energy Policy* (34 and 8), and *Energy Research and Social Science* (22 and 18) journals. However, the most cited paper on renewable energy (148 citations) was published in *Renewable and Sustainable Energy Reviews*

Table 1. Citations and publications in top journal percentiles for the topic T.5214 Household Energy; Energy; Smart Meters, keyphrases “energy efficiency” and “renewable energy” in SciVal, 2017–2023

Source: The SciVal and Scopus databases (as of June 12, 2023).

Key phrase	2017	2018	2019	2020	2021	2022	2023
Citation for publication							
Energy efficiency	21.5	21.1	10.2	14.3	7.6	2.1	0.2
Renewable energy	19.4	20.9	11.6	12.1	6.9	1.6	0.4
Publications in the top 10% journal percentiles by SiteScore Percentile (%)							
Energy efficiency	48.2	54	47.1	50.8	42.3	46	44.4
Renewable energy	44.4	42.1	33.3	40	45.5	42.3	46.2

Table 2. The most active contributors to the topic T.5214 Household Energy; Energy; Smart Meters for the key phrase “energy efficiency” in SciVal, 2017–2023

Source: The SciVal and Scopus databases (as of June 12, 2023).

Institutions	Scholarly output/ Citations	Countries/ Regions	Scholarly output	Scopus sources	Scholarly output
De Montfort University (UK)	17/220	United Kingdom	104	Energy Policy	34
Qatar University (Qatar)	15/283	United States	79	Energy Efficiency	25
University of Deusto (Spain)	13/81	Spain	35	Energy Research and Social Science	22
Harokopio University (Greece)	11/166	Germany	31	Energies	18
Aalborg University (Denmark)	10/105	Greece	31	Energy and Buildings	17

Table 3. The most active contributors to the topic T.5214 Household Energy; Energy; Smart Meters for the keyphrase “renewable energy” in SciVal, 2017–2023

Source: The SciVal and Scopus databases (as of June 12, 2023).

Institutions	Scholarly output/ Citations	Countries/ Regions	Scholarly output	Scopus sources	Scholarly output
Aalborg University (Denmark)	8/70	United Kingdom	27	Energy Research and Social Science	18
CNRS (France)	6/45	Germany	25	Energies	9
Delft University of Technology (Netherlands)	6/147	United States	19	Sustainability	9
Karlsruhe Institute of Technology (Germany)	6/98	Netherlands	16	Energy Policy	8
University of Helsinki (Finland)	5/53	Denmark	15	Renewable and Sustainable Energy Reviews	7

and studied smart home technologies in Europe (Sovacool & Del Rio, 2020). As for the energy efficiency topic, the article with the highest citation level (282 citations) was published in Energy Policy and considered the benefits and risks of smart home technologies (Wilson et al., 2017). In general, the latter is a quite popular theme for recent articles with high citation levels, along with investigating the acceptance of these technologies, the effects of their use in homes for energy efficiency and sustainable power provision (Trotta, 2018; Chen et al., 2017; Paone & Bacher, 2018; Bastida et al., 2019).

According to the data in Table 2, De Montfort University (United Kingdom) is the research leader in the number of papers (17 items) on the energy efficiency topic in households, closely followed by Qatar University (Qatar) and the University of Deusto (Spain). However, the scientists from Qatar University are the most cited, with 18.87 citations per publication and 283 citations for 15 articles. De Montfort University is in second place, with 12.94 citations per publication; the third one is Harokopio University (Greece), having 15.09 citations per publication. The United Kingdom (104 articles) and the United States (79) are the most

significant contributors to the number of published papers, followed by Spain, Germany, and Greece.

Considering renewable energy in homes (Table 3), Aalborg University is the leader with eight publications. It is followed by CNRS, Delft University of Technology, and Karlsruhe Institute of Technology, which have six publications each. However, the papers published by the Delft University of Technology are the most cited, with 147 citations and 24.5 citations per article. Karlsruhe Institute of Technology has 98 citations and 16.3 citations per article, while the University of Helsinki has 53 citations (4th place) and the second-highest score of 17.7 citations per paper. As for countries' distribution, the leaders in the green power research in households are the United Kingdom (27 articles), Germany (25), and the United States (19).

Both renewable energy and energy efficiency topics show an increasing trend in strengthening international collaboration. On average, almost one-third of the papers on energy efficiency was published by international teams, while this figure for articles on renewable energy was 26.9%. Overall, the share of international collaboration increased

Table 4. Top-5 authors by scholarly output within the topic T.5214 Household Energy; Energy; Smart Meters for the keyphrases “energy efficiency” and “renewable energy” in SciVal, 2017–2023

Source: The SciVal and Scopus databases (as of June 12, 2023).

Author	University, country	Scholarly output	Citations	Most cited paper on the topic
Energy Efficiency key phrase				
Amira, Abbas	University of Sharjah (United Arab Emirates)	16	256	The emergence of explainability of intelligent systems: Delivering explainable and personalized recommendations for energy efficiency (Sardianos et al., 2021) (40 citations)
Alsalemi, Abdullah	De Montfort University (the United Kingdom)	15	255	
Bensaali, Faycal	Qatar University (Qatar)	13	255	
Casado-Mansilla, Diego	the University of Deusto (Spain)	13	117	
Varlamis, Iraklis	Harokopio University (Greece)	11	202	
Renewable Energy key phrase				
Byrne, Joshua J.	Curtin University (Australia)	4	35	The influence of design and everyday practices on individual heating and cooling behavior in residential homes (Eon et al., 2018) (20 citations)
Daniel, Maxime	University of Bordeaux (France)	4	24	Cairnform: A shape-changing ring chart notifying renewable energy availability in peripheral locations (Daniel et al., 2019) (15 citations)
Jensen, Charlotte Louise	Aalborg University (Denmark)	4	55	Towards a practice-theoretical classification of sustainable energy consumption initiatives: Insights from social scientific energy research in 30 European countries (Jensen et al., 2018) (32 citations)
Milchram, Christine	Karlsruhe Institute of Technology (Germany)	4	108	Energy Justice and Smart Grid Systems: Evidence from the Netherlands and the United Kingdom (Milchram et al., 2018) (49 citations)
van de Kaa, Geerten	Delft University of Technology (Netherlands)	4	108	

from 18.5 in 2017 to 41.4% in 2021 in the energy efficiency field and from 20.0 in 2017 to 42.9% in 2021 in the green power research sphere.

The top-5 authors (by scholarly output) on the energy efficiency topic include scientists from the University of Sharjah (the United Arab Emirates), De Montfort University (the United Kingdom), Qatar University (Qatar), the University of Deusto (Spain), and Harokopio University (Greece) (Table 4). Most of their studies were performed in close international collaboration. They considered behavioral patterns and strategies for energy efficiency at homes, smart metering, other intelligent system issues, household energy data management, etc. Due to the international collaboration factor, these articles have higher citation scores.

The top-5 authors (by scholarly output) on the renewable energy topic include researchers from Curtin University (Australia), University

of Bordeaux (France), Aalborg University (Denmark), Karlsruhe Institute of Technology (Germany), and Delft University of Technology (Netherlands). Despite having the same number of published papers, the authors demonstrate different citation scores for their articles due to the more diversified topics of the publications. Many studies were performed in close international collaboration. They considered energy justice and smart grids, sustainable energy consumption initiatives, household practices, and green power availability as the most popular research issues.

It should be noted that papers of the considered authors on the energy efficiency topic have more than twice higher number of citations compared to the articles on the renewable energy topic. It can be explained by the extended period of energy efficiency research and the diversity of themes for green power in households.

3.2. Bibliometric analysis with the Scopus “Analyze search results” tool

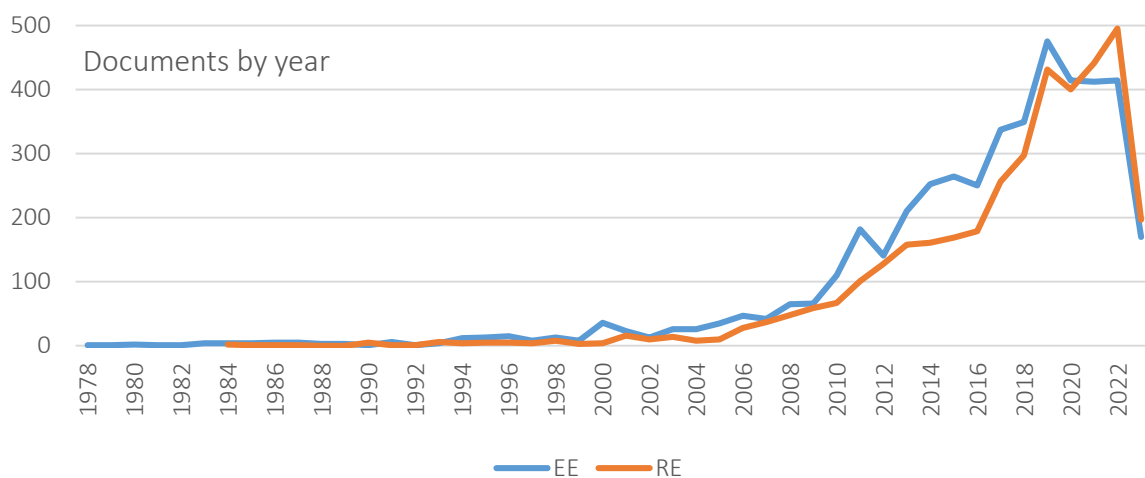
As it was mentioned in the Methods section, the combinations of keywords “energy efficiency” and “household” and “renewable energy” and “household” were used to form the arrays of publications on energy efficiency and renewable energy topics. Unlike the research area analysis in SciVal, all relevant publications in the Scopus database were considered without time limitations. Thus, as of June 12, 2023, the array of energy efficiency publications included 4,474 papers from 1978 to 2023, while the publication set on the renewable energy topic consisted of 3,761 documents in 1984–2023. It is worth noting that for 1978–1983, the articles on the renewable energy topic in households were not classified separately due to their insignificant number and small interest of researchers in this field.

Little attention to investigating energy efficiency issues in the residential sector was observed during 1978–2000, confirmed by less than ten annual publications in the Scopus database. From 2000 to 2002, the number of studies considering energy efficiency in households steadily increased yearly (from 36 in 2000 and 13 in 2002) up to 475 papers in 2019, with a little decline (down to 412–414 papers) in 2020–2022 due to the COVID-19 pandemic (Figure 4). The array of selected energy efficiency publications is presented by 74.7% of articles

and 25.3% of conference papers. Most studies belong to energy (26.1% with 2365 items), engineering (20.6% with 1863 items), and environmental sciences (18.4% with 1668 items), while social and economic sciences shares do not exceed 7% each. This distribution indicates the active research of energy efficiency technical aspects, whereas studies on economic and social mechanisms to motivate energy-efficient measures in the residential sector have far less attention. The leading journals in this field are Energy Policy (433), Energy and Buildings (175), Energy (159), Applied Energy (158), Energy Efficiency (147), and Energies (115 items), which is in line with the results of the research area analysis in SciVal.

The United States (670 items), the United Kingdom (552 items), and China (494 items) are the most significant contributors to the number of published papers on energy efficiency in the residential sector, followed by Germany (304 items), Australia (239 items), and India (207 items). The leading institutions on this topic are University College London (the United Kingdom) with 101 papers, Lawrence Berkeley National Laboratory (the United States) and ETH Zurich (Switzerland) with 56 documents each, Delft University of Technology (the Netherlands) with 48 items and Chinese Academy of Sciences (China) with 43 papers. These results somehow differ from results in SciVal, while the leading players – universities from the United Kingdom and the United States – remain the same.

Source: The Scopus database (as of June 12, 2023).



Note: 2022 and 2023 are incomplete years.

Figure 4. Documents on energy efficiency and renewable energy issues in households in Scopus, by year

The top-5 authors are J. Schleich from Fraunhofer Institute for Systems and Innovation Research ISI (Germany) with 23 papers; T. Oreszczyn from University College London (the United Kingdom) with 21 items; D. Blumberga from Riga Technical University (Latvia) with 19 documents; T. M. I. Mahlia from Sydney University of Technology (Australia) with 15 papers, and H. H. Masjuki from International Islamic University (Malaysia) with 14 documents. Most cited publications of these authors, who often engage in international collaboration, include studies on energy-efficient technology adoption in households, impacts of discount rates, energy demand, implicit costs, risks on implementing energy-efficient measures, mechanisms of energy audit, energy labeling, energy standards, and smart meters for homes (Mills & Schleich, 2010, 2012; Hong et al., 2006, 2009; Mahlia et al., 2002). It should be noted that papers researching economic mechanisms and social perception of energy-efficient technologies have the highest citing. It confirms the existence of public demand for such studies and their urgency.

Like the energy efficiency topic, green power issues in households have remained undeveloped for a long time. During 1984–2005 the annual number of papers on renewable energy in the residential sector did not exceed 10 (except for 16 in 2001 and 14 documents in 2003) in the Scopus database. The constant increase in studies began in 2006 when they grew to 28 and rocketed to 496 in 2022, with a small decline to 400 documents in 2020 compared to the previous year, due to the COVID-19 pandemic influence (Figure 4). The array of selected renewable energy publications is presented by 66.1% of articles and 33.9% of conference papers. Thus, the share of the conference papers is higher than for the energy efficiency topic and indicates new research directions are developing in this field.

Similar to the energy efficiency topic, large shares of studies on green power belong to energy (27.4% with 2154 items), engineering (19.9% with 1465 items), and environmental sciences (14.0% with 1100 items), while social and economic sciences shares do not exceed 6 and 5% respectively. Again, this distribution indicates the active research of renewable energy technical aspects along with far less attention of scientists to economic and social issues. Overall, the number of publications is sig-

nificantly lower than on the energy efficiency topic, which the relative novelty of the renewable energy theme for research can explain. The leading journals in the field are *Energies* (198), *Energy Policy* (165), *Renewable Energy* (112), *Applied Energy* (158), *Sustainability* (72), and *Energy* (69 items). Their range is almost in line with the results of the research area analysis in SciVal.

The United States (380), China (350), Germany (349), India (286), and the United Kingdom (282 articles) are the most significant contributors to the number of published papers on green power in the residential sector, followed by Australia (175), Poland (162 items) and other countries. The leading institutions on this topic are Aalborg University and Technical University of Denmark (Denmark), with 38 and 26 documents, respectively, Delft University of Technology (the Netherlands) with 33 items, AGH University of Krakow (Poland) with 32 papers, and Chinese Academy of Sciences (China) with 26 documents. These results mostly coincide with the results of the analysis in SciVal, although they have differences regarding some contributors like Poland, China, and their institutions, etc.

The top-5 authors are Q. Hassan from the University of Diyala (Iraq) with 12 papers; D. Streimikiene from Lithuanian Energy Institute (Lithuania) with ten items; V. Koivunen, from Aalto University (Finland) and S.-H. Yoo from Seoul National University of Science and Technology (South Korea) with nine papers each, and O.M. Babatunde from Tshwane University of Technology (South Africa) with eight documents. Most cited publications of these authors include studies on smart grids optimization, hybrid renewable energy systems, innovative policies for households, public acceptance of green power, energy poverty issues, and green energy transition mechanisms in the residential sector (Hassan, 2021; Strielkowski et al., 2019; Kim et al., 2020; Streimikiene et al., 2021; Babatunde et al., 2019). Comparing these results with analysis in SciVal, it is worth noting the similar urgent topics discussed in the research papers. At the same time, the list of authors with the highest number of publications is different. Overall, the conducted analysis confirms that the renewable energy topic is actively developing by opening new directions for research.

The most prominent sponsors funding studies on energy efficiency and renewable energy in the residential sector include the National Natural Science Foundation of China, the Horizon 2020 Framework Program, the European Commission European Regional Development Fund, and the Engineering and Physical Sciences Research Council.

To sum up, the results show the growing numbers of countries involved in household energy efficiency and renewable energy research and publications on the topic with highly diversified issues. Another strong trend is increasing international collaboration allowing significant progress in the field.

4. DISCUSSION

The results of the conducted analysis of research trends, contributing authors, institutions and countries, and highly cited papers show that while technical aspects of energy efficiency and green power in households are actively investigated, the scientific community is primarily interested in developing social, economic and environmental policies integrating energy-efficient and renewable energy technologies in the residential sector. Maximization of ecological and economic efficiency, as well as favorable social perception, are the critical criteria for such integration. These findings align with the conclusions of Dolšák (2023), Han and Wei (2021), and Zhang et al. (2021).

Since higher energy-efficient and renewable energy changes can be achieved using innovative technologies, scholars pay more attention to considering opportunities to apply smart devices for homes, electric vehicles, smart grids, the Internet of Things, etc. It contributes significantly to the environmental performance of energy-efficient and green power technologies, sustainable development of homes, and clean energy transition. This result is consistent with Zhang et al. (2021).

International cooperation led by the United States, the United Kingdom, and China is essential to researching household energy efficiency and renewable energy. This result confirms and develops the findings of Han and Wei (2021) and Ma et al. (2020), who emphasized the same leading coun-

tries and their international research collaboration on home energy consumption. Moreover, the top journals to publish papers on energy efficiency and green power issues in the residential sector almost coincide with those identified by Han and Wei (2021). They are Energy Policy, Energy Efficiency, Energy Economics, Energy Research and Social Science, and others. While Han and Wei (2021) indicated this list for 1983–2018, journals' leading role was preserved to disseminate research results until 2023, according to the conducted analysis. Ramnath and Harikrishnan (2021) mentioned Sustainability, Renewable and Sustainable Energy Reviews, and Energies among the top-10 journals, which is confirmed by the study outcomes.

On the contrary, the leading organizations revealed in the research do not align with Han and Wei (2021), Ramnath and Harikrishnan (2021), and Ma et al. (2020) except for the Chinese Academy of Sciences, Delft University of Technology and Aalborg University. In addition, only two influential authors (T. M. I. Mahlia and H. H. Masjuki) identified in the study are mentioned by Han and Wei (2021), one author (D. Blumberga) by Ramnath and Harikrishnan (2021), and one author (H. H. Masjuki) by Ma et al. (2020). This discrepancy is explained by the diversity of issues on home energy consumption and energy efficiency and renewable energy, differences in the considered periods, and ongoing progress in the field.

According to Han and Wei (2021) and Ma et al. (2020), the most cited papers cover residential energy use behavior, energy saving and its environmental impact, energy poverty, green energy transition, and energy policy. The study findings are in line with these results.

Overall, the conducted analysis revealed both similarities and differences in the research landscape compared to other scientific publications. While the importance of investigating home energy-efficient and green power changes is widely agreed upon, individual studies vary in focus and methodologies. This analysis contributes by offering a thorough and systematic review that illuminates the evolving trends and topics within the field. However, there are some limitations of the research that should be considered for future studies. Firstly, this paper analyzed the publications

from the Scopus database using a set of bibliometric methods, including SciVal (topic T.5214) and Scopus “Analyze search results” (keywords: “energy efficiency”, “renewable energy” and “household”) tools. Therefore, future studies should involve other review technics and software to visualize big data analysis results. Secondly, the analysis focused on articles and conference papers from the Scopus database. Thus, it is recommended to extend the range of publications by including other publication types (book chapter, review, etc.), and databases, for example, Web of Science.

CONCLUSION

The study presents the results of the bibliometric analysis on household energy efficiency and renewable energy research to identify the latest trends in this field. An array of 3,761 publications on renewable energy in households and 4,474 papers on energy efficiency in homes from the Scopus database were used to perform the analysis with the SciVal platform and Scopus “Analyze search results” tool. The main conclusions from the study are as follows.

Scholars have studied energy efficiency and renewable energy in households for several decades, but these topics have gained popularity in the last 20 years. In addition, the energy efficiency theme has a longer research history (since 1978) with a more extensive publication set than the renewable energy topic (since 1984). It is due to the slower development and commercialization of green power technologies for industry and households compared to energy-efficient technologies. At first, renewable energy facilities were quite expensive for homes, but thanks to technological progress and cost reduction, they became available first for developed countries and later for developing ones.

Initially, the publications on energy efficiency and renewable energy in homes studied mainly technical issues and then expanded to investigate social and economic impacts as opportunities for the mass use of these technologies appeared. However, despite high interest in these topics, the share of economic and social research papers in the field is several times lower than that of technical works.

Many publications on household energy efficiency and renewable energy demonstrate interdisciplinary character and strong international collaboration. For example, 31% of the energy efficiency papers and almost 27% of renewable energy articles were published by international teams. It increases opportunities for international technology transfer.

Both analysis tools revealed approximately the same leading countries contributing to energy efficiency and renewable energy research in the residential sector. They include the United States, the United Kingdom, China, and Germany as leading players with diversified international collaboration in both directions. In addition, Australia and Spain show high publishing results in the energy efficiency field, and India and the Netherlands in green power research.

The top authors (by scholarly output) on the household energy efficiency topic are from the United Kingdom, United Arab Emirates, Qatar, Spain, Greece, Germany, Latvia, and Australia. The papers with the highest citing consider economic mechanisms and social perception of energy-efficient technologies in homes. Researchers from Australia, France, Denmark, Germany, the Netherlands, Iraq, Lithuania, and Finland demonstrate the highest scholarly output on the renewable energy topic. The most cited publications of these authors are studies on innovative green power technologies and policies for households, renewable energy public acceptance, energy poverty issues, and green energy transition mechanisms in the residential sector.

Overall, the results showed a lack and a high societal demand for papers investigating economic and social impacts and management mechanisms for implementing energy-efficient and renewable energy technologies in households. Therefore, there is an urgency to continue research in the field. In addi-

tion to developing optimal instruments to implement effective home energy-efficient and green power technologies and practices, it is of utmost importance to create mechanisms ensuring the application of innovative energy-efficient and renewable energy technologies, zero energy building standards for new homes, compliance with energy efficiency requirements for buildings subject to partial restoration, thermal modernization for old buildings that do not meet modern energy efficiency standards, and green power sources involvement for home energy supply. Many of these issues are in demand in countries worldwide.

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