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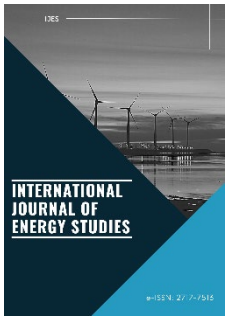

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Bibliometric analysis of energy efficiency in the context of developed and developing countries

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Highlights

- Academic studies on energy efficiency conducted by Türkiye, Germany, and Iran between 1990 and 2023 were examined.
- A bibliometric analysis of articles published in the fields of civil engineering, building construction technologies, and architecture on countries' energy efficiency was conducted.
- These studies are expected to significantly influence future research by fostering collaboration among researchers from different fields and countries, thereby providing new insights into energy efficiency.

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ABSTRACT

When we look at the studies conducted on energy efficiency in the last 30 years, researchers have studied many individual and mass effects of energy efficiency. Studies conducted in the academic field around the world constitute essential data for determining the tendencies of countries in this direction and their goals. In practice, including these academic studies is essential for achieving a country's development and energy efficiency goals. Many studies have been conducted on how countries dependent on foreign energy should proceed in this regard and what can be done in terms of savings and the use of renewable energy. This study aims to enrich the knowledge structure in the energy efficiency literature of Turkey, Germany, and Iran, countries with different economic development levels and energy policies, and to understand how energy efficiency is addressed in different economic and political contexts. In this context, the current literature was reviewed using the bibliometric method to understand the current information network of energy efficiency research in Türkiye, Germany, and Iran and to emphasize the future direction of scientific studies in this field. The Web of Science (WoS) data of countries subject to research between 1990-2023 were taken for analysis. This study analyzed 1411 articles published in civil engineering, building construction technologies, and architecture on energy efficiency in Türkiye, Germany, and Iran. A recently developed R studio program called "bibliometrics" was used to analyze the data, and the "biblioshiny" extension was used to visualize the outputs. In this study, the correct handling of the interactions of energy efficiency with renewable energy source consumption conservation revealed that countries showed a more holistic approach to the subject. In addition, concrete data has been presented for policymakers, revealing how energy efficiency studies differ according to the level of economic development. The analyses were conducted specifically for Turkey, Germany, and Iran. In general, such studies will benefit by bringing together researchers from different fields and countries to shed new light on energy-efficiency questions in future research.

Keywords: Energy efficiency, Türkiye, Germany, Iran, Bibliometric analysis, Research trends

1. INTRODUCTION

Energy is of great importance to a country's economic and social development. Countries rich in energy are economically strong because energy is the most important industrial input. In addition, one of the important determinants of a country's level of development is the amount of energy consumed per capita. Energy consumption, which is strongly related to socioeconomic development, has increased rapidly in recent years (Figure 1). It is inevitable that energy is the primary driver of economic growth and significantly affects the environment. Sustainable energy development, sustainable development, and the reduction of the effects of climate change are the primary goals of energy policies in all countries [1].

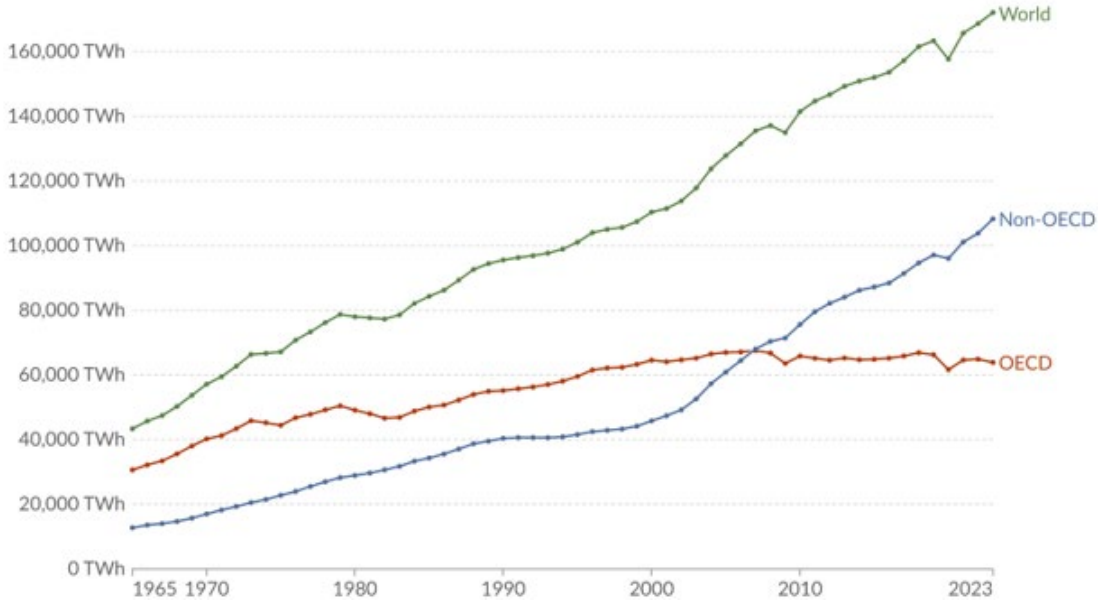

Figure 1. Change in primary energy consumption by geography [2]

These resources are predicted to be depleted under current usage conditions, despite the world's energy demand increasing by 4-5% yearly due to rapid population growth, industrialization, and rising living standards. It is stated that fossil energy resources, which are used intensively to meet energy demand, will be depleted shortly, and significant increases in energy prices are directing countries to search for new energy resources. The increase in energy demand will exceed 90% by 2035 [3]. At this point, countries aim to evaluate their potential most efficiently and become countries that dominate their own energy production and consumption balance. Securing the energy supply and reducing the contribution of energy to climate change are the two most important issues in the energy sector in terms of sustainability [4,5,6]. The use of renewable energy sources is of great importance in solving these problems. Increasing the share of renewable energy,

which has a positive effect on energy independence and energy efficiency, contributes positively to the economy of countries while also helping to achieve many goals, such as reducing energy bills, energy dependency, and greenhouse gas emissions (Figure 2), [7,8].

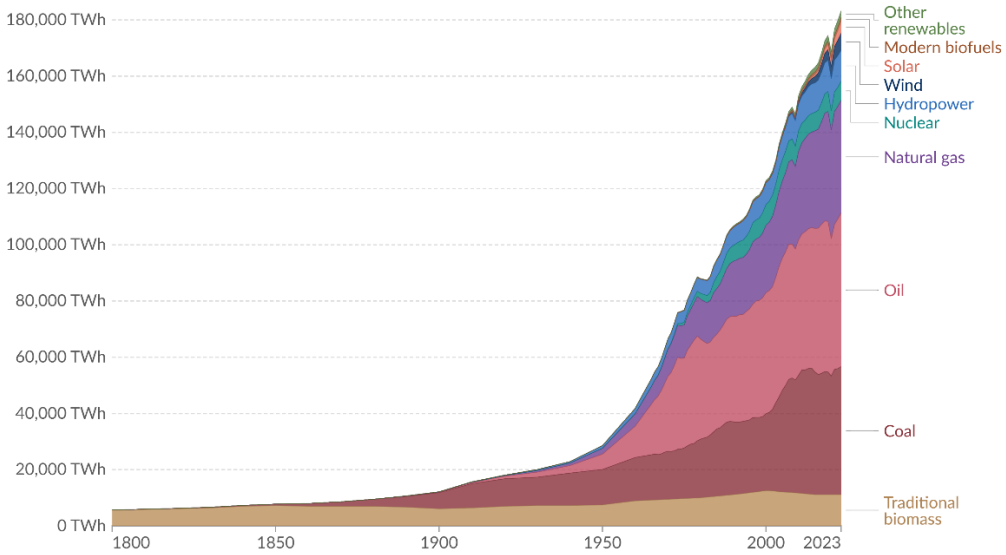

Figure 2. Global primary energy consumption by source [2]

To partially solve the increasing energy problem worldwide, in addition to using renewable energy sources, using energy efficiently also contributes to the solution. In this global context, the return to renewable resources is not just a local solution but a crucial step towards reducing the adverse effects of climate change. It is a sustainable model that can meet the energy demand of future generations, making it an essential part of the national development plans of many developed and developing countries. For instance, the EU's Energy Action Plan, initiated in 2007, set 20/20/20 targets that shaped the European energy policy. These targets, which aim to reduce greenhouse gas emissions by 20%, reduce primary energy consumption by 20%, and meet 20% of energy consumption from renewable sources, have a ripple effect on the global fight against climate change. The Energy Roadmap 2050, as part of this plan, further aims to reduce EU greenhouse gas emissions by 80-90% and increase energy efficiency by 27% by 2030 [9].

With regard to energy efficiency, the success stories of the United States, Europe, and Japan stand out. Geller et al. (2006) conducted a study on energy efficiency developments in major OECD countries since 1973. Their findings demonstrated that well-crafted policies can lead to a significant increase in energy efficiency. For instance, in the United States, targeted programs have resulted in an 11% reduction in energy consumption, a trend mirrored in Europe and Japan. This

success is a testament to the potential for further progress in energy efficiency and offers hope for a more sustainable future [10]. Another study, focusing on the contribution of energy to environmental efficiency in a sample of OECD countries, found that the United States, Ireland, and Switzerland have made substantial strides in energy and environmental efficiency over the past decade [11].

Türkiye-Germany-Iran Evaluation in Energy Efficiency

In recent years, there have been changes in countries' understandings of energy production and consumption. These changes effectively determine the social and economic status of developed and developing countries. When we look at global developments in energy, the primary energy demand is expected to increase by 5.8% in 2021. Fossil fuels accounted for 82% of this increase. Germany is making significant efforts to reduce the demand for consumable energy resources in line with its energy-efficiency targets. It has started to reduce the primary energy consumption with targets that will provide significant practical benefits. Although Türkiye and Iran have targets in this regard, no effective decrease was observed in reducing primary energy consumption (Figure 3).

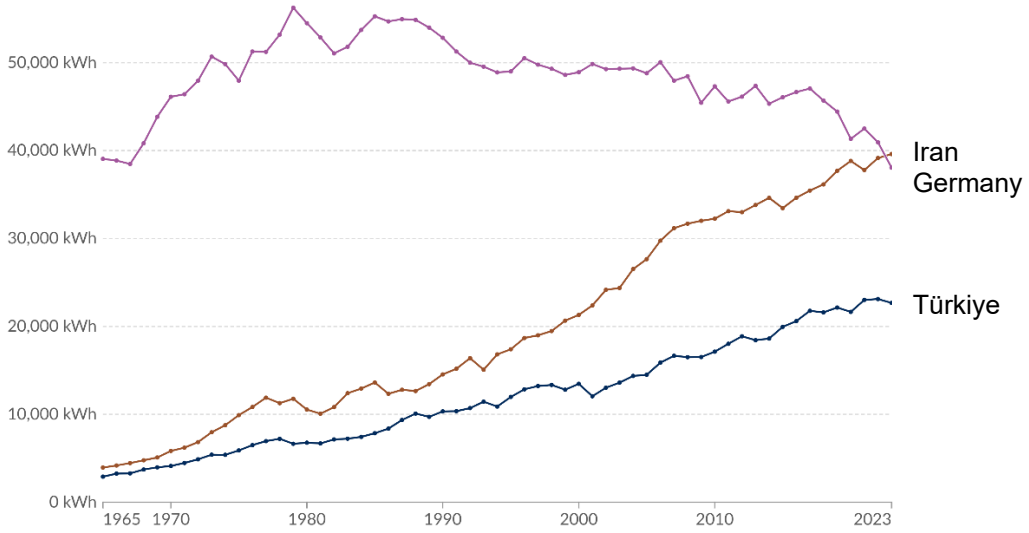

Figure 3. Primary energy consumption of Türkiye, Germany, and Iran [2]

To use energy effectively, prevent waste, reduce the burden of energy costs on the economy, and increase efficiency in the use of energy resources and energy to protect the environment, the Energy Efficiency Law was enacted in 2007 in Türkiye. The purpose of the law is to ensure the efficient use of energy, prevent waste, reduce the economic burden of energy costs, and improve the efficiency of energy resources and energy usage to protect the environment [12]. Following

the enactment of this law, Turkey's energy efficiency legislative framework was established through the publication of numerous regulations, circulars, and communiqués by the relevant ministries. In this context, the legislative arrangements have determined the actions to be taken to increase and support energy efficiency in the production, transmission, distribution, and consumption stages of energy, in industrial enterprises, buildings, transportation, agriculture, and service sectors, to develop energy awareness in society in general and to benefit from renewable energy sources. The Energy Efficiency Law and the Energy Performance in Buildings Regulation introduced the mandatory requirement of an Energy Identity Certificate (EIC) during the licensing process for both existing and new buildings to prevent energy loss. This initiative aims to achieve a 40% reduction in energy consumption [13,14]. Within the scope of energy efficiency studies in Türkiye, a 14% decrease in primary energy consumption is expected, which is in line with the targets determined in the National Energy Efficiency Action Plan (2017-2023). In addition, it aims to reduce the energy intensity per capita by 20% by 2023 [15], (Figure 4). Türkiye has also determined the goal of increasing renewable energy resources as a strategic priority, and within the scope of the 2023 National Energy Plan, it is aimed to increase the share of renewable energy resources in total energy production to 50% [16].

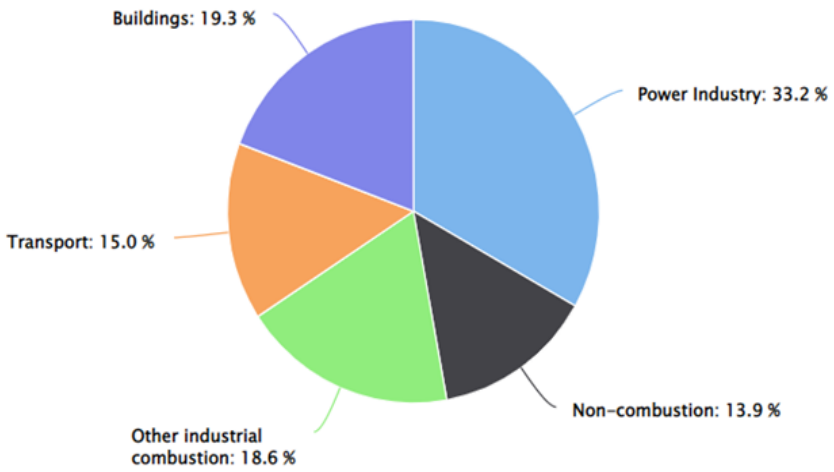

Figure 4. Fossil source CO_2 emissions produced by sectors in Türkiye [2]

As a member of the EU, Germany is performing significant work in energy efficiency studies. Germany is concerned about the climate crisis and aims to be less dependent on fossil fuels for a secure energy supply. It attaches great importance to energy studies, particularly in reducing its dependence on Russian energy sources rapidly and to a large extent. In addition to the directives and regulations of the European Union on energy efficiency, Germany determines the minimum energy requirement for the energy performance of the building envelope in existing and new

buildings using the Building Energy Act (GEG), Energy Saving Act (EnEG), Energy Saving Regulation (EnEV) and Renewable Energies Heat Act (EEWärmeG). Germany aims to reduce its CO_2 emissions by 65% by 2030 under the Climate Protection Act (2021). The energy sector, industry, transportation, construction sector, and agriculture aim to reduce CO_2 emissions by 65% compared to 1990. Germany sees renewable energy sources (wind and solar) as one of the most important options for reducing external dependence on energy and greenhouse gases. In this context, it aims to increase electricity production from renewable energy sources to 80% by 2050 and to increase the net zero energy building stock [17, 18].

Heating is of particular importance for achieving energy and climate targets. With 27% of the total primary energy consumption and 35% of the final energy consumption in Germany, the building sector plays a key role in the German Climate Protection Agreement. The housing sector accounts for 63% of the total building stock's final energy consumption [19]. The German building sector directly accounts for 14% of the total national greenhouse gas emissions and is indirectly responsible for approximately a quarter of Germany's total emissions [20], (Figure 5).

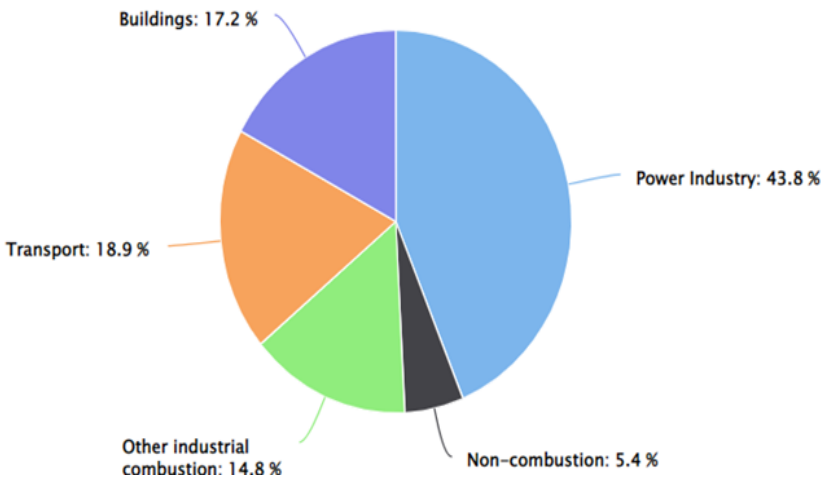

Figure 5. Fossil-sourced CO_2 emissions produced by sectors in Germany [2]

Iran is one of the most energy-intensive developing countries and is among the world's top ten carbon dioxide emitters. The country's energy consumption increase is approximately five times the world average, and approximately 35% of the energy is consumed in different types of buildings. If the current consumption trend continues, it is estimated that Iran will need to import energy despite being one of its largest energy producers [21]. Reducing primary energy consumption worldwide recognizing the importance of energy conservation, Iran established

several government organizations in 1995 to conduct research on energy conservation methods and renewable energies. The most notable of these are the “Iran Fuel Conservation Company” (IFCO), the “Iran Energy Efficiency Organization” (SABA) and the “Iran Renewable Energy Organization” (SUNA), [22]. After the establishment of these organizations, Iran has determined some strategies and plans to reduce the country's energy consumption, including buildings. These measures include the establishment of national building codes for energy saving in buildings, and increasing energy prices [23], (Figure 6).

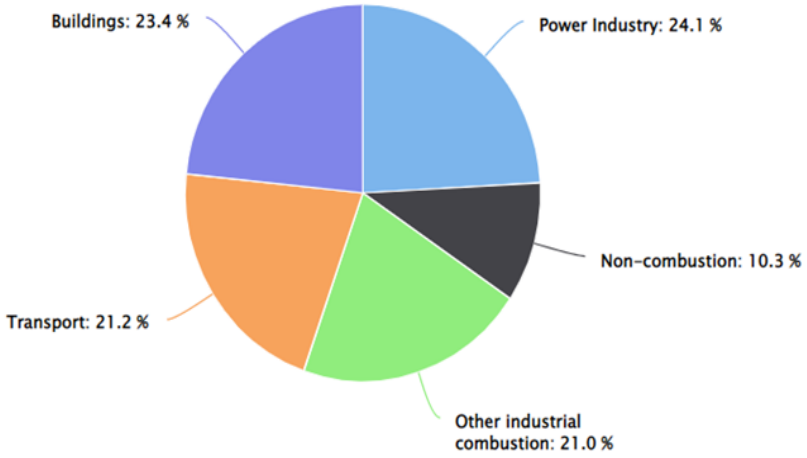

Figure 6. Fossil source CO_2 emissions produced by sectors in Iran [2]

According to a report by the Global Energy Society, the largest increase in energy consumption intensity in the world between 1990 and 2006 was recorded in Iran [24]. According to Iran's energy balance sheet statistics, energy consumption per capita is higher than that in countries such as Türkiye, India, Pakistan, Africa, and Venezuela. It is 1.61 times higher than average global final consumption per capita. The biggest factors in this high rate are low efficiency, high energy consumption, and the use of goods and services that consume high energy [25]. According to a British Petroleum Company study, Iran's energy consumption is much higher than that in more developed countries. This study stated that Iran's annual average energy consumption is 155Mt/year (420 ml per day), ranking 13th in the world [26]. Iran aims to increase the use of renewable energy sources using a sustainable and environmentally friendly approach because energy resources will be depleted soon. The country has a high potential to benefit from the wind and sunlight [27].

The literature shows that countries' energy efficiency policies vary. Countries differ in terms of geographical location, climate, economy, population, ideology, management style, and demographic, institutional, and cultural structures. Therefore, these differences effectively determine which country follows the more appropriate energy efficiency policies [28]. Accordingly, the study evaluated the reflection of different geographic, political, and social structures of Germany, Türkiye, and Iran on energy efficiency studies based on the current situation in the literature. Germany is a pioneering country worldwide in terms of energy efficiency and sustainable energy policies. Having a developed economy and advanced technology infrastructure offers extensive opportunities for developing and disseminating energy efficiency applications. Turkey, in addition to being a transit country in terms of energy due to its strategic geographical location, has a rapidly growing economy. Increasing energy demand and import dependency bring the necessity of increasing energy efficiency to the forefront. Türkiye has developed various legal regulations and incentive mechanisms in the field of energy efficiency in recent years. Iran, on the other hand, draws attention to its low efficiency and waste rates in energy consumption despite having one of the largest oil and natural gas reserves in the world. Despite the abundance of energy resources, Iran faces difficulties in sustainable energy policies and efficient energy use. In this context, evaluating the perspectives of these countries on energy efficiency in terms of scientific publications can be considered an exemplary study for analyzing the current situation of developed and developing countries.

2. METHOD

In many studies conducted worldwide on energy efficiency, targets are set to be more sensitive to the environment and energy both individually and socially, and countries support the studies conducted within this scope. Despite the negativities experienced in the world in recent years, the issue of efficient energy use has not changed and has even become more critical [28]. The aim of the study is to provide a broader perspective by comparing energy efficiency studies in the scientific literature of countries with different economic development levels and energy policies. In this context, a bibliometric analysis was conducted to understand the information structure of scientific publications on energy efficiency in the current literature of Türkiye, Germany, and Iran. The diversity of the information structure in the energy efficiency literature of these countries is considered to be important within the scope of the research problem. In this context, the following questions were examined in the context of sample countries with different economic development levels in the bibliometric analysis.

• What is the trend in scientific publications on energy efficiency in the sample countries? What information has emerged from existing publications?

• What topics do the countries focus on?

• What themes are related to energy efficiency, and how have these themes developed over time?

To answer these questions, the existing literature was reviewed using bibliometric methods to understand the current knowledge network of energy efficiency research (Figure 7). This analysis provides a comprehensive understanding of the current state of research and offers a promising glimpse into the future direction of research in this field, instilling a sense of hope and optimism in readers.

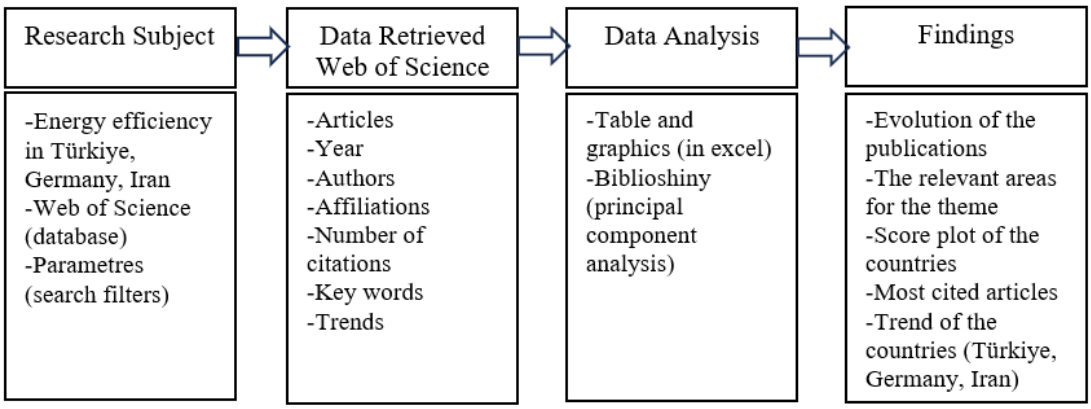

Figure 7. The framework of the study

The study determined energy efficiency as the primary variable, and bibliographic information in civil engineering, construction technology, and architecture, which are the most relevant categories in building and construction, was analyzed. Accordingly, the keyword "energy efficiency" was entered in the WoS database, and the data information was obtained by selecting the relevant countries and designated areas. Web of Science (WoS) data from 1990 to 2024 were used for this analysis. Thirty years were selected within the scope of the analysis, considering some critical global events such as the signing and implementation of the Kyoto Protocol and COP21, the most critical effects of Energy Efficiency research. To analyze the sample data, a recently developed R studio program called "bibliometrics" and the "bibliopshiny" extension were used to visualize the outputs [29]. Web of Science, which has a strong journal network dating back to 1990 and a high impact rate [30]. Chadegani et al.,(2013), was also influential in selecting relevant literature from this database.

3. FINDINGS

The current study analyzed 1411 articles in the literature on energy efficiency in buildings and related fields in Türkiye, Germany, and Iran between 1990-2023. In the studies contributed by 3834 authors, the framework of the topics in the related fields was determined using 4647 keywords. A total of 111 authors presented single-author studies on energy efficiency. 36% of the studies were international and multi-authored, and the author collaboration index per publication was 3.41. The annual production rate of articles was 6.92%, and the average number of citations per article was 18.8 (Figure 8).

Figure 8. General information of the analysis

Table 1 shows the number of articles published by countries according to their co-author networks in energy efficiency studies. Accordingly, in the WoS database, Iran was the country with the most publications with a rate of 37.3%, it also maintained a broad network of co-authors in the relevant literature. Germany is in second place with 36.6%, and Türkiye is in third place with 26.7%.

Table 1. Number of articles published by countries

Countries/Regions	Record Count	% of 1.411
IRAN	564	39.972
GERMANY	515	36.499
TURKİYE	344	24.380
USA	93	6.591
CHINA	85	6.024
ENGLAND	62	4.394
CANADA	51	3.614
AUSTRALIA	44	3.118
ITALY	40	2.835
SAUDI ARABIA	27	1.914

When we look at the number of articles published, it is seen that it has increased yearly. The increasing global concerns and effects of climate change on countries' energy consumption can explain this increasing trend. Although there has been a slight fluctuation in the number of publications since 2016, it is seen that the relevant literature has always been on an increasing trend. The number of publications that started to increase in 2000 increased, especially since 2006. One of the most important reasons for this may be the implementation of the Kyoto Protocol, which was accepted in 1997 by many countries in 2005. Table 2 lists the number of publications published after the year 2000. The table shows a significant increase in publications from 2018 to the present day. In particular, the action plan prepared by the EU in 2007 and the targets set for 2020 have started to take an essential place in the academic field, as well as in political studies in Germany, an EU member, and Türkiye, which aims for EU membership. According to the British Petroleum Company's report, the energy consumption in Iran is considerably higher than that in developed countries. The establishment of programs by the Iranian Energy Authority (SABA) to reduce carbon emissions by 2030 affects the number of publications in this field.

Table 2. Publication rate of articles by year

Publication Years	Record Count	% of 1.411
2023	131	9.284
2022	167	11.836
2021	187	13.253
2020	143	10.135
2019	109	7.725
2018	125	8.859
2017	69	4.890
2016	73	5.174
2015	65	4.607
2014	61	4.323
2013	51	3.614
2012	45	3.189
2011	37	2.622
2010	34	2.410
2009	26	1.843
2008	23	1.630
2007	19	1.347
2006	8	0.567
2005	9	0.638
2004	7	0.496
2003	7	0.496
2002	1	0.071
2001	1	0.071

This study analyzed these countries' studies in civil engineering, building construction technologies, and architecture related to energy efficiency. Accordingly, in the WoS categories, where energy efficiency-related studies are included, the Civil Engineering category ranks first, with a rate of 74.69%. Building construction technologies ranked second with 64.77%, and architecture ranks 9th with 4.67% (Table 3).

Table 3. Studies of countries in the top ten fields in the WoS category

Web of Science Categories	**Record Count**	**% of 1.411**
Engineering Civil	**1054**	**74.699**
Construction Building Technology	**914**	**64.777**
Energy Fuels	352	24.947
Engineering Mechanical	96	6.804
Materials Science Multidisciplinary	96	6.804
Engineering Environmental	94	6.662
Green Sustainable Science Technology	87	6.166
Water Resources	69	4.890
Architecture	**66**	**4.678**
Mechanics	56	3.969

The most commonly used language in the relevant literature was English (89.29%). Germany was second (9.78%), and Türkiye ranked third (0.78%). English was the most preferred language and common literature language. The fact that the language of the journals within the scope of WoS, where studies on energy efficiency are published, is primarily English, has also influenced the emergence of this picture (Table 4).

Table 4. Language of the articles

Languages	**Record Count**	**% of 1.411**
English	1260	89.298
German	138	9.780
Turkish	11	0.780
Spanish	2	0.142
Croatian	1	0.071
Italian	1	0.071
Polish	1	0.071

The total number of journals in which the studies of the countries analyzed on energy efficiency were published was 172. Among the top ten most relevant journals in this journal list, Energy and Buildings (240) ranked first, with a publication rate of 17%. This journal explicitly evaluates

studies on building energy performance within its scope. The Journal of Building Engineering (90) ranks second, with 6.37%, and Sustainable Cities and Society (83) ranks third, with a publication rate of 5.88% (Table 5).

Table 5. Most Relevant Sources

Sources	**Articles**	**% of 1.411**
ENERGY AND BUILDINGS	240	17
JOURNAL OF BUILDING ENGINEERING	90	6.37
SUSTAINABLE CITIES AND SOCIETY	83	5.88
BAUPHYSIK	63	4.46
BUILDING AND ENVIRONMENT	58	4.11
CONSTRUCTION AND BUILDING MATERIALS	54	3.82
OCEAN ENGINEERING	43	3.40
THIN-WALLED STRUCTURES	40	2.83
BUILDINGS	32	2.26
ENGINEERING STRUCTURES	26	1.84

As shown in Table 6, the journals based on the most local citation sources are Energy and Buildings (3090), Building Environment (1349), and Applied Energy (1126), which are the three most influential sources when considering publication quality. Energy and Buildings are international journals that publish articles on building energy use. The journal covers studies that aim to reduce the energy needs of a building and improve indoor environmental quality. The building Environment publishes articles on environmental performance at various spatial scales, from cities, communities, buildings, building systems, and assemblies to other built environments, such as transportation and industrial environments. Applied Energy supports innovation, research, and development in energy conversion and conservation, optimum use of energy resources, analysis and optimization of energy processes, reduction of environmental pollutants, and sustainable energy systems. These journals are leading journals that accept publications on energy efficiency. This shows that strong citation relationships are maintained among the leading journals. In this context, according to the WoS research areas where most of the relevant literature is included, the scope of these first three journals overlaps with studies in Building Construction and Civil Engineering, energy studies, materials science, and sustainability. Articles in these fields, mainly citing each other, increased the visibility of the journals.

Table 6. Most Local Cited Sources (from Reference Lists)

Sources	Articles
ENERGY AND BUILDINGS	3090
BUILDING ENVIRONMENT	1349
APPLIED ENERGY	1126
ENERGY	1042
RENEWABLE SUSTAINABLE ENERGY REVIEWS	971
CONSTRUCTION BUILDING MATERIALS	954
ENERGY CONVERSION MANAGEMENT	804
RENEW ENERGY	738
SUSTAINABLE CITIES SOCIETY	677
ENERGY STRUCTURE	634

Table 7 lists the top ten essential journals that publish the most on energy efficiency according to the beginning of the publication year (PYS), total citations received (TC), and H-indexes of the journals. Energy and Buildings rank first as the journal with the highest H-index and total citations (9820) for the analyzed period. Energy and Buildings primarily evaluates studies on energy efficiency in buildings within its scope. In this context, the journal covers 25% of the energy efficiency publications of the analyzed countries. Building and Environment ranks second with 58 publications and 2151 citations. Sustainable Cities and Society ranks second with 83 publications but 2498 citations. Building Environment contributes to the relevant literature with more qualified publications than equivalent journals.

Table 7. Top ten journals with local impact (Source Local Impact)

Element	h_index	g_index	m_index	TC	NP	PY_start
ENERGY AND BUILDINGS	57	85	2,591	9820	236	2003
SUSTAINABLE CITIES AND SOCIETY	30	42	2,143	2151	80	2011
BUILDING AND ENVIRONMENT	26	49	1,3	2498	54	2005
JOURNAL OF BUILDING ENGINEERING	26	36	2,6	1766	87	2015
THIN-WALLED STRUCTURES	23	40	1,353	1895	40	2008
CONSTRUCTION AND BUILDING MATERIALS	21	35	1,615	1346	52	2012
ENGINEERING STRUCTURES	14	23	0,824	671	23	2008
OCEAN ENGINEERING	13	21	0,765	527	36	2008
BUILDING RESEARCH AND INFORMATION	11	14	0,579	259	14	2006
WATER RESOURCES MANAGEMENT	10	17	0,625	315	17	2009

Figure 9 shows which core journal group the articles are most concentrated around when distributing them to journals according to Bradford's law. According to Bradford's law, while the

first group of journals publishes approximately one-third of the articles published on a particular subject, a group containing a second or more journals publishes another third of all articles, and a much larger journal group containing a much larger number of journals published the last third [31] Accordingly, Energy and Buildings, Journal of Building Engineering, Sustainable Cities and Society, and BAUPHYSIK journals published one-third of the publications as the first group journals.

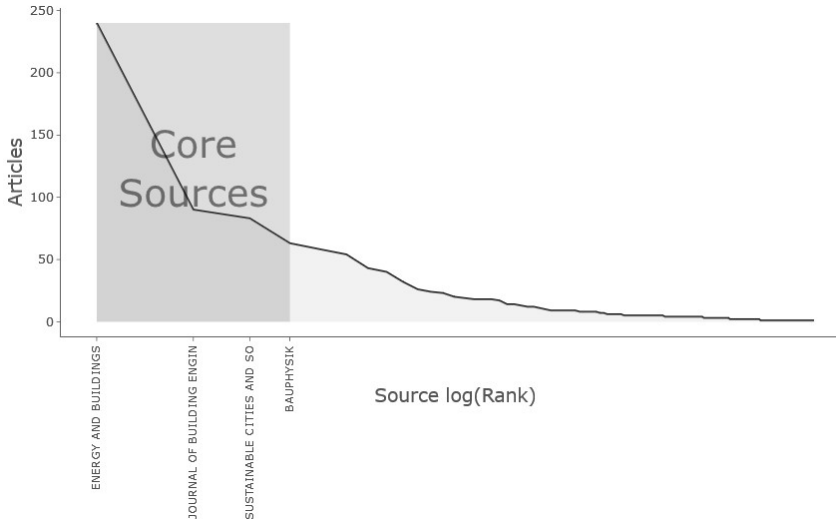

Figure 9. Source clustering through Bradford's Law

Table 8 shows the most productive authors in the energy efficiency field in Türkiye, Germany, and Iran over the last ten years. In total, 3838 authors contributed to the field, and the ten most productive authors published 129 articles in the last ten years. This constituted > 9.1% of the selected studies. The table includes three columns that show the author's name, number of publications, and fragmented articles. Fragmented articles represent a single author's contribution to the publications in question in cases where more than one author was included in the research study. According to this table, Hepbaslı A. is the author with the most connections, with 37 publications. The author's research focuses on the use of renewable energy sources in heating systems and heat pumps. Muller D. has 21 publications among the joint studies and has produced studies with his team on building energy systems, heat pumps, urban- and building-scale energy system modeling, and energy efficiency in buildings (Table 8).

Table 8. Most Relevant Authors

Authors	Articles	Articles Fractionalized
HEPBASLI A.	37	15,28
MÜLLER D.	21	5,89
DINCER I.	12	4,14
MOSTOFINEJAD D.	11	4,58
GALVIN R.	9	6,53
WAGNER A.	9	2,48
PFAFFEROTT J.	8	3,62
WANG Y.	8	1,48
EICKER U.	7	2,33
GHASSEMI H.	7	1,62

Hepbaslı A. has published regularly between 2003 and 2015. The author's most productive year is 2007. The author has maintained his productivity, especially with his publications, from 2007 to 2015. Muller D.'s publication production has continued from 2011 to the present. Muller increased the number of qualified publications, especially between 2017 and 2021. Dinçer published the relevant literature between 2005-2012. The author has intensified his work in this context in the last three years of his publication. When we evaluated the author's productivity by year, other authors, apart from these three authors, presented their publications, which they produced in small numbers, at irregular intervals (Figure 10).

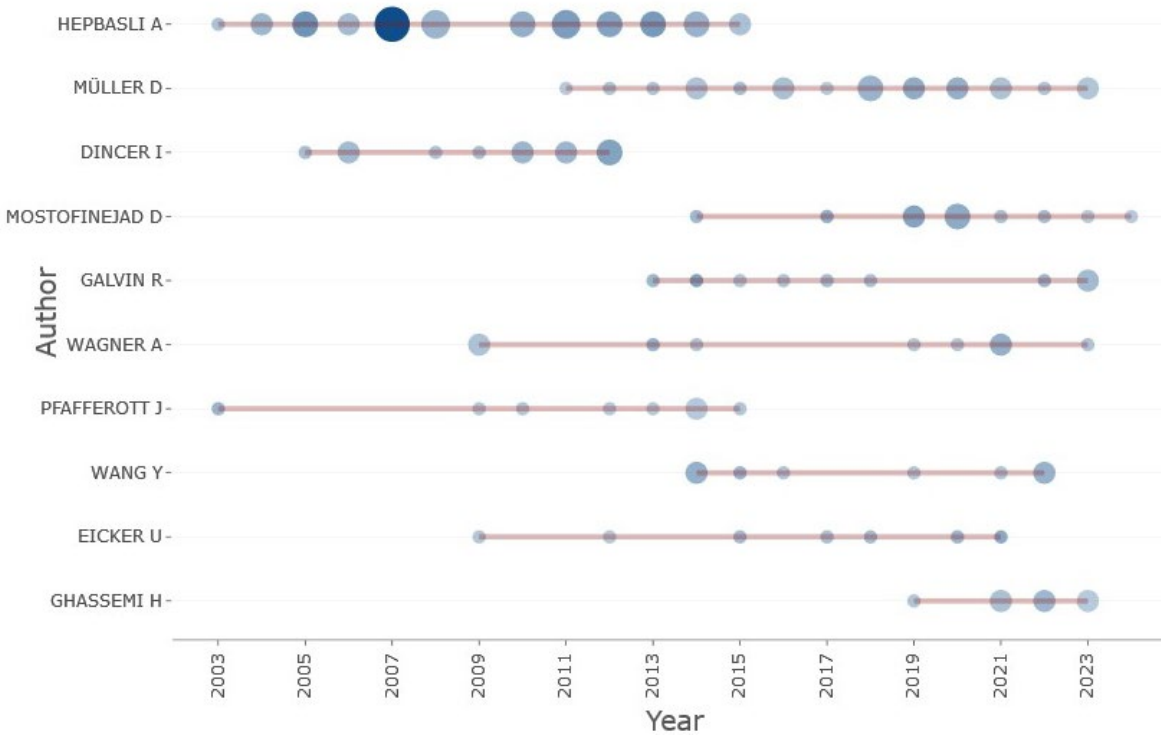

Figure 10. Authors' Production over Time

Table 9 lists the top 10 institutions published in the relevant literature. Considering the author's institution information of the published articles, Islamic Azad University has published 136 articles on energy efficiency (Table 9). This number constitutes 9.6% of the total articles. Tehran University follows it with 92 articles, and Istanbul Technical University with 66 articles.

Table 9. Most Relevant Affiliations

Affiliation	Articles
ISLAMIC AZAD UNIVERSITY	136
TEHRAN UNIVERSITY	92
ISTANBUL TECHNICAL UNIVERSITY	66
IRAN UNIVERSITY OF SCIENCE AND TECHNOLOGY	50
EGE UNIVERSITY	45
TARBIAT MODARES UNIVERSITY	37
TECHNICAL UNIVERSITY OF DARMSTADT	33
UNIVERSITY OF STUTTGART	31
SHARIF UNIVERSITY OF TECHNOLOGY	30
UNIVERSITY OF TABRIZ	30

The analysis of the first ten most cited articles on energy efficiency is presented in Table 10. Accordingly, MARSZAL AJ (2011), published in the Energy and Buildings journal, “Zero Energy Building – A Review of Definitions And Calculation Methodologies” is ranked first with 726 citations. The annual citation rate of articles was 51.86%. Esen H.’s article “Energy and exergy analysis of a ground-coupled heat pump system with two horizontal ground heat exchangers,” published in the Building Environment journal in 2007, ranks second with 342 citations. The author’s article “Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates,” published in the same journal in 2008, is ranked third with 246 citations.

Technical reports (31) on the subject were the most used sources in the local citation list of the articles. Buildings and the Environment, Applied Energy, and Energy Policies are among the top ten most used sources. These journals are where the most relevant articles are published. This shows that the quality of journal publications has a high citation rate. It is observed that it is the third most used source in theses, in addition to journal sources (Table 11).

Table 10. Most Global Cited Documents

Author, Paper	DOI	Total Citations	TC per Year	Normalized TC
MARSZAL AJ, (2011) Zero Energy Building – A review of definitions and calculation methodologies	https://doi.org/10.1016/j.enbuild.2010.12.022	726	51,86	11,90
ESEN H, (2007), Energy and exergy analysis of a ground-coupled heat pump system with two horizontal ground heat exchangers	https://doi.org/10.1016/j.buildenv.2006.10.014	342	19,00	4,72
ESEN H, (2008), Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates	https://doi.org/10.1016/j.buildenv.2007.02.016	246	14,47	6,29
JENSEN SO, (2017), IEA EBC Annex 67 Energy Flexible Buildings	https://doi.org/10.1016/j.enbuild.2017.08.044	244	30,50	11,60
OZGENER O, (2005), Experimental performance analysis of a solar-assisted ground-source heat pump greenhouse heating system	https://doi.org/10.1016/j.enbuild.2004.06.003	216	10,80	4,86
MOLHAVE L, (1997), Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations	https://doi.org/10.1111/j.1600-0668.1997.00002.x	183	6,54	1,00
GUNERHAN H, (2007), Determination of the optimum tilt angle of solar collectors for building applications	https://doi.org/10.1016/j.buildenv.2005.09.012	179	9,94	2,47
DE ALMEIDA A, (2011), Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations	https://doi.org/10.1016/j.enbuild.2011.03.027	168	12,00	2,75
SARHADDI F, (2010), Exergetic performance assessment of a solar photovoltaic thermal (PV/T) air collector	https://doi.org/10.1016/j.enbuild.2010.07.011	165	11,00	5,97
SHARIATI A, (2020), Extremely large oscillation and nonlinear frequency of a multi-scale hybrid disk resting on nonlinear elastic foundation	https://doi.org/10.1016/j.tws.2020.106840	162	32,40	8,45

Table 11. Most Local Cited References

Cited References	Citations
ANONYMOUS, TECHNICAL REPORT	31

PEREZ-LOMBARD L, 2008, ENERG BUILDINGS, V40, P394, DOI 10.1016/J.ENBUILD.2007.03.007	30
ANONYMOUS, THESIS	25
BEJAN A., 1995, THERMAL DESIGN OPTIM	24
FANGER P. O., 1970, THERMAL COMFORT. ANALYSIS AND APPLICATIONS IN ENVIRONMENTAL ENGINEERING.	17
DEB K, 2002, IEEE T EVOLUT COMPUT, V6, P182, DOI 10.1109/4235.996017	15
ABRAMOWICZ W., 1984, INT J IMPACT ENG, V2, P263, DOI DOI 10.1016/0734-743X(84)90010-1	14
ALEXANDER J.M., 1960, QUART J MECH APPL MATH, V13, P10, DOI DOI 10.1093/QJMAM/13.1.10, 10.1093/QJMAM/13.1.10	13
MA ZJ, 2012, ENERG BUILDINGS, V55, P889, DOI 10.1016/J.ENBUILD.2012.08.018	13
MAGNIER L, 2010, BUILD ENVIRON, V45, P739, DOI 10.1016/J.BUILDENV.2009.08.016	13

When the author's keywords in the relevant literature were analyzed, among the first ten keywords, "energy efficiency" (179) was the most used keyword with a rate of 23%. In particular, regarding the selected research area of architecture, building, and construction systems, the words "optimization" (55) with a rate of 7%, "thermal comfort" and "sustainability" (36) with a rate of 9%, "exergy" (38) with a rate of 5% and "energy" (37), with a rate of 5%, determined the framework of the research areas. Accordingly, the authors focused their energy efficiency studies on the energy-efficient improvement of buildings (Figure 11).

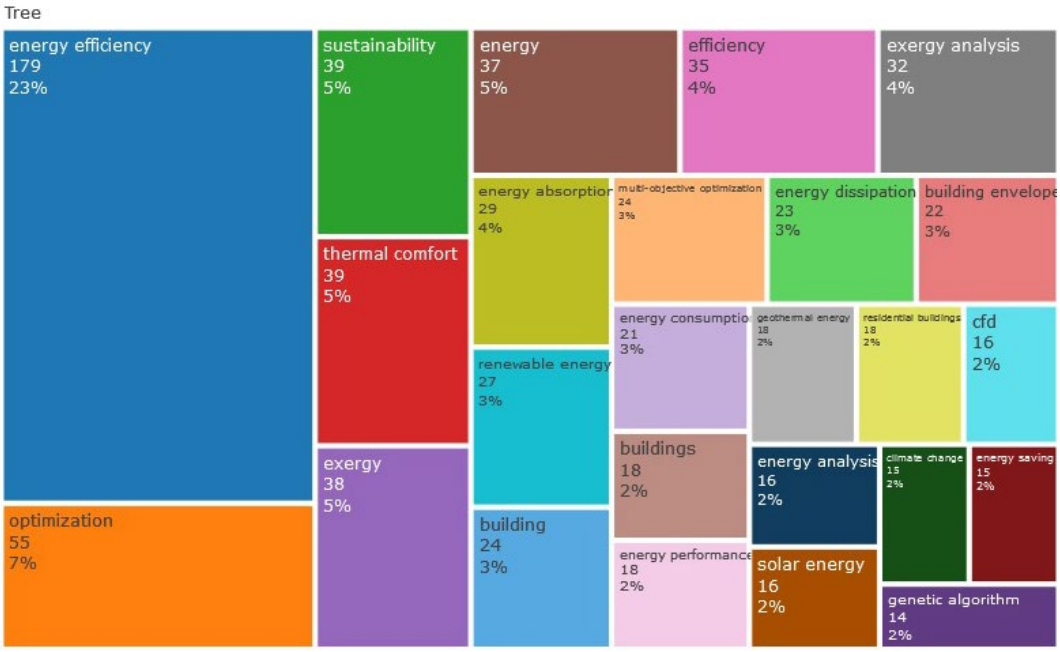

Figure 11. Author keywords

The thematic development of studies conducted in Türkiye, Germany, and Iran on energy efficiency between 1992 and 2023 is shown in Figure 12. In this diagram, each node represents a

theme cluster labeled with the keyword with the highest frequency and corresponding sub-period. The node size was proportional to the number of keywords for the corresponding theme. The flow between nodes indicates the evolutionary direction of the theme clusters. Edge width is the sum of the two connected themes. A series of themes developing during different sub-periods can be considered thematic areas. The keywords under which the studies were conducted in three different periods were analyzed in the evaluation. In the selected date ranges, the Kyoto Protocol, which entered into force in 2005 and is effective in energy efficiency studies worldwide, and the Paris Climate Change Agreement signed in 2016 were taken as the basis. Accordingly, the themes on which studies in the academic field are concentrated are analyzed in Figure 12. It was gathered under two themes between 1992-2005, 19 themes between 2006-2015, and nine themes between 2016-2024. Although energy efficiency was a theme in every period, its usage rate has increased since 2016. While the optimization theme group represents several theme clusters labeled from the sub-periods, its usage rate increased in 2016.

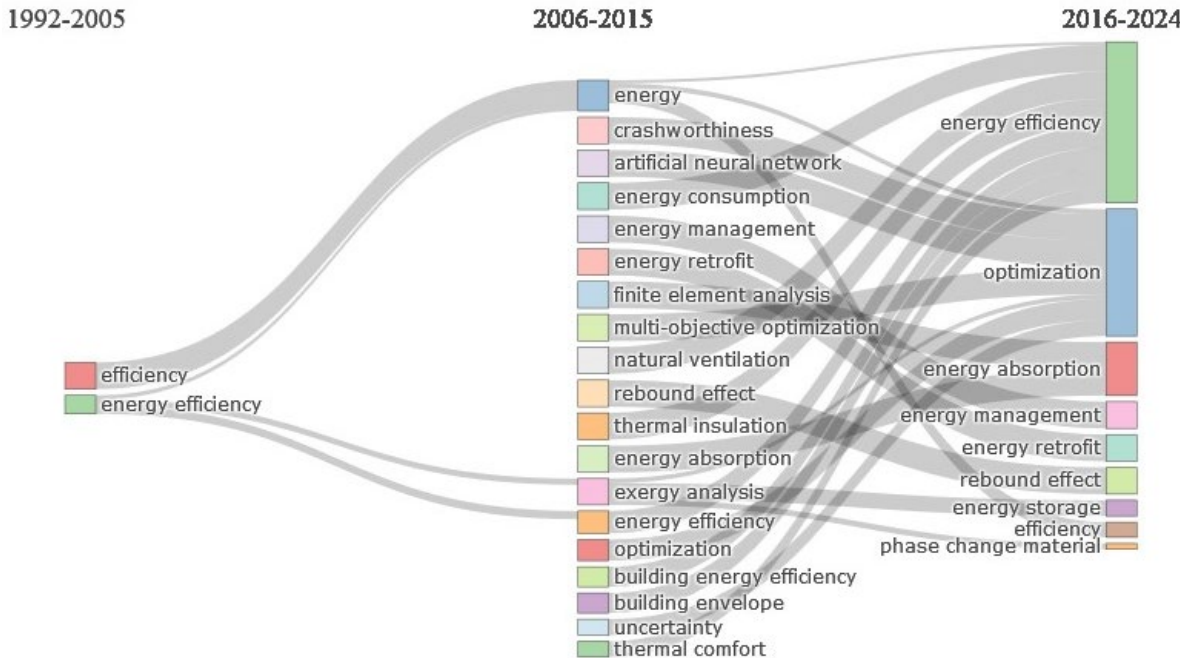

Figure 12. Thematic development of author keywords

3.1. Countries' Energy Efficiency Trends

In this study, trends in energy efficiency in Türkiye, Germany, and Iran were analyzed using author keywords and thematic developments in academic studies. Accordingly, the subject trends of the countries and topics on which the studies focused were determined. In this context, first, the articles of the countries were analyzed according to the sustainability principles in the WoS database. The sustainability goals targeted by countries in the relevant literature are shown in Figure 13. Among the top 10 goals with the most publications, the 13 Climate Action, 07 Affordable And Clean Energy, and 11 Sustainable Cities and Communities principles are among the top three. Accordingly, Germany targeted the 13 Climate Action principles (45%) the most, while Iran targeted seven Affordable and Clean Energy (24%) and 11 Sustainable Cities and Communities (34%).

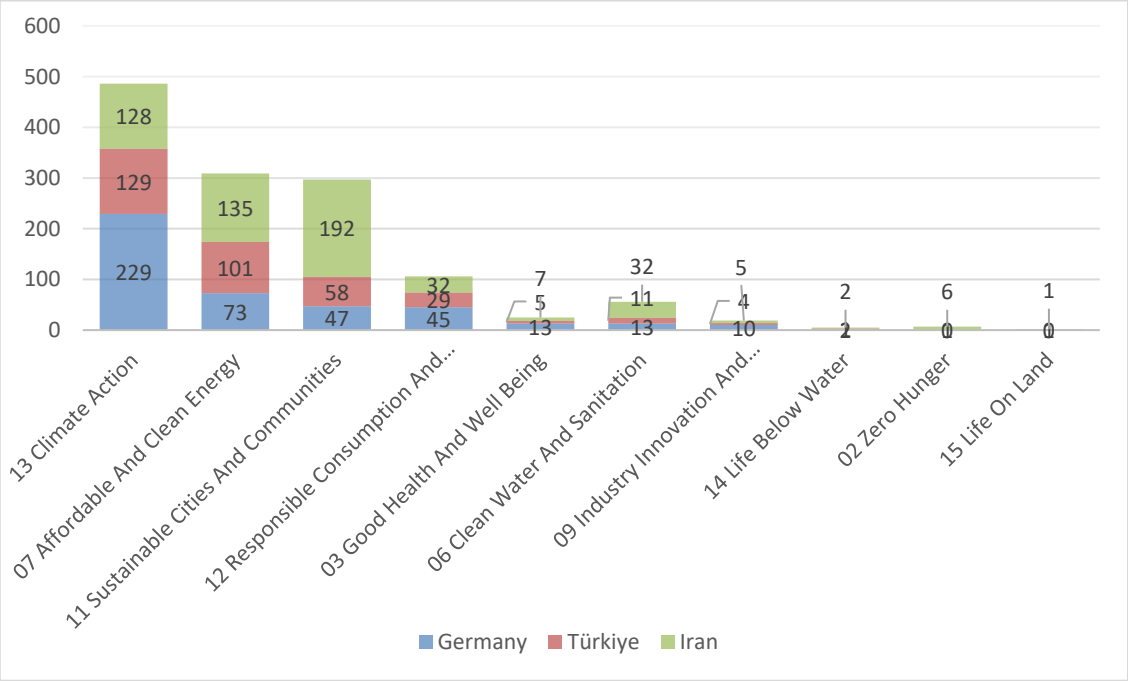

Figure 13. Number of publications of countries according to WoS sustainability targets

The keywords of articles are also an important detection tool for determining the tendency of countries to work on energy efficiency. In this context, among the most used keywords in the articles produced by countries, "energy efficiency" is the most commonly used word. Among these words, "thermal comfort," sustainability, "energy consumption," and "exergy" are among the keywords used by at least two countries (Table 12). When the exhaustibility of energy resources is considered, sustainability becomes an essential concept in these studies. In addition, studies carried out for energy efficiency and reducing energy consumption in buildings form the basis of

studies carried out under the title of thermal comfort in this context. The concept of a passive house in Germany shows that the country has given great importance to studies on this subject from the past to the present. In Iran, the concept of natural ventilation depends on the climate. Studies on the use of geothermal energy resources in Türkiye in terms of energy efficiency are noteworthy. Exergy studies can also be conducted in Iran and Türkiye.

Table 12. Author keywords of the countries

Germany		**Türkiye**		**Iran**	
energy efficiency	**88**	**energy efficiency**	**54**	optimization	43
thermal comfort	**15**	**exergy**	**28**	**energy efficiency**	**38**
building envelope	13	energy	26	energy absorption	27
sustainability	**11**	efficiency	24	energy dissipation	17
energy performance	9	exergy analysis	24	multi-objective optimization	15
monitoring	8	building	17	**sustainability**	**14**
residential buildings	8	geothermal energy	15	**thermal comfort**	**14**
resource efficiency	8	**sustainability**	**15**	**energy consumption**	**10**
energy consumption	**7**	buildings	13	**exergy**	**10**
passive house	7	energy analysis	12	genetic algorithm	10

4. CONCLUSION

This study analyzed the characteristics of academic research publications, institutional cooperation, research bases, and evolutionary trajectories of Türkiye, Germany, and Iran in the field of energy efficiency. The following results emerged regarding the tendencies of these countries, whose academic studies on energy efficiency were evaluated within a common analysis framework:

• In this study, data from articles published between 1990-2023 in the WoS database were accessed using the bibliometric method. Accordingly, since 2006, the number of published articles has increased, and issues related to energy, environment, and climate change have attracted more academic attention. Iran, Germany, and Türkiye produced 39%, 36%, and 24% of the articles, respectively.

• The journal Energy and Buildings published the most relevant publications on energy efficiency. This journal provides extensive coverage of this subject. However, many qualified journals published in this field also include publications in the relevant literature. The Energy and Buildings journal was the most cited journal in the reference list of publications. Technical reports are the most essential sources that articles use as references at a local scale.

• The author who contributed to the relevant literature by receiving the most citations within the scope of the subject was Marszal Aj. The author's article titled "Zero Energy Building - A Review of Definitions and Calculation Methodologies," published in the Energy and Buildings journal in 2011, was the most cited article on a global scale.

• Among the author keywords of the countries, energy efficiency stands out as a word that clearly expresses the main title of the subject from the 90s to the present. The words thermal comfort and sustainability were also the most used words within the scope of the research area. In this context, the thematic development of countries within the scope of the subject was evaluated, especially when the number of articles started to increase in 2006. The thematic development of author keywords was evaluated in three periods according to the Kyoto Protocol that entered into force in 2005 and the Paris Climate Change Agreement signed in 2016. Accordingly, while many keywords related to energy efficiency and energy emerged in 2006 and energy efficiency until 2016, energy efficiency has increased in importance since 2016, and energy conservation, energy management, and optimization have been the most frequently seen words. When the keywords of the countries were analyzed separately, common words emerged. However, the importance that Germany has placed on the concept of a passive house for years is also evident in the articles of its authors. In recent years, Germany has set goals to reduce dependency on exhaustible energy resources, making the passive household energy-efficiency relationship even more important.

• When we evaluate the articles published by countries separately within the sustainability goals, Germany has become the country that produced the most publications on climate change within the first ten goals. Iran has become the country that produced the most publications on "Affordable and Clean Energy" and "Sustainable Cities and Communities."

The concept of sustainability and the exhaustibility of energy resources has become a fundamental focus of energy efficiency studies. Reducing energy consumption in buildings and ensuring thermal comfort have emerged as key priorities in these studies. Country-specific approaches are shaped by geographical and climatic conditions, as well as the energy policies and technological infrastructures of each nation.

Energy efficiency and renewable energy sources will soon become more detailed and operational among climate-change mitigation strategies. As a result, this study will be a reference for researchers in this field by revealing the research trends of Türkiye, Germany, and Iran, evaluated within the scope of developed and developing countries, and can influence the formation of collaborations in the academic field. In addition, the results of the study can identify gaps in the

literature and create opportunities for new research projects and collaborations. For example, subtopics such as the relationship between renewable energy, energy storage, and conservation can be emphasized as areas that require further investigation. The study can also contribute to the development of energy efficiency applications on a global scale by encouraging information sharing and collaboration between developed and developing countries. The bibliometric study revealed the research trends, priorities, and strengths of countries in specific areas such as energy efficiency. These data can be an important guide in shaping and developing policies. The effects of bibliometric studies on energy efficiency in Germany, Türkiye, and Iran on policy development can be evaluated as follows: Countries can develop more effective energy efficiency policies in line with sustainable development goals in light of academic studies. Bibliometric data can help increase international partnerships by determining areas of cooperation in countries' energy policies (e.g., the Paris Climate Agreement). Thematic density in countries' energy efficiency studies indicates which areas need more investment. As a result, bibliometric studies provide a data-driven approach to shaping countries' energy efficiency policies, contributing to the transformation of research results into concrete applications.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Özlem Aydın: Conceptualization, Analysis; Writing- review & editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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