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Advancing SDGs with IoT: Enhancing thermal comfort and energy efficiency- A bibliometric study

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ABSTRACT

There is a large body of research on the Internet of Things (IoT) utilization to achieve Thermal comfort while maintaining Energy efficiency (IoT-TE). This research offers insights to promote the achievement of Sustainable Development Goal 7 (affordable and clean energy) and Sustainable Development Goal 11 (sustainable cities and communities). Based on the proposed hypothesis, IoT-TE research is highly relevant to SDG 7 and SDG 11. Therefore, this paper conducts a bibliometric analysis of publications that support SDGs in IoT-TE. 873 articles from the Scopus database up to December 2023 were analyzed with its significant trends. A substantial portion of the citations focused on research published within the past ten years, reaching a notable peak in 2018 with an estimated 15,000 citations. IoT-TE research predominantly supported target was 7.3 Target (double the improvement in energy efficiency). This is the first comprehensive bibliometric analysis of IoT-TE literature supporting SDGs. The identified research gaps will influence IoT-TE research future directions and encourage cooperative research efforts. Furthermore, the research themes showed that energy efficiency is the forefront keyword of the current bibliometric research about IoT-TE. This study will help decision-makers and practitioners interested in SDGs understand the latest advances in research and achieve sustainability.

1. Background

Given the current growing population and urban expansion, the built environment increases the needs of energy and resources in order to meet people's demands. Questions about the energy crisis and climate change have largely focused on excessive energy use and waste production, particularly in buildings [1]. Given the growing need to ensure occupant thermal comfort, the operational phase of buildings accounts for a high portion of total energy consumption in most countries [2]. Reducing building energy consumption while preserving indoor thermal comfort forms a typical optimization problem and requires a perceptive system design to be solved [3], which is introduced by the Industry 5.0 revolution. The International Energy Agency (IEA) indicates that the first step toward a data-driven strategy is digitalization, which makes energy efficiency more valuable than it was in the past [4].

Recent digital innovations, especially the Internet of Things (IoT), have the potential to significantly improve user comfort and energy services in buildings by using smart energy management devices [5]. It can also improve how responsive the energy consumed is in relation to user behavior and comfort. IoT, which was originated in 1985 by Peter T. Lewis, is an advanced technology that allows these systems to offer cutting-edge security solutions, remotely control appliances, and monitor occupant behavior to increase efficiency and user comfort [6]. By utilizing conventional information and communication technology (ICT), The building's systems may become more interconnected because of the Internet of Things (IoT) paradigm [7]. The integration of IoT devices into the building's system goes beyond the idea of building digitalization to seamlessly transfer information about the building and the needs of its users.

The ambitious global targets of the Sustainable Development Goals (SDGs) include improving planning, management, mitigation, and adaptation to climate change, as well as expanding access to energy [8]. SDG 7, which focuses on affordable and clean energy, has several related indicators. SDG 7 intends to develop universal access to reliable, affordable, and modern energy services. The ambition of SDG 7 is to double the global improvement in energy efficiency by 2030. Also, its goal is to provide modern and sustainable energy services to everyone in developing countries by upgrading technology and building new

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infrastructure. SDG 11 encourages reducing cities environmental impact by developing inclusive and sustainable urbanization to integrate sustainable human settlement management in all countries [9].

In order to make the 2030 Agenda of the SDGs, it is important to examine the improvement of energy use technologies by utilizing IoT and its contributions to SDG 7 and SDG 11. As IoT has the potential to ensure buildings energy management, it contributes to SDG 7 and its associated targets, particularly Targets 7.1 (universal access to modern energy), 7.3 (double the improvement in energy efficiency), and 7.5 (expand and upgrade energy services for developing countries). In addition, as highlighted by Sustainable Development Goal 11, smart urban planning is crucial to building resilient, safe, and affordable cities with green and culturally inspiring environments. The use of IoT towards more sustainable cities could be integrated within Targets 11.1 (safe and affordable housing), 11.3 (inclusive and sustainable urbanization), 11.6 (reduce the environmental impact of cities), and 11.9 (implement policies for inclusion, resource efficiency, and disaster risk reduction). Assessing IoT-TE existing literature and the relevant SDGs offers clear directions to stakeholders for further research to employ smart devices to enhance the responsiveness to energy consumption in relation to user behavior and comfort, and to guarantee buildings' energy efficiency and thermal comfort (Fig. 1).

To date, no comprehensive research has been done to assess how IoT research relates to SDG 7 and SDG 11 in terms of Thermal Comfort and Energy Efficiency. This study assessed IoT-TE research related to SDG 7 and SDG 11 and its related targets using bibliometric and text-mining techniques. This comprehensive study aimed to analyze topic's future directions and trends, which includes top prolific authors, journals, countries, and institutions, as well as the number of publications and citations. This process identifies the gaps that should be covered by additional research that could help achieve SDGs 7 and 11 and advance knowledge of the use of IoT to ensure thermal comfort and energy efficiency.

2. Methodology

2.1. Design

The Bibliometric analysis method was used in this study to recognize the existing scientific of the IoT-TE literature related to SDG 7 and SDG 11. Text-mining approach brought an advanced quantitative and qualitative analysis of top publishing journals, countries, and authors, the research trends, and thematic hotspots. Results were assessed based on a previously followed methodology in several published bibliometric research works [10–13].

2.2. Data collection and search strategy

Scopus platform was used to extract the bibliographic database on December 4, 2023. Scopus platform provides a comprehensive database

Fig. 1. Sustainable Development Goals (SDGs).

of 5000 international journals with over 25,100 publications in different research subjects and more [14]. The Scopus platform was used due to cover extensive literature and integrating multiple databases that challenge the bibliometric process. The Scopus database was selected over other databases due to its user-friendly interface and extensive coverage of relevant literature; for instance, Google Scholar covered only 109 research articles related to the topic. Additionally, Scopus offers significant indexing advantages, particularly for engineering and sustainability journals, ensuring the inclusion of high-quality, peer-reviewed publications that are essential for conducting rigorous academic research in these fields.

The search query template *(TITLE-ABS-KEY)* embedded within the Scopus database was used to search for titles, abstracts, and keywords of publications related to the topic. Publications related to the topic was filtered using a list of relevant filtering terms. An initial list of 1292 publications was proposed for the bibliometric analysis using the terms "Internet of things or IoT" and combined it with the keywords "Buildings or houses". To specify the research, we added the terms "Thermal comfort" and "Energy efficiency" to the search query.

To address certain discrepancies and modify the list of terms exclusively associated with SDG 7 and SDG 11 and their targets, a specific search query was conducted on these targets, see Fig. 2. Some Targets of SDG 7 were excluded from the search query because of the irrelevant publications to the subject but extracted because of referring to "Buildings" keyword (such as Target 7.2 and 7.4). Moreover, part of SDG 11 targets needed more specific search queries; for example, numerous publications that belonged to Target 11.5 were included in Target 11.6 due to insignificant indexed terms. Furthermore, Target 11.9 included the general meaning of resource efficiency. As a result, a more focused search was carried out for publications on energy efficiency in relation to IoT technology. SDG 7.2 and 7.4 are considered irrelevant to IoT research as the study does not engage directly with renewable energy generation or international cooperation in clean energy technologies. Moreover, SDG 11 targets may be irrelevant to IoT research as the study does not address issues like accessible transport (11.2), cultural heritage preservation (11.4), disaster risk reduction (11.5), inclusive public spaces (11.7), policy implementation (11.8), or urban-rural planning (11.A), which fall outside the typical technical scope of IoT systems. To limit the research fields to publications related to IoT-TE, the irrelevant research areas have been excluded, in particular, Decision Sciences, Physics and Astronomy, Social Sciences, Chemistry, Molecular Biology, Biochemistry, Medicine, Genetics, Earth and Planetary Sciences, and other similar fields. The time frame is not restricted, and the search returned 873 publications. All search queries used are illustrated in Table 1 in the N files.

2.3. Data management and statistical analysis

Using the Bibliometrix package in R program (Biblioshiny software version 4.1) [15], an open-source software that combines multiple analysis techniques, a quantitative analysis was conducted. The obtained data was transformed by Biblioshiny into a bibliometric file to be analyzed, and Microsoft Excel 2019 software was used to create charts. Parameters included document type, number of publications and citations, the dominant language, the top cited publications, yearly output, and the top prolific journals, authors, countries, and institutions were analyzed. Standard Competition Ranking (SCR) was used to rank the measurements, which is employed in other bibliometric publications. The SCImago Journal Rank (SJR) was utilized to evaluate published journals. Using SciVal, a feature for in-depth analysis provided by Scopus, the top keywords in the publications of the most prolific authors were found to reveal the covered topics.

The VOSviewer 1.6.19 software was used to perform Text mining analysis [16], which is used to examine various bibliometric parameters and then display the findings in cluster visualizations. The software was also employed to analyze co-occurrence networks of authors' keywords.

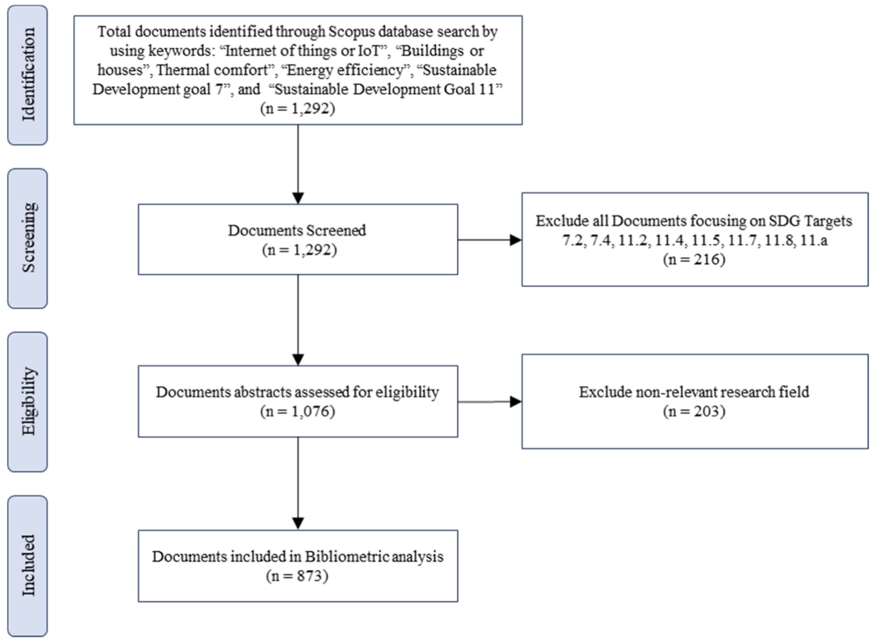

Fig. 2. PRISMA flow chart for bibliometric analysis and scoping review of IoT-TE literature.

Table 1
Top 3 prolific institutions in terms of publication on IoT-TE research for each SDG Target.

SDG Target	SCR	Affiliation	Articles
7.1 Universal Access To Modern Energy	1	International University Of Rabat	15
	2	National Chung Hsing University	10
	3	Riga Technical University	9
7.3 Double The Improvement In Energy Efficiency	1	International University Of Rabat	19
	1	National University Of Singapore	19
	2	Qatar University	18
7.5 Expand And Upgrade Energy Services For Developing Countries	1	International University Of Rabat	14
	2	National Chung Hsing University	10
	3	Riga Technical University	9
11.1 Safe And Affordable Housing	1	Chung-Ang University	10
	2	Riga Technical University	9
	3	Linnaeus University	8
11.3 Inclusive And Sustainable Urbanization	1	Chung-Ang University	10
	2	Linnaeus University	8
	3	Aurel Vlaicu University Of Arad	7
11.6 Reduce The Environmental Impact Of Cities	1	Construction Technologies Institute	10
	1	National Chung Hsing University	10
	2	Politecnico Di Torino	9
11.9 Implement Policies For Inclusion, Resource Efficiency And Disaster Risk Reduction	1	University Of Pisa	9
	2	Waseda University	8
	3	The Hong Kong Polytechnic University	7

A map of thematic hotspots of IoT-TE research was created using the top 250 index words (with >10 occurrences) as the analysis unit; however, selective filtering resulted in the inclusion of 235 index words in the final map. Index terms that are not thematic or generic were removed (e.g., office buildings, commercial buildings, artificial intelligence, machine learning, and others). The distance between the index words in the final map showed the degree of co-occurrence in the same publications. VOSviewer was used to create color-coded clusters of every map. Lastly, using the extracted information, world map charts of countries' scientific publications were made using a web-based mapping application called Datawrapper [17]. A flowchart of the overall analysis steps is shown in Fig. 3.

3. Results

3.1. *Publications and citations yearly output, document type, and publications' dominant language*

Publication and citation trends are illustrated in Fig. 4. IoT-TE's first publication was discovered in the Scopus database in 2007, and the publication years covered were 2007 to 2023. The majority (76.3 %, $n =$ 654) of publications were between 2017 and 2022, where the peak was noticed in 2022. Furthermore, scientific attention to the citations of these publications was first in 2018, but most citations related to publications were from 2016 to 2021. Additionally, Fig. 5 presents the overall bibliometric characteristics of the extracted publications, such as the publications and citations number, authors number, and the top 3 prolific journals. It also includes the dominant language, document types, research fields, and publications' thematic hotspots. The annual growth rate of the publications was 9.93 %, and 39 % of the IoT-TE publications found on the publication search date were published in open-access journals.

Using Scopus search query, 873 publications on IoT-TE that support SDG 7 and SDG 11 were extracted. These articles addressed a range of IoT-TE research and SDG 7 or SDG 11 targets-related subjects. As shown in Fig. 6 (bar chart), The IoT-TE research publication contributing to SDG 7 and SDG 11 is greater than the overall publications that contribute to other SDGs by around four times. Pie Chart of the same figure shows the majority of articles (33 %) focused on target 7.3, which is to double the improvement in energy efficiency with 288 publications. These studies included discussions of how to use IoT to enhance energy efficiency. IoT technology impact in ensuring access to modern energy services was the subject of Target 7.1 (universal access to modern energy), which attracted attention and was addressed by 132publications

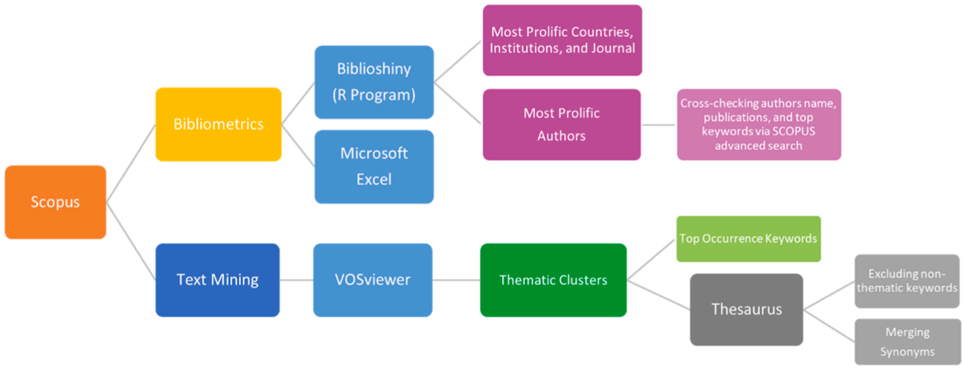

Fig. 3. Flowchart of the analysis steps.

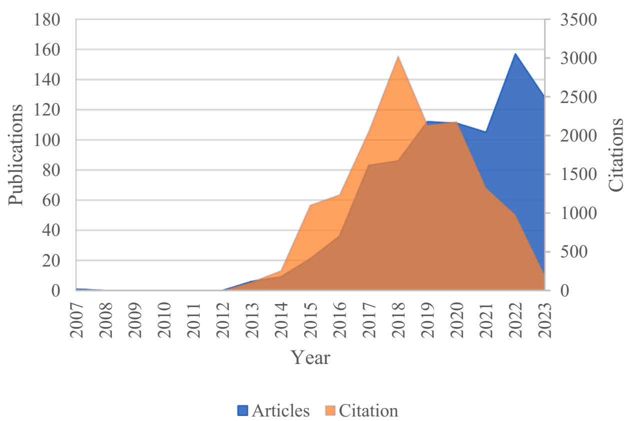

Fig. 4. Publication and Citation trends of IoT-TE supporting SDG 7 and SDG 11.

with Target 7.5 (Expand and upgrade energy services in all countries).

Target 11.3 (inclusive and sustainable urbanization) was the next, with 105 publications, followed by Target 11.6 and Target 11.1 (87 and 86 publications, respectively). Finally, target 11.9 (implement policies for inclusion, resource efficiency, and disaster risk reduction), which concentrated on expanding the number of cities implementing and adopting policies related to energy, received relatively little attention and was only addressed by 5 % of publications (only 43 publications).

3.2. Countries, institutions, sources, authors, and top-cited articles

IoT-TE research has increased over the last 10 years from 6 publications in 2013 to an average of 143 publications for 2022/2023. As shown in Fig. 7, the topic of the study has been thoroughly investigated worldwide, with publications coming from 78 nations. The USA and India are the most scientifically productive countries (122 and 110 publications, respectively). China followed this with 88 publications, Italy with 76 publications, and Spain and the UK with 55 publications each. The maps in Fig. 8 compare the global IoT-TE research contributions to the global accomplishments of SDG 7 (Map A) and SDG 11 (Map B). Map A shows that SDG 7 has been achieved in a few countries (Brazil, Costa Rica, Denmark, Iceland, Austria, Norway, Finland, and Sweden), and it remains a major challenge worldwide. However, Map B indicates that till now no one has achieved the SDG 11 Targets, and it remains a significant challenge worldwide [18]. According to correlation analysis, there were no significant relationships between countries' accomplishment of SDG 7 or SDG 11 and its IoT-TE publications. However, according to data from HG Insights [19], the United States hosts over 4.2 million companies projected to invest approximately $25 billion in Internet of Things (IoT) technologies, representing 33.4 % of the global IoT market share. This significant investment aligns with the country's leading position in IoT-TE publications. Following the United States, China, Japan, and the United Kingdom are identified as the next largest markets, accounting for 14 %, 7 %, and 5 % of global IoT expenditures, respectively; which also exhibit significant research activity in the IoT domain, indicating a correlation between national investment levels and scholarly publication volumes.

Fig. 9 shows four clusters representing international co-authorship networks illustrating the impact of geographic proximity on authors' collaboration. The study is based on the frequency of co-authorship among IoT-TE researchers, expressed as the affiliated countries of each author. The same-colored countries are part of the same collaboration cluster, which is indicative of the authors of the same publications from these nations frequently collaborating.

In Map A (Fig. 9), the Blue cluster comprised of East Asia countries, along with Australia. This cluster includes China, Japan, Taiwan, and India. Similarly, with the yellow cluster (Pakistan, South Korea, and Malaysia), these countries are strongly linked with the US, the highest IoT-TE publications country. The Green cluster contained regionally close countries in Europe, including Spain, France, Greece, and Austria. These countries have a strong link with red cluster-affiliated countries; Finland, Portugal, Sweden, Russia, and Denmark. Canada and Saudi Arabia are also related to this cluster. These two clusters are also linked with Italy and Romania cluster (purple cluster).

USA and India affiliated authors, which have the highest number of publications, are strongly connected with China and Australia affiliated authors. The figure displayed the highest international co-authorships with nearly all 30 countries. Authors who are Morocco-affiliated seemed to have the highest co-authorship rates when compared to authors who are affiliated with Europe, which is represented by the strong ties between these countries.

The average publication years for the countries mentioned above are visually superimposed on Map B, which primarily fell between 2018 and 2022 as determined by VOSviewer software. The publications from Saudi Arabia, India, China, Denmark, Sweden, and Malaysia were rather recent when compared to publications from Finland, Sweden, and Japan. The average citation number per publication is overlayed on Map C. The countries with the highest average number of citations per publication were Finland, Austria, Canada, Sweden, and the US; Kuwait had the highest average number of 100 citations per publication. The majority of other nations had an average of 60–80 citations per publication.

Furthermore, Map D displays the normalized data, which were corrected by using VOSviewer to account for the longer period between older documents related to their citation. The countries with the most normalized citations per publication were Canada, Singapore, Finland, Pakistan, and Denmark, with Canada and Singapore leading the pack with about 3.2 citations per publication per year.

In terms of the most prolific institutions of IoT-TE among the selected SDG 7 and SDG 11 Targets (shown in Table 1 and ranked via SCR), many targets consistently supported a certain topic by particular institutions.

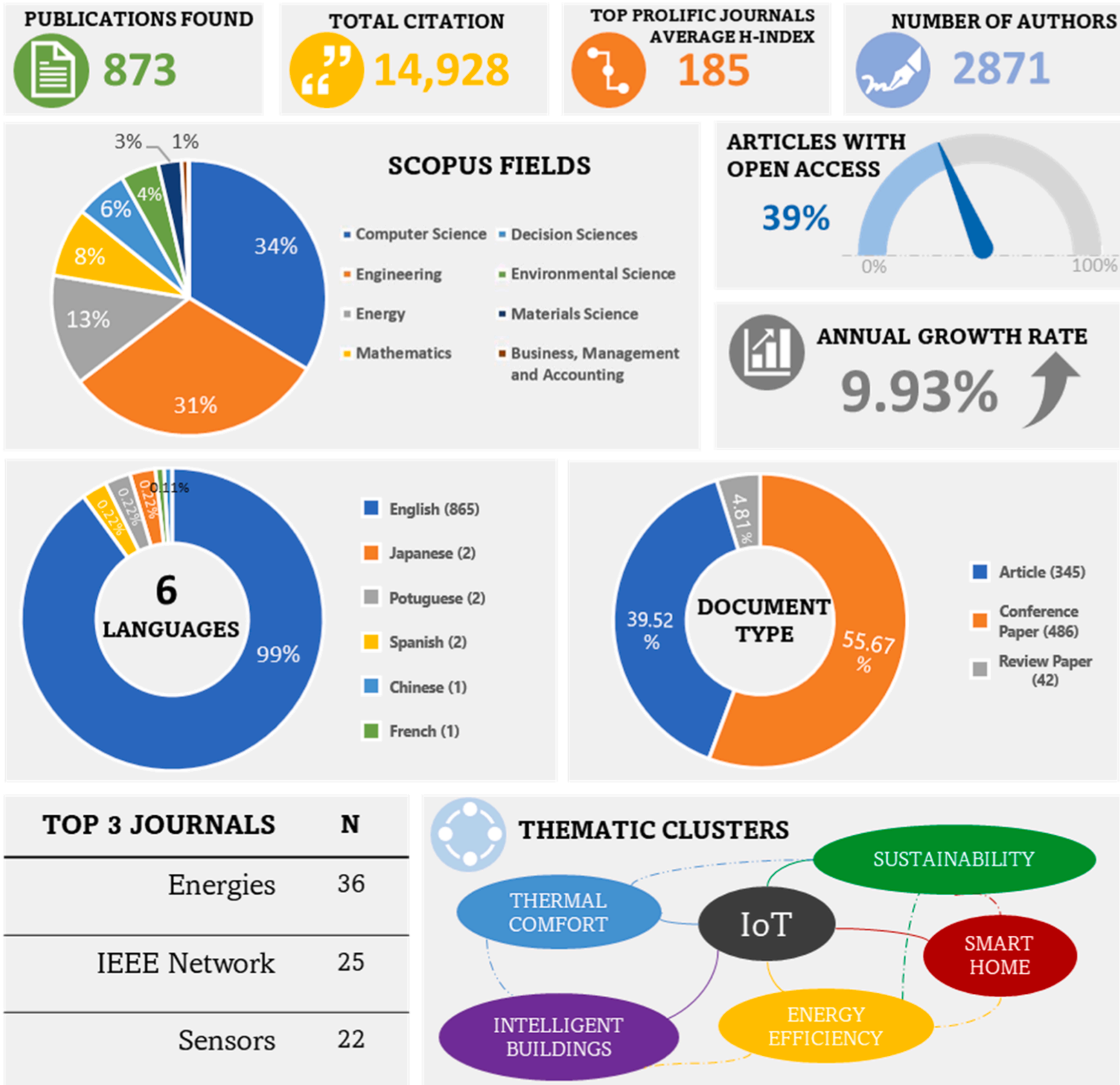

Fig. 5. General bibliometric characteristics of the publications.

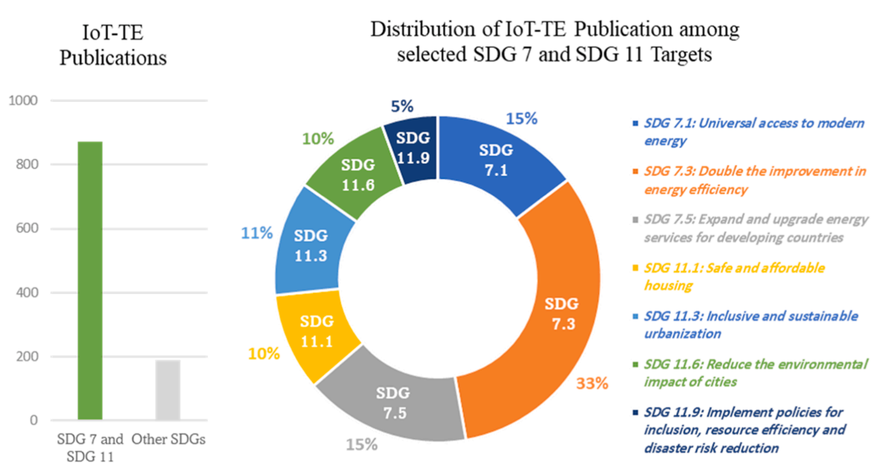

Fig. 6. The bar chart shows the distribution of IoT-TE literature among SDG 7 and SDG 11 targets relative to other SDGs. The Pie Chart displays the percentage across selected SDG 7 and SDG 11 targets that are related to IoT-TE publications.

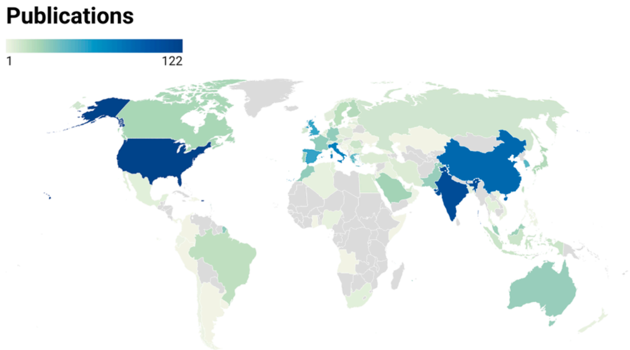

Fig. 7. Comparative color-coded world map of countries' scientific production of publications related to the topic.

For example, the International University of Rabat in Morocco and the National University Of Singapore in Singapore were the top Producers of IoT-TE publications addressing Target 7.3 (Double The Improvement In Energy Efficiency). In Addition, Riga Technical University and National Chung Hsing University show interest in both SDG 7 and SDG 11 Targets. However, the International University Of Rabat publishes research on all SDG 7 Targets.

Table 2 lists the details of the top 3 journals that published IoT-TE research from 2007 to 2023 by each target, with their article number, citations, citation/article ratio (C/A), SJR (SCImago Journal Rank), and h-Index. The top five journals for publishing IoT research were Energies, IEEE Network, sensors, and ACM International Conference. Sensors and Energies Journals appeared to frequently publish research in most of the targets. However, on a citation basis, IEEE Internet of Things Journal was in the lead (1327 citations). Moreover, IoT-TE research supporting Target 7.3 received the most citations. Target 7.1 (Universal Access To Modern Energy) had the next highest citation, which is verified by the number of publications. Also, Target 11.9 gets the least citations (only 125 citations). In terms of the most cited publications (shown in Table 3 with the journal, author, and document type), Energies was found as the top publishing journals, and a study conducted by Hossein Motlagh et al. [20] that focused on the adoption of IoT in the energy sector was the top cited article.

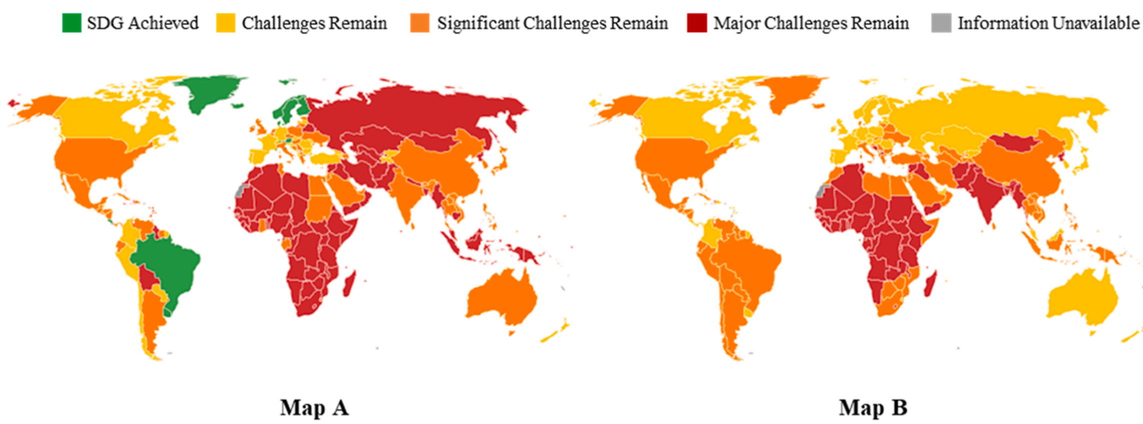

Fig. 8. Worldwide maps achievement of SDG7 (Map A) and SDG 11 (Map B).

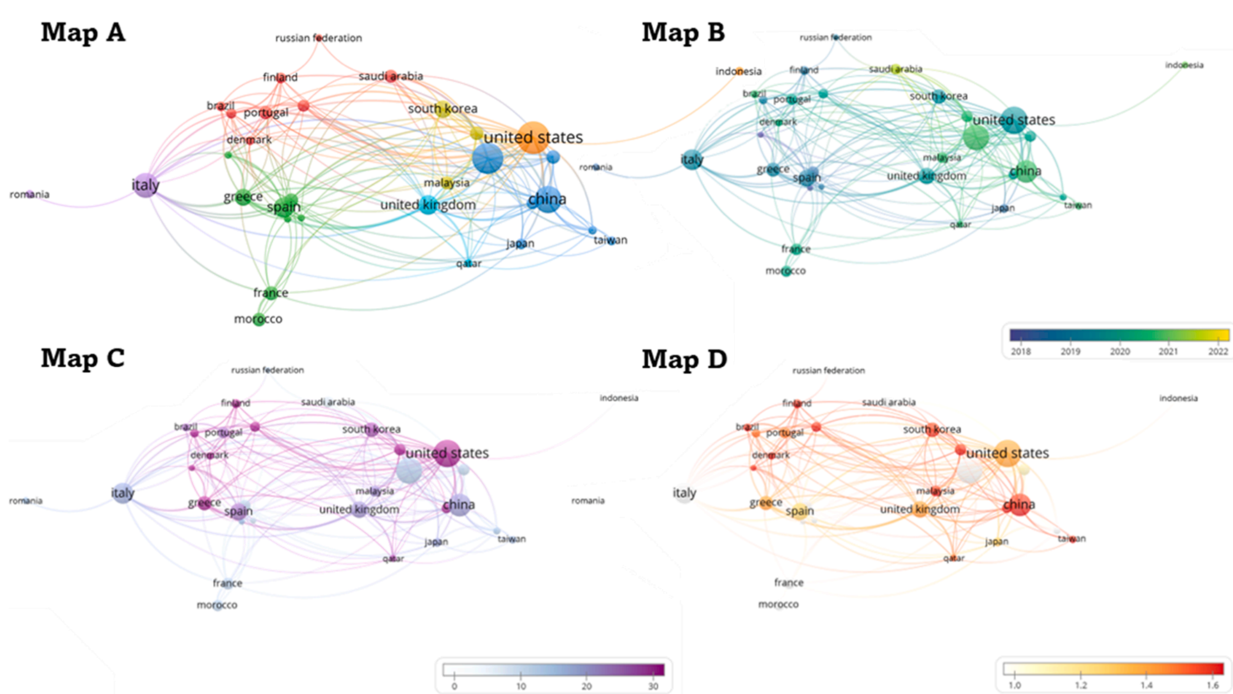

Fig. 9. Co-authorship network of 30 affiliated countries.

Table 2
Top 3 Journals in terms of published research related to IoT-TE for each SDG Target.

SDG Target	SCR	Journals	Articles		Citation	C/A[b]	SJR[c]	H-Index
			N	%				
7.1 Universal Access To Modern Energy	1	Energies	15	7.04	735	49	0.632	132
	2	IEEE Network	9	4.23	216	24	0.926	204
	3	Sensors	7	3.29	152	21.71	0.764	219
7.3 Double The Improvement In Energy Efficiency	1	Energies	39	4.55	1066	27.33	0.632	132
	2	IEEE Network	35	4.08	984	28.11	0.926	204
	3	Sensors	33	3.85	1562	47.33	0.764	219
7.5 Expand And Upgrade Energy Services For Developing Countries	1	Energies	9	7.63	734	81.56	0.632	132
	2	Applied Sciences	4	3.39	55	13.75	0.492	101
	2	Energy and Buildings	4	3.39	107	14.86	1.608	214
11.1 Safe And Affordable Housing	1	Sensors	12	5.97	546	233.5	0.764	219
	2	Advances In Intelligent Systems And Computing	9	4.48	384	42.67	0.184	58
	3	IEEE Network	7	3.48	105	15	0.926	204
11.3 Inclusive And Sustainable Urbanization	1	Sensors	10	7.19	506	50.6	0.764	219
	2	Advances In Intelligent Systems And Computing	6	4.32	68	11.33	0.184	58
	2	IEEE Network	6	4.32	226	37.67	0.926	204
11.6 Reduce The Environmental Impact Of Cities	1	Energies	9	6.47	116	12.89	0.632	132
	2	Sensors	4	2.88	175	43.75	0.764	219
	3	Advances In Intelligent Systems And Computing	3	2.16	56	18.67	0.184	58
11.9 Implement Policies For Inclusion, Resource Efficiency And Disaster Risk Reduction	1	Energies	4	5.97	27	6.75	0.632	132
	1	Sustainability	4	5.97	42	10.5	0.664	136
	2	Advances In Intelligent Systems And Computing	3	4.48	56	18.67	0.184	58

Finally, Table 4 lists the top 3 authors (by SCR) who have published the most about IoT-TE for each target, with their citations and countries of affiliation. Similar to the publishing journals, particular authors were attracted by specific topics associated with SDG 7 and SDG 11 Targets. The most prolific authors for SDG 7 Targets were Bakhouya M with 22 publications and Marques G for SDG 11 with 15 publications. Overall, the only authors/organizations that produced IoT-TE publications were those involved in Target 11.3. Using the Scopus Database to examine the frequency of keywords in the publications, it was discovered that most of the prolific authors examined the Internet of Things in relation to Thermal Comfort or Energy Efficiency. The connections between the Internet of Things and Demand and Operation Management also catch the interest of fewer authors.

4. Research hotspots and categories

Fig. 10 presents the most frequently researched target research hotspots, which are recognized by clusters of the author's common keywords for IoT-TE publications supporting the SDG 7 and SDG 11 targets. The average publication year and average normalized citation average are also displayed visually beside these clusters. The rest targets' clusters are illustrated in the Supplementary files.

The most frequent research target found was Target 7.3 (double the improvement in energy efficiency). Common hotspots were overall intelligent buildings, automation, and energy utilization (Fig. 10A). Smaller thematic clusters were information management, energy conservation, and data handling. Several research papers have also addressed the concept of Energy Storage using IoT to improve efficiency. These articles all show that IoT devices could perform advanced tasks in energy storage [38–40].

IoT-TE publications focusing on this target were published in 2014–2020 (Fig. 10B), where energy management is the most recently published topic. Smart building, energy savings, and energy consumption were also recent research themes. Sustainability, Smart City, Optimization, and Demand Response keywords have the highest average normalized citations (1.4–1.6) for IoT-TE publications related to Target 7.3 (Fig. 10C).

IoT-TE publications related to Target 7.5 (expand and upgrade energy services for developing countries) had 4 definite thematic clusters (Supplementary Figure 2, Map A): Big Data (red cluster), Buildings (green cluster), automation (blue cluster), and Data handling (yellow cluster). The buildings-related clusters and automation clusters appeared to be recently published hotspots (Map B). However, specific keywords have the most average normalized citations, which are "demand side management," "big data," "energy management," and "energy storage" (Map C).

Research hotspots supporting Target 11.3 compromise inclusive and sustainable urbanism (Supplementary Figure 4, Map A). It includes Smart cities, energy management systems, and embedded systems in the context of IoT. Moreover, Urban growth was addressed in fewer publications, where IoT-generated data provides insights for urban planners regarding infrastructure development and energy services [41,42]. This Target publications had five clear thematic clusters: Demand response management using IoT technology, Building Automation, Building management system, and Energy storage.

The 130 publications that strictly covered modern energy services (Target 7.1) had three clear thematic hotspots: Renewable energy resources IoT technology access, IoT and energy efficiency, and Buildings. The main keywords for renewable energy resources were solar energy and smart power grids [43–46]. These thematic clusters are mainly published from 2017–2021. Renewable energy and Sustainable development have the highest average normalized citation rate (1.4–1.6).

Less research was focused on Targets 11.1, 11.6, and 11.9. The research Thematic clusters and thorough explanations are provided in Supplementary Figures 1, 2, and 3. Target 11.1 (safe and affordable housing) shared many similarities in IoT-TE research hotspots with many SDG Targets, particularly energy efficiency, energy management systems, and automation. IoT-TE publications relevant to Target 11.9 (Implement policies for inclusion, resource efficiency, and disaster risk reduction) showed three thematic hotspots: circular economy, quality control, and characteristics of indoor environment.

Target 11.6 (Reduce the environmental impact of cities) focused on the effects of utilizing IoT on the environment. The thematic cluster revealed that the global warming crisis, carbon footprint, indoor air pollution, and waste management are the most frequently studied topics. Collective research concentrates on the advantages of IoT utilizing for indoor environmental monitoring [47–49], where it indicates that IoT-based systems can be used to detect any changes in thermal

Table 3
Top 3 cited publications on related IoT-TE for each SDG Target.

SDG Target	SCR	Authors	Title	Citations	Journal	Document Type
7.1 Universal Access To Modern Energy	1	Hossein Motlagh et al. [20]	Internet of Things (IoT) and the Energy Sector.	368	Energies	Article
	2	Liu et al. [21]	Intelligent Edge Computing for IoT-Based Energy Management in Smart Cities.	357	IEEE Network	Magazine Article
	3	Pan et al. [22]	An internet of things framework for smart energy in buildings: designs, prototype, and experiments.	278	IEEE Network	Article
7.3 Double The Improvement In Energy Efficiency	1	Ejaz et al. [23]	Efficient Energy Management for the Internet of Things in Smart Cities.	357	IEEE Network	Magazine Article
	2	Nižetić et al. [24]	Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management.	257	Journal of cleaner production	Article
	3	Slabicki et al. [25]	Adaptive configuration of LoRa networks for dense IoT deployments.	216	IEEE Access	Conference paper
7.5 Expand And Upgrade Energy Services For Developing Countries	1	Mondejar et al. (2021)	Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet.	223	Science of The Total Environment Journal	Article
	2	Lizana et al. (2018)	Energy flexible building through smart demand-side management and latent heat storage.	95	Applied Energy	Article
	3	AlFaris et al. (2017)	Intelligent homes' technologies to optimize the energy performance for the net zero energy home.	86	Energy and Buildings	Article
11.1 Safe And Affordable Housing	1	Barcelo et al. [26]	IoT-Cloud Service Optimization in Next Generation Smart Environments.	142	IEEE Network	Article
	1	Sobin [27]	A survey on architecture, protocols and challenges in IoT.	142	Wireless Personal Communications	Article
	2	Marinakis & Doukas [28]	An advanced IoT-based system for intelligent energy management in buildings.	137	Sensors	Article
11.3 Inclusive And Sustainable Urbanization	1	González-Briones et al. [29]	Multi-agent systems applications in energy optimization problems: A state-of-the-art review.	98	Energies	Article
	2	Mahapatra et al. [30]	Energy management in smart cities based on internet of things: Peak demand reduction and energy savings.	94	Sensors	Article
	3	Gonzalez-Vidal et al. [31]	A methodology for energy multivariate time series forecasting in smart buildings based on feature selection.	89	Energy and Buildings Journal	Article
11.6 Reduce The Environmental Impact Of Cities	1	Saini et al. [32]	Indoor air quality monitoring systems based on internet of things: A systematic review.	84	International Journal Of Environmental Research And Public Health	Article
	2	Salamone et al. [33]	Design and development of a nearable wireless system to control indoor air quality and indoor lighting quality.	73	Sensors	Article
	3	Agostinelli et al. [34]	Cyber-physical systems improving building energy management: Digital twin and artificial intelligence.	68	Energies	Article
11.9 Implement Policies For Inclusion, Resource Efficiency And Disaster Risk Reduction	1	Al-Kuwari et al. [35]	Smart-home automation using IoT-based sensing and monitoring platform.	110	IEEE Network	Conference Paper
	2	Mataloto et al. [36]	LoBEMS—IoT for building and energy management systems.	55	Electronics	Article
	3	Teisserenc and Sepasgozar [37].	Adoption of blockchain technology through digital twins in the construction industry 4.0: A PESTELS approach.	53	Buildings	Article

comfort parameters (Temperature, Humidity, etc.) that could indicate a potential safety hazard or environmental issue and relevant to energy consumption.

IoT-TE publications supporting each SDG 7 and SDG 11 Targets researched topics and their frequency of coverage are summarized by the word clouds in Fig. 11. Each word cloud had around 30 author keywords. Keywords, such as Internet of Things, Energy Efficiency, and Energy Management, are the most published in all word clouds, which coincided with the thematic clusters illustrated in Fig. 10. The color intensity of each keyword reflects its frequency of occurrence, with darker shades indicating higher frequencies. Unexpected topics were found. For example, fewer publications related to Target 7.5 (expand and upgrade energy services for developing countries) also addressed Energy harvesting and scheduling. Moreover, Energy Storage and Digital Storage concepts were addressed by some publications relevant to all SDG 7 Targets and Target 11.3. There is a growing demand for effective and dependable energy storage solutions as the market for renewable energy sources expands. The incorporation of IoT technology into energy storage systems facilitates remote control, data analysis, and real-time monitoring, which creates an interest in comprehensive research about the topic. Most IoT-TE publications considered the frequency of the occurrence of Decision-making and Data Acquisition keywords. The

Table 4
Top 3 authors in terms of number of publications on published research related to IoT-TE for each SDG Target.

SDG Target	SCR	Authors	Articles		Citations	Countries of Affiliation	Top three key-phrases
			N	In Scopus			
7.1 Universal Access To Modern Energy	1	Bakhouya M	7	220	2390	Morocco	Air Conditioning; Building Controls; Thermal Comfort.
	2	Ouladsine R	5	59	661	Ireland	Smart Cities; Internet of Things; Big Data.
	3	Elmouatamid A	4	109	1845	Greece; Austria	Household Energy; Energy; Smart Meters; Smart Cities; Internet of Things; .Big Data.
7.3 Double The Improvement In Energy Efficiency	1	Bakhouya M	10	220	2390	Morocco	Air Conditioning; Building Controls; Thermal Comfort.
	1	Liu Y	10	46	2559	China; Singapore; Norway	Edge Computing; Federated Learning; Remote Internet of Things.
	2	Park S	9	96	1217	South Korea; USA	Smart Cities; Big Data; Internet of Things; Demand Side Management; Demand Response; Energy Conservation.
7.5 Expand And Upgrade Energy Services For Developing Countries	1	Bakhouya M	5	220	2390	Morocco	Air Conditioning; Building Controls; Thermal Comfort.
	2	Liu Y	3	46	2559	China; Singapore; Norway	Edge Computing; Federated Learning; Remote Internet of Things.
	2	Matsui K	3	42	363	Japan	Zero Energy Buildings; Air Conditioning; Demand Response; Zero Energy Buildings; Air Conditioning.
11.1 Safe And Affordable Housing	1	Marques G	4	188	2137	Portugal; Italy	Fog Computing; Network Protocol; Internet of Things; Air Quality Monitoring; Air Quality.
	2	Pitarma R	3	76	921	Portugal	Air Quality Monitoring; Air Quality.
	3	Argunan P	2	34	393	India	Smart Cities; Internet of Things; Big Data; Air Conditioning; Building Controls; Thermal Comfort.
11.3 Inclusive And Sustainable Urbanization	1	Argunan P	2	34	393	India	Smart Cities; Internet of Things; Big Data; Air Conditioning; Building Controls; Thermal Comfort.
	1	Jain M	2	17	47	USA, India	HVAC; Intelligent Buildings; Sensor; Air Conditioning; Building Controls; Thermal Comfort.
	1	Park S	2	96	1217	South Korea; USA	Smart Cities; Big Data; Internet of Things; Demand Side Management; Demand Response; Energy Conservation.
11.6 Reduce The Environmental Impact Of Cities	1	Marques G	5	188	2137	Portugal; Italy	Fog Computing; Network Protocol; Internet of Things; Air Quality Monitoring; Air Quality.
	2	Belussi L	3	46	738	Italy	Energy; Renovation; Thermal Comfort; Sensor; Smart Objects.
	3	Danza L	3	52	940	Italy	Energy; Refurbishment; Renovation; Sensor; Smart Objects; Thermal Comfort.
11.9 Implement Policies For Inclusion, Resource Efficiency And Disaster Risk Reduction	1	Marques G	5	188	2137	Portugal; Italy	Fog Computing; Network Protocol; Internet of Things; Air Quality Monitoring; Air Quality.
	2	Curado A	3	55	226	Portugal	Energy; Refurbishment; Renovation; Thermal Comfort; Sustainability; Green Buildings.
	3	Arnesano M	2	46	512	Italy	Air Conditioning; Building Controls; Thermal Comfort.

word clouds for all SDG 7 and SDG 11 related publications shared a majority of the author keywords with those for Target 7.3. Their comparatively high ranking is indicative of the fact that Target 7.3 (double the improvement in energy efficiency) was the focus of most IoT-TE publications.

5. Discussion

According to these research findings, it's shown that IoT-TE research has a potential contribution to support SDG 7 and SDG 11 related targets. IoT-TE research overwhelmingly supports Target 7.3 compared with the various SDG 7 and SDG 11 targets. Additionally, only this target received constant support from dedicated authors and institutions that published on IoT-TE. However, The IoT-TE research revealed distinct and well-defined thematic hotspots that align with the majority of SDG 7 and SDG 11 Targets.

IoT-TE publications supporting SDG 7 and SDG 11 productivity trends have increased steadily From 2007 to the present, with a notable peak in 2021–2022. This corresponds to the Industrial Revolution 4.0, which revolves around the idea of digitalization and encompasses digital transformation, automation, data analytics, connected devices, and the Internet of Things (IoT) and Artificial Intelligence (AI) technologies. Broadening the concepts of Industry 4.0 and Industry 5.0 revolution are a new and developing stage of industrialization in which robots and cutting-edge technologies collaborate to improve workplace procedures, combined with a stronger emphasis on sustainability, resilience, and a more human-centric approach. This is playing an increasingly important role towards smart indoor environmental control along with improving energy efficiency in buildings.

According to the contribution analysis and comparison of IoT-TE research to each SDG, it became clear that the amount of IoT-TE research pertaining to SDG 7 overwhelmingly exceeded the other SDGs, and next came SDG 11. However, IoT-TE research was surprisingly linked with other SDGs, such as SDG 12 (Responsible consumption and production) with 19 documents or SDG 13 (Climate action) with 85 documents. In order to address power consumption problems and promote sustainable practices in homes and businesses for a sustainable future, IoT is used to address the main issues facing contemporary societies to mitigate the effects of greenhouse gases and guarantee balanced economic growth [50]. It's also feasible to navigate urban day-ahead energy management while taking climate change into account by using IoT techniques. Developing an optimized equipment planning scheme that takes energy losses into account comprehensively has become a critical area of study in the IoT energy management

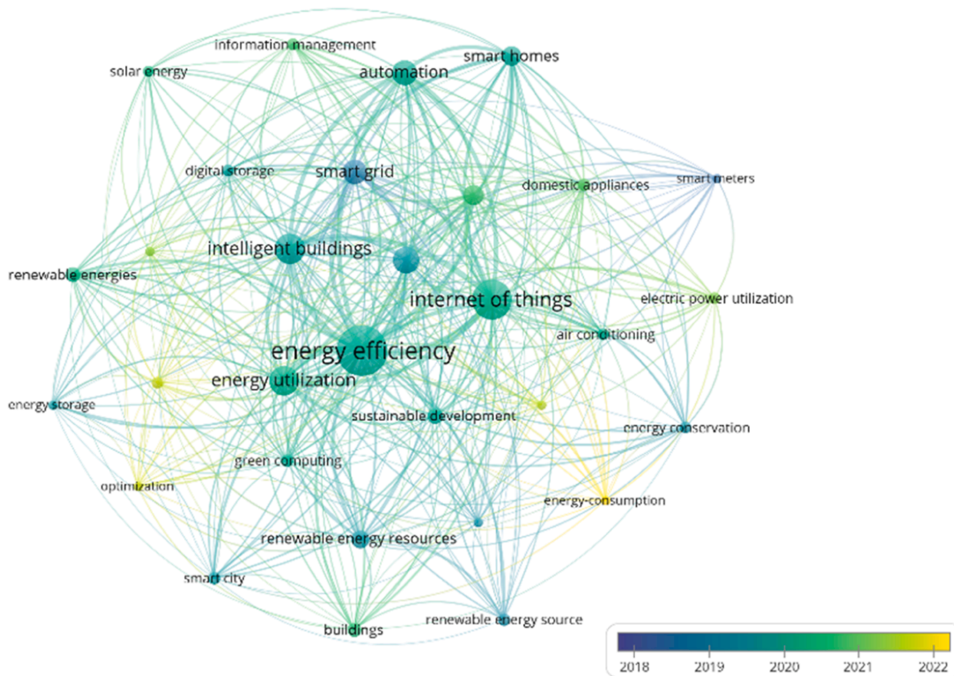

Fig. 10B. Average Publication Year of Research Themes (2018–2022): Visualization of the temporal trends in IoT-TE research.

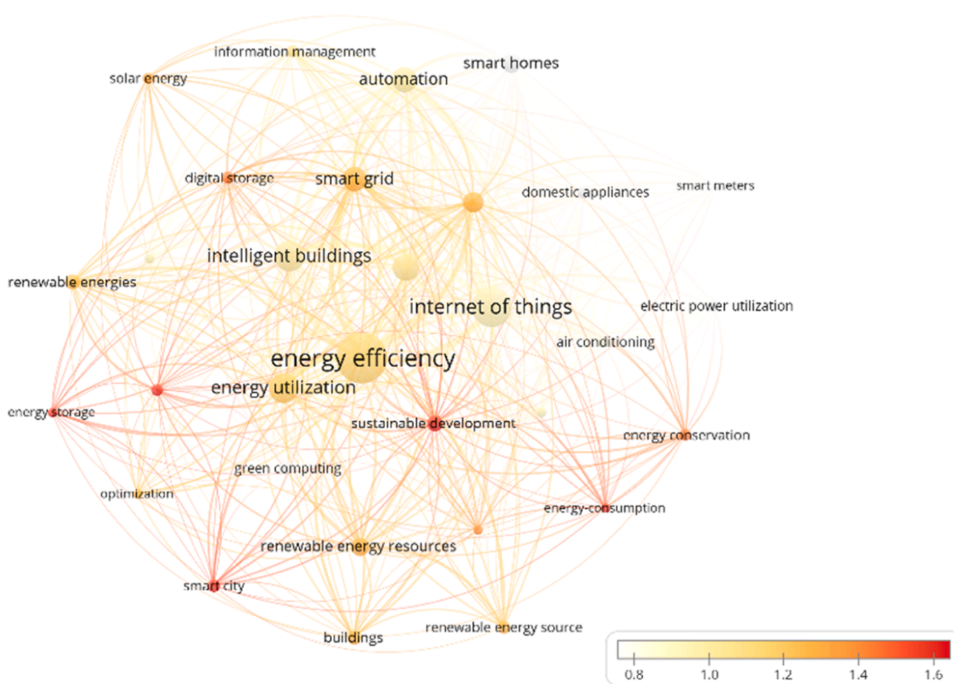

Fig. 10C. Average Normalized Citation Impact (0.8–1.6): Illustration of citation impact, with color coding indicating the average normalized citation score of different thematic clusters.

system. Equipment planning techniques drive the evolution of energy-efficient solutions and practices [51].

Results conclude that many authors, sources, and institutions have a constant interest in IoT-TE research addressing SDG 7 and SDG 11 generally. However, these were likely to involve the top prolific authors, institutions, and sources of IoT-TE research supporting Target 7.3 (double the improvement of energy efficiency), as this was the predominant target addressed (Fig. 6). This could be explained by the fact that the majority of IoT-TE research focuses on energy efficiency and energy management with the current population growth and urban expansions. Scholars have an interest in the built environment research regarding energy conservation strategies that are related to energy crisis and climate change issues [1].

The second most often supported target in IoT-TE publications was Target 7.1 (universal access to modern energy) and Target 7.5 (Expand and upgrade energy services for developing countries). Target 7.1 focuses on emerging renewable energy resources to achieve energy efficiency. The management and control of energy interactions throughout

Fig. 11. Word clouds for the top author keywords of all IoT-TE publications that discuss each target of SDG 11 and SDG 7 in general.

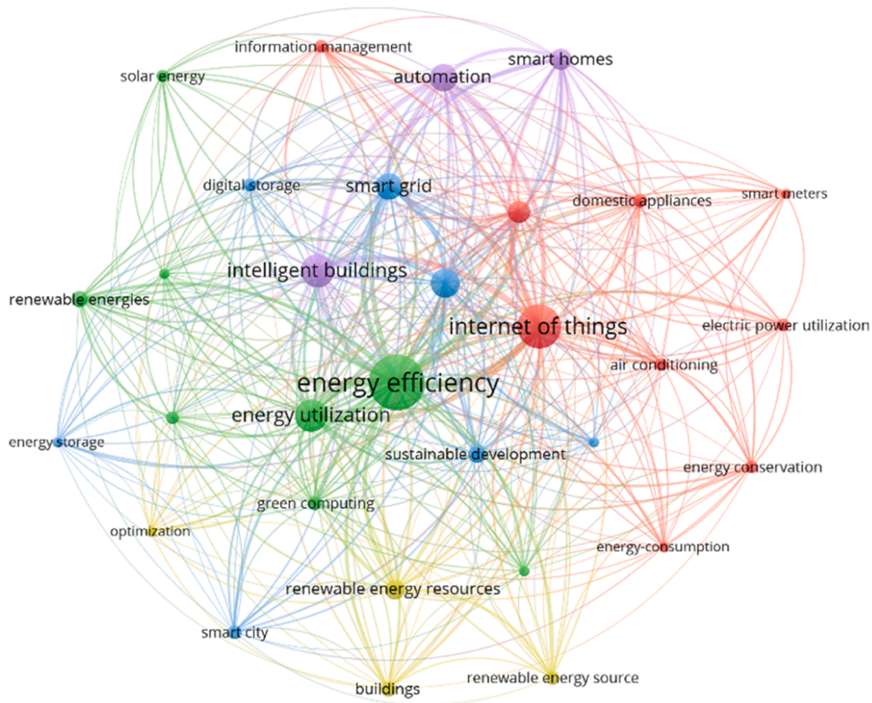

Fig. 10A. Thematic Clusters in IoT-TE Research: Circle size and links show frequency and connection strength; the same color indicates co-occurrence in publications.

the networked energy infrastructures of the future multi-energy grid could be addressed with practical solutions by the use of IoT technology [52]. Target 7.5 mentions that, in line with the individual support programs of other SDGs, by 2030, it aims to create and update technology and infrastructure and offer all developing countries cutting-edge sustainable energy services [9]. Both targets 7.1 and 7.5 were also the next most cited targets (Table 3), which matched the targets, which, following Target 7.1, represented the fields with the heaviest amount of research.

A relatively smaller number of IoT-TE publications addressed the other SDG 11 targets. All SDG 7 targets publications discussed energy management concepts in the context of IoT-TE because they focused on generally energy-related topics compared to other SDG 11 targets. The themes of the SDG 11 targets were more specialized and niche. Furthermore, a large number of publications may have been pertinent to multiple targets because the sum of the publications in Fig. 6 was greater than the number of extracted publications. Nonetheless, studies relevant to every target indicated a significant rise over the past few years (Fig. 4).

Target 11.1 (safe and affordable housing) highlights the goal of providing a respectable and comfortable living environment and assure good quality and economically affordable housing. Incorporating intelligent technologies, such as IoT, that seek to ensure sustainability as well as affordability by improving energy efficiency, reducing resource waste, and creating healthy living environments [53,54]. However, when introducing new technology, several factors should be taken into consideration, including employing appropriate data management, outlining helpful information exchanges and handling complicated human-building conflicts [55]

Target 11.3 (inlcusive and sustainable urbanisation) reflects the use of IoT in opening new opportunities within the urban paradigm. To address the exponential growth in population and urbanization, the Information Communication Technologies (ICT) and IoT integration within the city management can be broadly defined as an effort to exponentially improve the quality of people's life [56]. Similarly to Target 11.6, which focuses on implementing IoT to reduce cities' environmental impact, this approach expedites the process of transforming cities into conscious entities and mitigates a number of serious urbanism-related issues, including traffic jams, pollution of the environment, and limitation of natural resources. The effective and appropriate use of industrial resources for economic development and the use of information and technology for infrastructure communications is what defines a smart city. It aims to achieve social and environmental sustainability for city inhabitants [57].

The largest research cluster is related to Target 11.6 (reduce the environmental impact of cities) concerning the use of IoT to reduce cities environmental impact. Regardless of the benefits of IoT in preserving energy, IoT technologies can help cities overcome several challenges, including reducing pollution, traffic congestion, use of resources, ensuring public safety, improving the quality of life, maintaining the environment, and managing costs [58]. The architecture of the Internet of Things (IoT) permits sensors to gather environmental variables related data and also makes it easy to integrate with any other kind of sensors that are used to measure relevant parameters to the city environment. This will therefore help to enhance the decision-making process, from improving city planning to enhancing the life quality for the city inhabitants [59,60].

Target 11.9 (Implement policies for inclusion, resource efficiency, and disaster risk reduction) was the least supported by IoT-TE research. The concept of resource efficiency is reflected in the research clusters that support other targets. Considering disaster management, it's difficult to be analysed by IoT devices. Major contributing factors, like climate change and rapid urbanization, are increasing the frequency and intensity of disasters, making disaster risk management a complex and complicated field. However, according to AbdelAziz et al. [61], IoT has proven to be a potent tool in disaster management, where it enables real-time data collection and monitoring to allow early warnings, more precise predictions, and rapid response.

In addition, the COVID-19 pandemic and World Health Organization (WHO) terms were only referenced in IoT-TE research related to Target 11.6 and Target 11.9. No distinct clusters or themes on this topic attracted a high volume of publications or citations. Although IoT technologies played a vital role in mitigating the spread of COVID-19 and enhancing environmental monitoring [62,63], this significance was not reflected in the academic output; based on 658 articles that were published from 2019 to 2023, only 45 included COVID-related keywords (5 % of the total publications), highlighting a notable gap in the literature.

The researchers' geographic proximity appears to have an impact on their international collaborations, as evidenced by a few of the co-authorship clusters in Fig. 9. IoT-TE research was shared in the European region through the UK and is highly connected to the US and India (the highest interest in IoT-TE research. Authors in eastern Asia and Australia are also strongly linked to the IoT-TE research field. However, achieving SDGs worldwide affects publishing research on IoT-TE that supports related SDGs. For example, Authors from the US and India were especially linked to many authors with European affiliations, which is attributed to the selected SDGs achievements among these countries. Therefore, further IoT-TE research in many other countries may focus on specific SDG 7 and SDG 11 targets that cater to sustainability in energy efficiency and thermal comfort.

Thematic hotspot analysis offers a deeper insight into the explored fields in the research inquiry at different SDG 7 and SDG 11 targets. All hotspots were used to show how SDG 7 and SDG 11 targets are related to IoT-TE research and to highlight the unaddressed research gaps. Most of the selected targets have common research hotspots, such as energy efficiency, energy management, intelligent buildings, and sustainability. Given that the targets' themes were nearly identical, with only slight variations, this overlap was expected. For instance, Targets 7.1 and 7.3 focus on energy efficiency, but Target 7.1 added renewable energy resources to achieve energy efficiency.

Energy storage, which was an expanding research hotspot in Target 7.3 publications, is the contribution of the target achievement (double the energy efficiency). This hotspot was also spotted in Target 7.5 and Target 11.3 thematic hotspots. This remarks on the significant role of energy storage systems in providing long-term benefits through extended lifespan and recyclability [64]. Another pivotal role of energy storage systems is shaping the environmental impact and sustainability of our energy resources. Energy storage technology deployment is becoming more crucial as the need for clean and reliable energy grows in order to reduce greenhouse gas emissions, promote the integration of renewable energy sources, and maintain grid stability [65].

A review of the existing literature on IoT-TE SDG 7 and SDG 11 revealed a lack of studies focusing on the impact of emerging Artificial Intelligence (AI) technology with IoT-TE. Artificial intelligence (AI) methods examine gathered data, identify trends, and process actions according to those trends, while Internet of Things (IoT) technology promotes device connectivity and gathers intensive amounts of data related to the desired problem. The integration of AI techniques and IoT devices goes beyond the building digitalization concept to facilitate the seamless transfer of information about the building and its users' needs [1]. Many previous studies provide an intelligent IoT and AI-based control system for maintaining thermal comfort while achieving energy efficiency, and results show superior performance in bringing thermal comfort and energy saving [66–68].

Moreover, research focused on city development and innovation with the use of IoT-TE may advance other SDGs achievement through SDG synergies. For instance, improving energy efficiency using new technologies and renewable energy resources will increase the global manufacturing of new devices that look towards innovation and infrastructure development. This is promoted through SDG 9 targets and indicators (Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation) [69–71].

5.1. Challenges and barriers

When applying new technology, many challenges and barriers are faced to know if it is worth adopting or not. Challenges are categorized into four categories: financial and economic, technical, environmental, and policies and regulations. This categorization enables stakeholders to identify specific areas of concern, assess trade-offs, and develop targeted strategies to overcome barriers, thereby supporting informed decision-making regarding the implementation of IoT technologies.

5.1.1. Financial and economic challenges

Used query string: TITLE-ABS-KEY ((IoT OR "Internet of Things") AND TITLE-ABS-KEY(Buildings* OR Residential Building* OR Office Building* OR House*) OR TITLE-ABS-KEY("Thermal Comfort") OR TITLE-ABS-KEY("Energy Efficiency") AND TITLE-ABS-KEY (cost* OR finance* OR economic*).

Due to the research interest, it was found that IoT-embedded system is associated with several financial and economic issues. Capital expenses are high when integrating the IoT system into an existing building system. It includes the price of devices, connectivity costs, and the cost of infrastructure [72]. Additionally, IoT system requires regular maintenance and servicing to ensure its functionality [73,74]. In the IoT market, there's a lack of standard price because it depends on the functions needed when implementing the system. Because of this, building owners may find it challenging to compare the costs and benefits of various systems by looking for the best offer. It can be challenging to determine the payback period of IoT systems in certain situations because the more costs and savings that this system adds, the closer the payback estimate will be for IoT system investments [75].

5.1.2. Technical challenges

Used query string: TITLE-ABS-KEY ((IoT OR "Internet of Things") AND TITLE-ABS-KEY(Buildings* OR Residential Building* OR Office Building* OR House*) OR TITLE-ABS-KEY("Thermal Comfort") OR TITLE-ABS-KEY("Energy Efficiency") AND TITLE-ABS-KEY ("Technical*" OR "performance*").

Technical challenges regarding using IoT systems within a building may include data processes and analytics. Thermal comfort has several parameters, and the ability to link all the data gathered together and process it effectively is difficult while managing to achieve energy efficiency [1]. The more sophisticated network analytics is to monitor and manage device networks, the more difficult it is to implement this technology [76]. Integrating the IoT system with an existing building infrastructure is considered the most complex technical challenge. Software development requires a number of devices to be installed with 24-hour internet connection and electrical power usage [77]. Furthermore, Network security is an important component when embedding IoT solutions to ensure adequate security. Simply hacking a network device isn't very harmful compared to shutting down a whole power grid. Cyberattack targets without adequate network security could cost hundreds of thousands of dollars to fix and possibly irreversibly harm the network [78,79].

5.1.3. Environmental challenges

Used query string: TITLE-ABS-KEY ((IoT OR "Internet of Things") AND TITLE-ABS-KEY(Buildings* OR Residential Building* OR Office Building* OR House*) OR TITLE-ABS-KEY("Thermal Comfort") OR TITLE-ABS-KEY("Energy Efficiency") AND TITLE-ABS-KEY (Environment* OR emission*).

It is unknown how IoT technologies will affect the environment in the long run. It would require a significant amount of energy to support IoT devices production and operation. To guarantee the required energy for IoT devices production lines, a greater use of fossil technologies would result from the increased implementation of IoT technologies [80]. In the long run, the production of electronic equipment may lead to an imbalanced waste of scarce metals and resources in general, which could be a serious problem. Furthermore, only 20 % of electronic waste is currently recycled [81]. Considering the growing demands of the market, this raises in e-wastes doubts about the capacity of available resources to produce IoT products. The manufacturing of electronic devices has resulted in the use of water, different chemicals, and fossil fuels, all of which have influence on the environment.

5.1.4. Policies and regulations challenges

Used query string: TITLE-ABS-KEY ((IoT OR "Internet of Things") AND TITLE-ABS-KEY(Buildings* OR Residential Building* OR Office Building* OR House*) OR TITLE-ABS-KEY("Thermal Comfort") OR TITLE-ABS-KEY("Energy Efficiency") AND TITLE-ABS-KEY (Policy OR Policies OR Policymaker* OR regulation*).

IoT systems encounter a number of challenges with regard to policies and regulations. Implementation standards create a framework and guidelines for the use of IoT by various companies and stakeholders. In order to provide guidance, this policy establishes a governance structure that includes a legal framework, an advisory committee, and a governance committee to make decisions regarding the scope of IoT [82]. Ineffective governance, standards, and regulations have resulted in a steady decline in IoT network and device security and the emergence of a wide range of privacy problems. The absence of building regulations related to the use of IoT in buildings can make it challenging for building owners to weigh the benefits and drawbacks of the system to adhere to a standard set of guidelines. Building owners may find it difficult to obtain these resources and make long-term plans because the kinds and amounts of financial incentives and subsidies for IoT systems vary depending on the use functions and are subject to change over time [83]. Building owners find it challenging to excess energy to the power grid since some countries have a lack clear regulation governing the use of net metering for IoT systems. As a result, Installing IoT systems that comply with local standards and regulations can be difficult for building owners because they can differ greatly between related authorities [84].

6. Strength and limitations

This study was the first to thoroughly evaluate the bibliometric characteristics of IoT-TE scientific literature that supports SDG 7 and SDG 11 Targets. The quantitative productivity and research attention of IoT-TE publications were examined to support SDG 7 and SDG 11, along with their related targets. In addition, a list of the top prolific authors and sources of IoT-TE publications that touch on the main ideas of SDG 7 and SDG 11 was provided. Through qualitative analysis, we investigated the IoT-TE literature's thematic research clusters that support the SDG 7 and SDG 11 targets.

The analysis was extracted from the Scopus database. Out of six databases (Scopus, Web of Science (WoS), Microsoft Academic, Dimensions, Google Scholar, and OpenCitations), 57 % of citations are covered by Scopus [85]. Furthermore, a greater number of publications that WoS does not cover are covered by Scopus, including publications with a substantial number of citations and references [86]. Since there was no time limit on the publications that were extracted, our results are indicative of the temporal research trends of IoT-TE research in the previous two decades.

To improve data accuracy, the obtained database went through data cleaning, especially with regard to the authors publications and the existing literature thematic hotspots on IoT-TE relevant to SDG 7 and SDG 11. The absence of journals that were not included in the Scopus index limited the scope of this study. While the majority of authors choose to publish in international journals, some choose to do so because of institutional or national allegiance in emerging journals. This could have had an impact on how accurately we represented the IoT-TE literature that was available to support SDGs 7 and 11 as well as related targets. Thus, additional bibliometric analyses of IoT-TE literature should be considered by incorporating multiple databases.

7. Implications and research gaps

The analysis results of IoT-TE technology in relation to SDG 7 and SDG 11 have prominent implications on the research-related policies improvement that aid in SDG achievement. It highlights the significance of a well-organized and strong research agenda that addresses important gaps in knowledge and comprehension aligned with the SDGs. Several bibliometric reviews have explored the intersection of IoT and sustainability. Ur Rehman et al. [87] analyzed general IoT trends in smart cities, while Stan et al. [88] mapped IoT applications across the broader Sustainable Development Goals (SDGs).However, these studies tend to adopt a broad perspective and do not delve deeply into the thematic connections between IoT in the built environment and specific SDG targets. In contrast, this study offers a focused bibliometric analysis of IoT applications for thermal comfort and energy efficiency (IoT-TE), directly linking them to selected SDG targets. This targeted approach not only highlights an underexplored niche but also provides a more refined understanding of how IoT-TE contributes to sustainability transitions within urban infrastructures.

The implications of studying IoT-TE research taking into account SDG 7 and SDG 11 are twofold. First, this study provides more insight into how the building's energy management systems interact with the IoT architecture. Second, by focusing on nearly zero energy buildings, air quality monitoring, energy savings with thermal comfort, and other related topics, this information aids in the development and customization of IoT applications that support energy efficiency through smart building technologies and the pursuit of the SDGs. Prior to 2020, these were required, and the COVID-19 pandemic has increased the importance of this field of research and development. As a result, scalable and cost-effective solutions are needed to implement smart building technologies in various contexts.

In Addition, the most distinctive characteristics of the present and future eras are Artificial Intelligence (AI) and Machine Learning (ML) techniques. They can provide vital resources that could be used to investigate the connection between IoT applications and achieving thermal comfort while maintaining energy efficiency [89]. To identify patterns and trends of energy usage that would be difficult or impossible for human engineers to detect, extensive research and application of AI technology are required [90]. This will deepen our knowledge of the impact of the IoT on sustainability, process optimization, and waste reduction, and opens up enormous possibilities for resource conservation and energy optimization in a variety of industries. Moreover, to enhance the systematic understanding of these emerging technologies, it is essential to integrate AI with Digital Twin systems and Smart Infrastructure trends. This integration can be effectively explored through bibliometric analysis by examining publication frequency, co-keyword networks, and identifying underexplored research gaps. Such an approach allows for the mapping of knowledge structures, the tracking of technological convergence, and the recognition of evolving research priorities in the intersection of IoT and AI with the SDGs.

Future research could explore the integration of Artificial Intelligence (AI) with IoT systems to enhance predictive performance, particularly for real-time monitoring and adaptive control in thermal comfort and energy efficiency (IoT-TE) applications. AI can significantly improve forecasting accuracy for indoor environmental conditions and occupant behavior, enabling smarter, more responsive building operations. Additionally, future studies should investigate the role of IoT-TE in advancing SDG 11.9, which focuses on disaster resilience and risk reduction, by assessing how IoT-enabled environments can contribute to early warning systems, hazard detection, and post-disaster recovery. Cross-regional and multi-disciplinary comparative studies are also recommended to examine how contextual differences—such as climate, policy frameworks, and socio-economic conditions—influence the implementation and effectiveness of IoT-TE technologies, providing a more nuanced understanding of their global applicability.8. Conclusion

This study brought a thorough quantitative and qualitative summary of the scientific literature on the application of IoT to achieve thermal comfort and energy efficiency supporting SDG 7 and SDG 11. It identified the patterns in research publications and the most productive countries, journals, and authors according to their fields of interest. The trends and networks of collaboration between these authors and their respective countries were revealed by complementary text mining. Additionally, it determined the most researched IoT themes along with their citation frequency. The study findings are the following:

- This bibliometric analysis consists of 873 Publications that range from 2007 to 2023.
- Publications and citation trends of IoT-TE were revealed.
- Top 3 prolific authors, journals, countries, and institutions were reviewed per selected targets.
- Most IoT-TE publications focus on Target 7.3 (Double the improvement in Energy Efficiency).

Results demonstrated the rapid scientific growth of IoT utilization in the last 15 years. It also showed IoT-TE research is highly relevant to SDG 7 and SDG 11. As mentioned above, Target 7.3 (Double the improvement in Energy Efficiency) is the focus of most IoT-TE research, as indicated by the number of pertinent research publications and the scientific level addressed by specific authors, journals, and institutions. Consequently, our results will help researchers identify the IoT-TE research gaps relevant to the SDGs targets and can also influence future research directions and collaborations.

CRediT authorship contribution statement

Lama Alhaj Husein: Writing – original draft, Visualization, Validation. **Emad S. Mushtaha:** Writing – review & editing, Supervision. **Imad Alsyouf:** Writing – review & editing, Supervision. **Khaled Obaideen:** Software, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.100873.

Data availability

Data will be made available on request.

References

[1] L.A. Husein, I. Alsyouf, E. Mushtaha, A. Alzghoul, Towards High-Performance Buildings Using IoT and AI technologies: A Comprehensive Review, 2022.
[2] E. Mushtaha, O. Helmy, Impact of building forms on thermal performance and thermal comfort conditions in religious buildings in hot climates: a case study in Sharjah city, Int. J. Sustain. Energy 36 (10) (2017) 926–944.
[3] S.A. Dabous, T. Ibrahim, S. Shareef, E. Mushtaha, I. Alsyouf, Sustainable façade cladding selection for buildings in hot climates based on thermal performance and energy consumption, Results. Eng. 16 (2022) 100643.
[4] International Energy Agency (IEA), Digitalization and Energy, IEA, Paris, France, 2019. Available: https://www.iea.org/reports/digitalisation-and-energy.
[5] C. Ghenai, L.A. Husein, M. Al Nahlawi, A.K. Hamid, M. Bettayeb, Recent trends of digital twin technologies in the energy sector: a comprehensive review, Sustain. Energy Technol. Assessm. 54 (2022) 102837.
[6] W.T. Sung, S.J. Hsiao, The application of thermal comfort control based on Smart House System of IoT, Measurement 149 (2020) 106997.
[7] S. Rinaldi, P. Bellagente, A.L.C. Ciribini, L.C. Tagliabue, T. Poli, A.G. Mainini, S. Lupica Spagnolo, A cognitive-driven building renovation for improving energy efficiency: the experience of the ELISIR Project, Electronics 9 (4) (2020) 666.
[8] D. Chirambo, Towards the achievement of SDG 7 in sub-Saharan Africa: creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030, Renew. Sustain. Energy Rev. 94 (2018) 600–608.
[9] United Nations, Transforming Our world: The 2030 Agenda For Sustainable Development, United Nations, Department of Economic and Social Affairs, New York, 2015.
[10] K. AbuShihab, K. Obaideen, M. Alameddine, R.A.F. Alkurd, H.M. Khraiwesh, Y. Mohammad, M.E. Faris, Reflection on Ramadan fasting research related to sustainable Development goal 3 (Good Health and Well-Being): a bibliometric analysis, J. Relig. Health (2023) 1–31.
[11] A. Kalantari, A. Kamsin, H.S. Kamaruddin, N. Ale Ebrahim, A. Gani, A. Ebrahimi, S. Shamshirband, A bibliometric approach to tracking big data research trends, J. Big. Data 4 (1) (2017) 1–18.
[12] K. Obaideen, K.H.A. Shihab, M.I. Madkour, M.E. Faris, Seven decades of Ramadan intermittent fasting research: bibliometrics analysis, global trends, and future directions, Diab. Metab. Syndrome 16 (8) (2022) 102566.
[13] G. Song, J. Wu, S. Wang, Text mining in management research: a bibliometric analysis, Secur. Commun. Netw. 2021 (2021) 1–15.
[14] Elsevier, Scopus Content Coverage Guide, Elsevier, 2020. Available online: https://www.elsevier.com/solutions/scopus/how-scopus-works/content (Accessed 20 January 2023).
[15] M. Aria, C. Cuccurullo, bibliometrix: an R-tool for comprehensive science mapping analysis, J. Informetr. 11 (4) (2017) 959–975.
[16] N.J. Van Eck, L. Waltman, VOS: a new method for visualizing similarities between objects, in: Advances in Data Analysis: Proceedings of the 30th Annual Conference of the Gesellschaft für Klassifikation eV, Freie Universität Berlin, March 8–10, 2006, Springer Berlin Heidelberg, Berlin, Heidelberg, 2007, pp. 299–306.
[17] Datawrapper, Create Charts and Maps [Software], 2023. https://www.datawrapper.de/.
[18] Sustainable development report. (2023). Available at https://s3.amazonaws.com/sustainabledevelopment.report/2023/sustainable-development-report-2023.pdf.
[19] HG Insights, Internet of Things (IoT) Market Report, HG Insights, 2025. Retrieved from, https://hginsights.com/market-reports/internet-of-things-iot-market.
[20] N. Hossein Motlagh, M. Mohammadrezaei, J. Hunt, B. Zakeri, Internet of Things (IoT) and the energy sector, Energies 13 (2) (2020) 494.
[21] Y. Liu, C. Yang, L. Jiang, S. Xie, Y. Zhang, Intelligent edge computing for IoT-based energy management in smart cities, IEEE Netw. 33 (2) (2019) 111–117.
[22] J. Pan, R. Jain, S. Paul, T. Vu, A. Saifullah, M. Sha, An internet of things framework for smart energy in buildings: designs, prototype, and experiments, IEEE Internet Things J. 2 (6) (2015) 527–537.
[23] W. Ejaz, M. Naeem, A. Shahid, A. Anpalagan, M. Jo, Efficient energy management for the internet of things in smart cities, IEEE Commun. Mag. 55 (1) (2017) 84–91.
[24] S. Nižetić, N. Djilali, A. Papadopoulos, J.J. Rodrigues, Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management, J. Clean. Prod. 231 (2019) 565–591.
[25] M. Slabicki, G. Premsankar, M. Di Francesco, Adaptive configuration of LoRa networks for dense IoT deployments, in: NOMS 2018-2018 IEEE/IFIP Network Operations and Management Symposium, IEEE, 2018, pp. 1–9.
[26] M. Barcelo, A. Correa, J. Llorca, A.M. Tulino, J.L. Vicario, A. Morell, IoT-cloud service optimization in next generation smart environments, IEEE J. Sel. Areas Commun. 34 (12) (2016) 4077–4090.
[27] C.C. Sobin, A survey on architecture, protocols and challenges in IoT, Wirel. Pers. Commun. 112 (3) (2020) 1383–1429.
[28] V. Marinakis, H. Doukas, An advanced IoT-based system for intelligent energy management in buildings, Sensors 18 (2) (2018) 610.
[29] A. González-Briones, F. De La Prieta, M.S. Mohamad, S. Omatu, J.M. Corchado, Multi-agent systems applications in energy optimization problems: a state-of-the-art review, Energies 11 (8) (2018) 1928.
[30] C. Mahapatra, A.K. Moharana, V.C. Leung, Energy management in smart cities based on internet of things: peak demand reduction and energy savings, Sensors 17 (12) (2017) 2812.
[31] A. Gonzalez-Vidal, F. Jimenez, A.F. Gomez-Skarmeta, A methodology for energy multivariate time series forecasting in smart buildings based on feature selection, Energy Build. 196 (2019) 71–82.
[32] J. Saini, M. Dutta, G. Marques, Indoor air quality monitoring systems based on internet of things: a systematic review, Int. J. Environ. Res. Public Health 17 (14) (2020) 4942.
[33] F. Salamone, L. Belussi, L. Danza, T. Galanos, M. Ghellere, I. Meroni, Design and development of a nearable wireless system to control indoor air quality and indoor lighting quality, Sensors 17 (5) (2017) 1021.
[34] S. Agostinelli, F. Cumo, G. Guidi, C. Tomazzoli, Cyber-physical systems improving building energy management: digital twin and artificial intelligence, Energies (Basel) 14 (8) (2021) 2338.
[35] M. Al-Kuwari, A. Ramadan, Y. Ismael, L. Al-Sughair, A. Gastli, M. Benammar, Smart-home automation using IoT-based sensing and monitoring platform, in: 2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018), IEEE, 2018, pp. 1–6.
[36] B. Mataloto, J.C. Ferreira, N. Cruz, LoBEMS—IoT for building and energy management systems, Electronics 8 (7) (2019) 763.
[37] B. Teisserenc, S. Sepasgozar, Adoption of blockchain technology through digital twins in the construction industry 4.0: a PESTELS approach, Buildings 11 (12) (2021) 670.

[38] P.N. Borza, M. Machedon-Pisu, F. Hamza-Lup, Design of wireless sensors for IoT with energy storage and communication channel heterogeneity, Sensors 19 (15) (2019) 3364.
[39] D. Falabretti, M. Moncecchi, C. Brivio, M. Delfanti, M. Merlo, V. Musolino, IoT-oriented management of distributed energy storage for the primary frequency control, in: 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), IEEE, 2017, pp. 1–6.
[40] F. Häggström, J. Delsing, Iot energy storage-a forecast, Energy Harvest. Syst. 5 (3–4) (2018) 43–51.
[41] A.M. Hassan, A.I. Awad, Urban transition in the era of the internet of things: social implications and privacy challenges, IEEE Access 6 (2018) 36428–36440.
[42] D. Liu, M. Zhao, H. Xu, M. Mehrgan, A new model to investigate the impact of innovative IT services on smart urban growth: the mediating role of urban planners' knowledge, Growth Change 52 (2) (2021) 1040–1061.
[43] P.U. Ilavarasi, Monitoring of solar energy using IOT, Indian J. Emerg. Electron. Comput. Commun. 4 (1) (2017) 596–601.
[44] R. Morello, C. De Capua, G. Fulco, S.C. Mukhopadhyay, A smart power meter to monitor energy flow in smart grids: the role of advanced sensing and IoT in the electric grid of the future, IEEE Sens. J. 17 (23) (2017) 7828–7837.
[45] H. Shahinzadeh, J. Moradi, G.B. Gharehpetian, H. Nafisi, M. Abedi, IoT architecture for smart grids, in: 2019 International Conference on Protection and Automation of Power System (IPAPS), IEEE, 2019, pp. 22–30.
[46] A.S. Spanias, Solar energy management as an internet of Things (IoT) application, in: 2017 8th International Conference on Information, Intelligence, Systems & Applications (IISA), IEEE, 2017, pp. 1–4.
[47] M.N. Hassan, M.R. Islam, F. Faisal, F.H. Semantha, A.H. Siddique, M. Hasan, An IoT based environment monitoring system, in: 2020 3rd International Conference on Intelligent Sustainable Systems (ICISS), IEEE, 2020, pp. 1119–1124.
[48] J. Shah, B. Mishra, IoT enabled environmental monitoring system for smart cities, in: 2016 International Conference on Internet of Things and Applications (IOTA), IEEE, 2016, pp. 383–388.
[49] S.R. Shinde, A.H. Karode, S.R. Suralkar, Review on-IoT based environment monitoring system, Int. J. Electron. Commun. Eng. Technol. 8 (2) (2017) 103–108.
[50] B.M. AlWadi, V. Aravamudhan, K. Mohanasundaram, M. Abduljawad, The role of smart technologies in reducing energy consumption and promoting sustainable practices in households and businesses, in: 2023 International Conference on Information Technology (ICIT), IEEE, 2023, pp. 327–334.
[51] Z. Huang, G. Jin, Navigating urban day-ahead energy management considering climate change toward using IoT enabled machine learning technique: toward future sustainable urban, Sustain. Cities Soc. 101 (2024) 105162.
[52] B. Kazemi, A. Kavousi-Fard, M. Dabbaghjamanesh, M. Karimi, IoT-enabled operation of multi energy hubs considering electric vehicles and demand response, IEEE Trans. Intell. Transport. Syst. 24 (2) (2022) 2668–2676.
[53] C. Jung, J. Awad, A. Chohan, The planning of smart elderly housing in Dubai with IoT technologies, Open House Int. 46 (4) (2021) 668–681.
[54] A. Moghayedi, B. Awuzie, T. Omotayo, K. Le Jeune, M. Massyn, C.O. Ekpo, P. Byron, A critical success factor framework for implementing sustainable innovative and affordable housing: a systematic review and bibliometric analysis, Buildings 11 (8) (2021) 317.
[55] Y.S. Abraham, S. Terreno, S. Asadi, A.O. Afolabi, Sustainability in affordable housing: trends and opportunities for connected communities, Comput. Civil Eng. (2021) 1220–1227.
[56] S.E. Bibri, The IoT for smart sustainable cities of the future: an analytical framework for sensor-based big data applications for environmental sustainability, Sustain. Cities Soc. 38 (2018) 230–253.
[57] J.E. Gómez, F.R. Marcillo, F.L. Triana, V.T. Gallo, B.W. Oviedo, V.L. Hernández, IoT for environmental variables in urban areas, Procedia Comput. Sci. 109 (2017) 67–74.
[58] F.A. Almalki, S.H. Alsamhi, R. Sahal, J. Hassan, A. Hawbani, N.S. Rajput, J. Breslin, Green IoT for eco-friendly and sustainable smart cities: future directions and opportunities, Mobile Netw. Appl. 28 (1) (2023) 178–202.
[59] A. Razmjoo, A. Gandomi, M. Mahlooji, D. Astiaso Garcia, S. Mirjalili, A. Rezvani, S. Memon, An investigation of the policies and crucial sectors of smart cities based on IoT application, Appl. Sci. 12 (5) (2022) 2672.
[60] C. Wang, J. Gu, O.S. Martinez, R.G. Crespo, Economic and environmental impacts of energy efficiency over smart cities and regulatory measures using a smart technological solution, Sustain. Energy Technol. Assessm. 47 (2021) 101422.
[61] N.M. AbdelAziz, K.A. Eldrandaly, S. Al-Saeed, A. Gamal, M. Abdel-Basset, Application of GIS and IoT technology based MCDM for Disaster risk management: methods and case study, Decis. Mak. 7 (1) (2024) 1–36.
[62] Z. Fadlullah, M.M. Fouda, A.S.K. Pathan, N. Nasser, A. Benslimane, Y.D. Lin, Smart IoT solutions for combating the COVID-19 pandemic, IEEE Internet Things Mag. 3 (3) (2020) 10–11.
[63] K. Kumar, N. Kumar, R. Shah, Role of IoT to avoid spreading of COVID-19, Int. J. Intel. Netw. 1 (2020) 32–35.
[64] C. Acar, A comprehensive evaluation of energy storage options for better sustainability, Int. J. Energy Res. 42 (12) (2018) 3732–3746.
[65] M.A. Hannan, A.Q. Al-Shetwi, R.A. Begum, P.J. Ker, S.A. Rahman, M. Mansor, Z. Y. Dong, Impact assessment of battery energy storage systems towards achieving sustainable development goals, J. Energy Storage 42 (2021) 103040.
[66] L. Jiang, R. Yao, K. Liu, R. McCrindle, An epistemic-deontic-axiologic (EDA) agent-based energy management system in office buildings, Appl. Energy 205 (2017) 440–452.
[67] D. Meana-Llorián, C.G. García, B.C.P. G-bustelo, J.M.C. Lovelle, N. Garcia-Fernandez, IoFClime: the fuzzy logic and the internet of things to control indoor temperature regarding the outdoor ambient conditions, Fut. Gener. Comput. Syst. 76 (2017) 275–284.
[68] Y. Zhao, P.V. Genovese, Z. Li, Intelligent thermal comfort controlling system for buildings based on IoT and AI, Fut. Internet 12 (2) (2020) 30.
[69] J.H.C. Nobrega, I.S. Rampasso, V. Sanchez-Rodrigues, O.L.G. Quelhas, W. Leal Filho, M.P. Serafim, R. Anholon, Logistics 4.0 in brazil: critical analysis and relationships with SDG 9 targets, Sustainability 13 (23) (2021) 13012.
[70] D. Teh, T. Rana, The use of internet of things, big data analytics and artificial intelligence for attaining UN's SDGs. Handbook of Big Data and Analytics in Accounting and Auditing, Springer Nature Singapore, Singapore, 2023, pp. 235–253.
[71] L. Velazquez, The fundamental concepts of SDG9. SDG9–Industry, Innovation and Infrastructure, Emerald Publishing Limited, 2021, pp. 5–37.
[72] E. Fleisch, What is the internet of things? An economic perspective, Econ. Manag. Financ. Markets 5 (2) (2010) 125–157.
[73] L.F. Osako, M.O. Matsubayashi, S.M. Takey, P.A. Cauchick-Miguel, E. Zancul, Cost evaluation challenges for internet of things (iot) based product/service-systems (pss), Procedia CIRP 84 (2019) 302–306.
[74] N. Šikanjić, Z.Ž. Avramović, E. Jakupović, The financial aspect of iot process automation in creating new value for the economy, EMC Rev.-Econ. Market Commun. Rev. 18 (2) (2019).
[75] M. Maryska, P. Doucek, P. Sladek, L. Nedomova, Economic efficiency of the internet of Things solution in the energy industry: a very high voltage frosting case study, Energies 12 (4) (2019) 585.
[76] G. Desogus, E. Quaquero, G. Rubiu, G. Gatto, C. Perra, Bim and iot sensors integration: a framework for consumption and indoor conditions data monitoring of existing buildings, Sustainability 13 (8) (2021) 4496.
[77] Y.N. Malek, A. Kharbouch, H. El Khoukhi, M. Bakhouya, V. De Florio, D. El Ouadghiri, C. Blondia, On the use of IoT and big data technologies for real-time monitoring and data processing, Procedia Comput. Sci. 113 (2017) 429–434.
[78] Hamza, A., Gharakheili, H.H., & Sivaraman, V. (2020). IoT network security: requirements, threats, and countermeasures. *arXiv preprint arXiv:2008.09339*.
[79] W.H. Hassan, Current research on Internet of Things (IoT) security: a survey, Comput. Netw. 148 (2019) 283–294.
[80] S. Nižetić, P. Šolić, D.L.D.I. Gonzalez-De, L. Patrono, Internet of Things (IoT): opportunities, issues and challenges towards a smart and sustainable future, J. Clean. Prod. 274 (2020) 122877.
[81] Thebalancesmb (2020). Web source: rick Leblanc. Thebalancesmb.Com/e-waste-recycling-facts-and-figures-2878189, (Accessed 25 March 2020).
[82] A. Karale, The challenges of IoT addressing security, ethics, privacy, and laws, Internet Things 15 (2021) 100420.
[83] W. Dutton, Putting things to work: social and policy challenges for the internet of things, Info 16 (3) (2014) 1–21.
[84] S.S. Costigan, G. Lindstrom, Policy and the internet of things, Connections 15 (2) (2016) 9–18.
[85] A. Martín-Martín, M. Thelwall, E. Orduna-Malea, E. Delgado López-Cózar, Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations, Scientometrics. 126 (1) (2021) 871–906.
[86] M. Visser, N.J. Van Eck, L. Waltman, Large-scale comparison of bibliographic data sources: scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic, Quant. Sci. Stud. 2 (1) (2021) 20–41.
[87] U. ur Rehman, P. Faria, L. Gomes, Z. Vale, Future of energy management systems in smart cities: a systematic literature review, Sustain. Cities Soc. 96 (2023) 104720.
[88] M. Stan, A. Dima, D.Ø. Madsen, C. Dobrin, Quantifying impact: bibliometric examination of IoT's evolution in sustainable development, Internet Things (2024) 101370.
[89] C. Tomazzoli, S. Scannapieco, M. Cristani, Internet of things and artificial intelligence enable energy efficiency, J. Ambient. Intell. Humaniz. Comput. 14 (5) (2023) 4933–4954.
[90] H. Farzaneh, L. Malehmirchegini, A. Bejan, T. Afolabi, A. Mulumba, P.P. Daka, Artificial intelligence evolution in smart buildings for energy efficiency, Appl. Sci. 11 (2) (2021) 763.