A Science Mapping Analysis of Energy Efficiency and Affordable Housing Research

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ABSTRACT

The research landscape on energy efficiency and affordable housing research (EE-AHR) was critically examined through bibliometric analysis and a literature review of Scopus-indexed publications from 2001 to 2023. Results showed that the total publications and total citations on AH are 630 documents and 4,347 citations. Document type distribution revealed articles (75.7%), conference proceedings (19.8%), and reviews (4.4%). The observably high EE-AHR metrics are attributed to stakeholders' productivity, funding, and collaborations among other various authors, affiliations, and countries strategically involved in EE-AHR. The most prolific authors are Gurran, N. and Milligan, V., whereas UNSW *Sydney* is the most productive affiliation. Likewise, the most productive country is the United States, whereas China's National Natural Science Foundation is EE-AHR's most active funder. Social network analysis revealed that collaboration, particularly between affiliations, was critical to productivity in the EE-AHR landscape. Keywords co-occurrence identified *Energy,* Efficiency, Affordable Housing, Housing, and Housing Policy as the 3 top keywords. In contrast, Housing Sector Dynamics, Sustainable Housing Development, and Urban Development Planning are thematic research areas on AHR. Systemic literature review revealed that EE-AHR is multidisciplinary and impactful, particularly as it seeks to build secure, resilient, inclusive, and sustainable human settlements and cities as per the UN SDGs Goal 11. As such, it has significant potential for future research, collaboration, and growth. Nonetheless, critical research gaps (e.g., examining globalized application techniques, social outcomes, and organizational frameworks) in EE-AHR must be tackled comprehensively. Future research will also need to explore technology applications, innovative materials, social integration, environmental sustainability, and net-zero carbon goals applicable to AH.

Keywords: Energy Efficiency**,** Affordable Housing, Sustainable Development, Housing Policy, Social Housing, Urban Planning
JEL Classifications: R3, Q2, Q4

1. INTRODUCTION

The world is currently facing numerous socio-economic, geopolitical, and environmental challenges (Hashmi et al., 2022). One such challenge is the rapid and uncontrollable rise in the global population (Buzdin et al., 2021). With the population of humans on the planet rising at geometric proportions, it has been predicted that this outcome could result in imminent and future challenges (Lidicker Jr, 2020). As such, there have been growing calls for action among various global stakeholders to forestall disastrous

consequences in the near future. Such calls voice the urgent need to design and develop new, contemporary, and sustainable cities for the future that will help humanity to survive and prosper in green living and culturally stimulating settings (Masekesa and Fuo, 2024). This has become particularly necessary against the backdrop of other global challenges, such as global warming and climate change, which threaten humanity and future generations (Rahman et al., 2013).

Given this, the United Nations proposed and established the sustainable development goals (SDG). According to goal number 11 (G-11), the UN-SDGs seek to build secure, resilient, inclusive, and sustainable human settlements and cities (United Nations, 2015). In addition, G-11 also calls on humanity to deploy novel and intelligent urban planning strategies with the potential to create safe, affordable, and resilient cities. As such, it is envisaged that SDG G-11 will help to address the many challenges that the planet's rising demographics could pose. One such problem is that of affordable housing (AH), which is considered an integral tenet of the UN-SDGs.

AH is a global issue marked by economic inequalities, swift urbanization, and environmental problems that are facing both developing and developed countries (Costarelli et al., 2019; Czischke and van Bortel, 2023). Such factors, along with urban expansions, will cause 70% of the global population to live in cities by 2050 (Goldie and MPIA, 2019; UNSD, 2024). This development will lead to higher housing costs, destitution, congestion, and informal settlements. Therefore, there is an urgent need to identify, examine, and highlight the challenges posed by affording housing problems. This approach could go a long way in increasing understanding of such complex issues and proffer effective solutions.

Over the years, numerous researchers across the globe have examined the concept of energy efficiency (EE) in affordable housing (AH). Several articles, reviews and conference papers have been published to present an overview of the nature and dynamics of EE-AH. The idea has been widely examined by numerous researchers across countries such as India (Mukhija, 2004), Hong Kong (Chiu, 2007), Viet Nam (Nguyen et al., 2018), the United States (Nguyen et al., 2013), China (Wang and Murie, 2011), South Africa (Moghayedi and Awuzie, 2023), Australia and England (Gurran and Whitehead, 2011), among others. Other studies have examined the role of finance in EE-AH through the provision of provident funds (Yeung and Howes, 2006), as well as the combination of land-based finance fiscal autonomy and land supply (Hu and Qian, 2017). The findings have shown that policies proposed for EE-AH in the selection regions have many shortcomings. Due to such weakness, other researchers have proposed region-selected policies strategically designed to address the dynamics of EE-AH. The Whitehead group examined various planning policies for the implementation of AH in England. However, Zou (2014) and Shi et al. (2016) examined the EE-AH policy and contradictions observed in the sector in China. In contrast, Gopalan and Venkataraman (2015) examined the EE-AH policies in India.

As clearly mapped out in the US-SDG G11, housing provision for the future will require more than just sustainable strategies. As such, researchers working on EE-AH studies have adopted various innovative technologies to address the challenges facing the research landscape. Hence, the use of innovative or smart tools to address EE-AH challenges has become a niche area. Aurand (2010) proposed the use of smart tools to examine the housing density, typologies, and land uses related to AH research. Likewise, Wallbaum et al. (2012) proposed the use of a sustainability assessment tool to determine the most suitable construction technologies used for energy efficiency in affordable housing. Other researchers such as Welch (2013), Ren et al. (2015), and Akinwumi et al. (2019) in the design and development of access roads, energy systems, and construction materials used in AH.

Based on the review of the literature, it will appear that numerous researchers worldwide have been actively involved in the research landscape on EE-AH. Despite several studies on the subject areas, the scientific literature on the topic currently lacks a comprehensive study that examines the growth and development trajectories. Therefore, the current paper proposes to critically examine the evolution of EE and AH research over the last two decades.

This study uses bibliometric analysis (BA) in conjunction with a comprehensive literature review to map the trajectory of the AH discourse, identify recurring themes, and identify important research gaps. We focus on the years 2001-2023, which are marked by major changes in housing policies, economic fluctuations, and technological advancements. This timeframe enables us to capture the dynamic responses of EE-AH research to global events like the COVID-19 pandemic, the rise of the Sustainable Development Goals (SDGs), and the 2008 financial crisis.

2. METHODOLOGY

The flowchart methodology adopted to explore and examine the research landscape on Energy Efficiency (EE) and Affordable Housing (AH) studies is presented in Figure 1. The study adopted the three-pronged approach of analysing the publication trends, bibliometric data, and literature review of the publications on the topic from 2001 to 2023. The first step involved the identification of EE-AH research publications indexed in the Scopus database. This database was selected because it is considered one of the most wide-ranging sources of scientific citations and scholarly abstracts (Elsevier Scopus, 2022).

The first step involved the identification of the publications on EE-AHR based on related keywords and Boolean operators in the Scopus database. The first search resulted in 692 document results based on the search terms: (TITLE ("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing") AND ABS ("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing") AND KEY ("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing")) AND PUBYEAR > 2000 AND PUBYEAR < 2024. Due to the numerous unwanted search results (e.g., non-English or traditional peer review results, the search data was subsequently screened.

Hence, screening was performed to eliminate the unwanted terms based on the screening operation: (TITLE (("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing") AND ABS ("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing") AND KEY ("Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing")) AND PUBYEAR > 2000 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j") OR LIMIT-TO (SRCTYPE, "p")) AND (EXCLUDE (LANGUAGE, "French") OR EXCLUDE (LANGUAGE, "Lithuanian") OR EXCLUDE (LANGUAGE, "Portuguese"))). The screening process resulted in 630 document results comprising English-language publications comprising articles, conference papers, and reviews only.

The third stage involved the analysis of the published documents (hereafter termed publications) on the topic using bibliometric analysis (BA) and systematic literature review (SLW). BA is a statistical approach commonly used to explore the research landscape on any specific subject area based on its publications indexed in various scientific databases (Wong et al., 2021). Over the years, the BA technique has been extensively utilized to examine and highlight the research landscape on different subject areas such as environmental pollution (Ozabor et al., 2024), climate change (Ajibade et al., 2023), waste valorisation (Nyakuma et al., 2021), renewable energy (Ajibade et al., 2023), safety research (Otitolaiye and Abd Aziz, 2023), air quality assessment (Tan et al., 2023), and computer science (Kong et al., 2024), among others. In this study, the BA approach was also employed
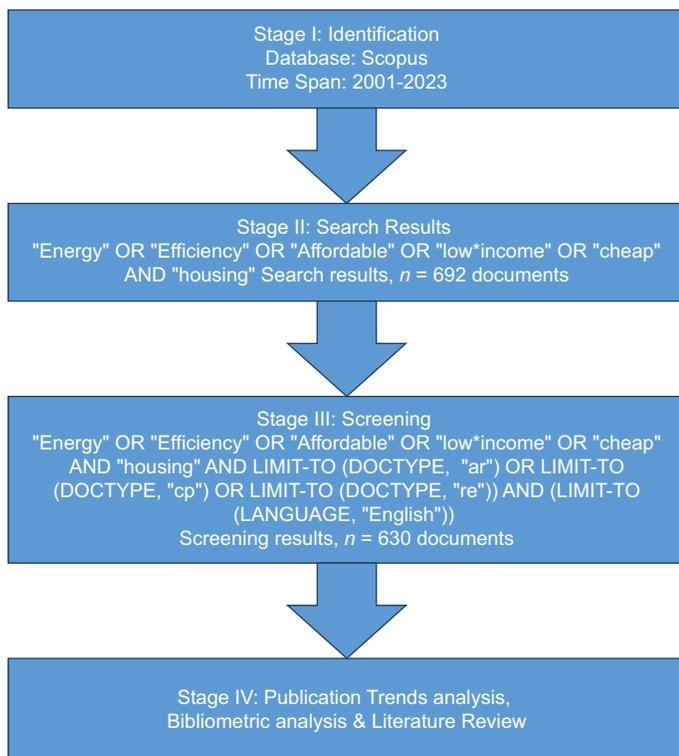
to elucidate the productivity of various stakeholders, examine the publications/research trends, and highlight future directions for the EE-AHR research topic. Hence, the co-authorships, citations, and keyword co-occurrences on EE-AHR were examined using VOSViewer software (version 1.6.20).

The final stage was the systematic literature review (SLW) of developments in the field of EEAHR. This analysis was carried out according to Lotka's law, which posits that the most highly cited publications on any given subject (such as EE-AHR) could be used to describe the developments in the field. In bibliometric analysis, Lotka's Law posits that a small fraction of authors or publications have a substantial impact on citations, which could offer critical insights into the significant advancements and trends in the field.
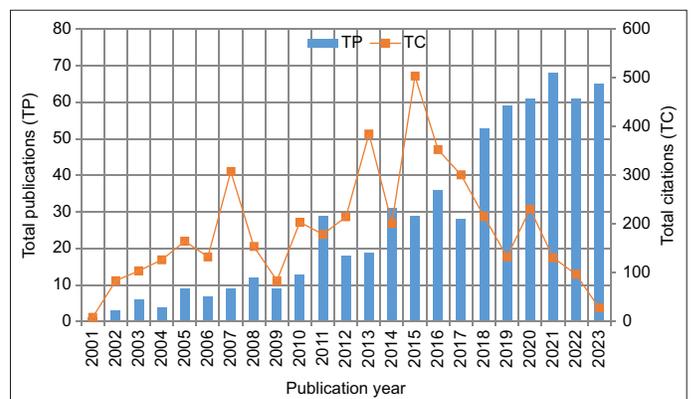
3. RESULTS AND DISCUSSION

3.1. Publication Trends Analysis

Figure 2 presents a graph of the temporal changes in total publications (TP) and total citations (TC) on energy efficiency (EE) and affordable housing research (AHR) publications from the year 2001 to 2023. The graph is based on publications data recovered from Elsevier's Scopus database. As observed, the charts show an incremental trend, with the TP increasing from 1 to 68 publications (27.39 publications on average per year), culminating in a total of 630 document results during this period. In contrast, the total number of citations (TC) was 4,347, with an average of 189 each year. In comparison, the TC displayed an erratic pattern of increase and drop, with high values recorded in 2007 (308 citations), 2013 (385 citations), and 2015 (504 citations).

The high TC and TP metrics observed for EEAHR reflect its growing importance not only as a research field but also as a socially impactful aspect of modern society. The United Nations Sustainable Development Goal Number 11 strives to build human settlements and cities that are secure, resilient, inclusive, and sustainable. In addition, it aims to enhance informal settlements and encourage sustainable urbanization while guaranteeing resistance to natural calamities and facilitating cheap housing access. Lastly, the goal seeks to support participation in the process of urban planning, as well as promote social inclusion and preserve natural/cultural heritage. Given this, there has

Figure 1: Flowchart methodology for EE-AHR publications recovery and analysis

Stage I: Identification
Database: Scopus
Time Span: 2001-2023

Stage II: Search Results
"Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing" Search results, *n* = 692 documents

Stage III: Screening
"Energy" OR "Efficiency" OR "Affordable" OR "low*income" OR "cheap" AND "housing" AND LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English"))
Screening results, *n* = 630 documents

Stage IV: Publication Trends analysis, Bibliometric analysis & Literature Review

Figure 2: Temporal changes in total publications and citations on EE-AHR (2001-2023)

been a lot of research on the topic across the globe, which has resulted in numerous types of publications spanning various subject areas.

Figure 3a and b show the distributions of various document types and subject areas on EE-AHR from 2001 to 2023 in the Scopus database. As observed, the document types comprise articles, conference papers, and reviews, which account for 477, 125, and 28 of the TP. As observed, there is a clear preference for articles among AHR researchers, which numerous studies have surmised is due to the high-quality standards, academic excellence, and scholarly prestige afforded by peer-reviewed articles (Zaidi et al., 2023). Figure 3b shows the top subject area categories for EE-AHR publications in Scopus. As can be seen, the top 3 subject areas (publications count) are Social Sciences (369), Engineering (189), and Environmental Science (182). Other notable areas include business, management, accounting, and energy. Based on the findings, it could be reasonably surmised that EE-AHR cuts across numerous subject areas from STEM (science, technology, engineering, and mathematics) to HASS (humanities, arts, and social sciences). As such, it is a multidisciplinary area of research with significant research and social impact on people across the globe.

The impact of the field of EE-AHR could also be attributed to the medium of publications or source titles in which research on the topic has been published over the years. Figure 4 shows the distribution of source titles that have published seminal works on EEAHR over the period from 2001 to 2023. The top three source titles are Housing Studies with 22 publications, followed by Sustainability (Switzerland) with 21 publications, and IOP Conference Series Earth and Environmental Science with 17 publications. Other notable sources include Cities (14), Habitat International (11), and Urban Studies (10). The data shows that the top sources comprise a mixture of journals as well as conference proceedings, which suggests that researchers in the landscape largely prefer to publish their works in these two publications mediums. Typically, the publication of works in such media can result in high visibility and citations, which can give rise to highly cited publications.

Table 1 presents the most highly cited publications on energy efficiency and affordable housing research between 2001 and 2023, based on data from Scopus. As observed, the most cited publications each gained between 71 and 128 citations (or 91.3 on average). Overall, the top 20 most cited publications have gained a total of 1826 citations, which accounts for 42.01% of the TC on the topic.

The topmost cited publications have been published in source titles such as Building and Environment, Habitat International, Transport Policy, International Journal of Housing Policy, Journal of Cleaner Production, Land Use Policy, and Energy Policy, among others. Further analysis shows that the outlined source titles have high impact factors (IF), such as Building and Environment (7.4), Habitat International (6.8), Transport Policy (6.8), International Journal of Housing Policy (3.5), Journal of Cleaner Production (11.1), Land Use Policy (7.1), and Energy Policy (9). As observed, the journals have IFs ranging from 3.5 (International Journal of Housing Policy) to 11.1 (Journal of Cleaner Production), which indicates the citations are largely linked to the reputation of the journals where the various authors and stakeholders publish the research in the researcher's landscape. Section II presents an overview of the major stakeholders actively involved in the study of affording housing worldwide.

3.2. Stakeholders Analysis
In this study, the four major stakeholders identified in the Scopus database are the Authors, Affiliations, Countries, and Funding organizations. The impact of each of these on the productivity and impact of the subject area will be examined in the following sub-sections. The relationships between stakeholders influence the direction, impact, and visibility of research. As a result, research productivity and relevance are contingent upon the availability of resources, different viewpoints, and cooperative efforts (Ajibade et al., 2024; Nyakuma et al., 2023).

3.2.1. Authors
Figure 5 presents the list of the top 5 researchers on energy efficiency and affordable housing research between 2001 and 2023, as deduced from Scopus. The data shows that the top spot for the most prolific author on EE-AHR is taken by two authors, Gurran, N. and Milligan, V., who have 9 publications. Furthermore, the authors Davison, G., Adabre, M.A., and Chan, A.P.C. have published 7, 5, and 5 publications, respectively. Otherwise, termed researchers, the authors are individuals who design and perform experiments or students to address the research gaps or problems in any given field. As a result, their research activities are subsequently communicated in various published documents. Furthermore, the expertise, collaboration, and networking of researchers promote the credibility and visibility of their findings in the scientific literature.

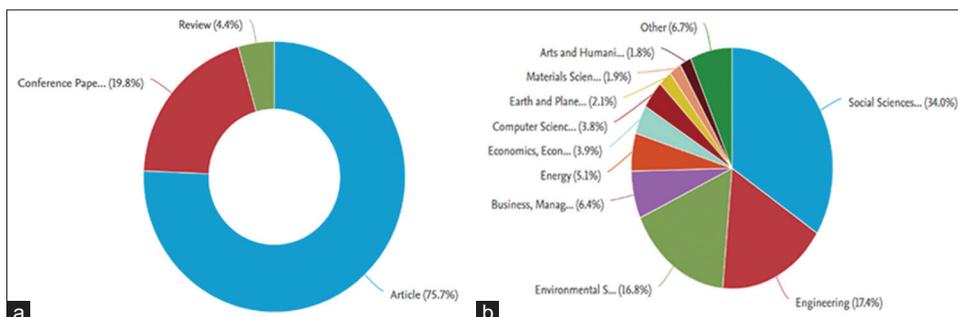**Figure 3:** Distributions of various (a) document types; (b) subject areas on EE-AHR (2001-2023)

Table 1: Most highlight cited publications on EE-AHR (2001-2023)

References	Title	Cited by
Adabre and Chan (2019)	Critical success factors (CSFs) for sustainable affordable housing	128
Shi et al. (2016)	Affordable housing policy in China: New developments and new challenges	115
Welch (2013)	Equity in transport: The distribution of transit access and connectivity among affordable housing units	115
Nguyen (2005)	Does affordable housing detrimentally affect property values? A review of the literature	107
Chan and Adabre (2019)	Bridging the gap between sustainable housing and affordable housing: The required critical success criteria (CSC)	104
Wang and Murie (2011)	The new affordable and social housing provision system in China: Implications for comparative housing studies	104
Whitehead (2007)	Planning policies and affordable housing: England as a successful case study?	104
Zou (2014)	Contradictions in China's affordable housing policy: Goals vs. structure	100
Tighe (2010)	Public opinion and affordable housing: A review of the literature	98
Gan et al. (2017)	How does affordable housing become more sustainable? A stakeholder study	91
Diamond and McQuade (2019)	Who wants affordable housing in their backyard? An equilibrium analysis of low-income property development	83
Wallbaum et al. (2012)	Indicator-based sustainability assessment tool for affordable housing construction technologies	81
Gopalan and Venkataraman (2015)	Affordable housing: Policy and practice in India	80
Adabre et al. (2020)	Critical barriers to sustainability attainment in affordable housing: International construction professionals' perspective	78
Christophers (2014)	Wild Dragons in the city: Urban political economy, affordable housing development and the performative world-making of economic models	75
Yeung and Howes (2006)	The role of the housing provident fund in financing affordable housing development in China	75
Hu and Qian (2017)	Land-based finance, fiscal autonomy, and land supply for affordable housing in urban China: A prefecture-level analysis	73
Chegut et al. (2016)	Energy efficiency and economic value in affordable housing	73
Scally and Tighe (2015)	Democracy in Action?: NIMBY as Impediment to Equitable Affordable Housing Siting	71
Gurran and Whitehead (2011)	Planning and Affordable Housing in Australia and the UK: A Comparative Perspective	71

Figure 4: Distribution of source titles on EE-AH research (2001-2023)
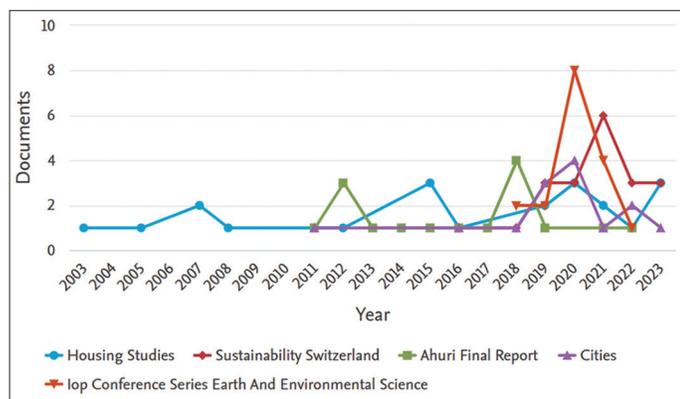
Figure 5: Top 5 researchers on EE-AH research (2001-2023)
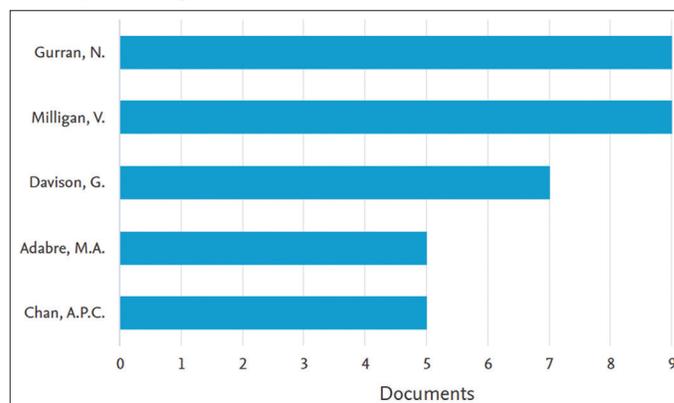
3.2.2. Affiliations

Figure 6 shows the top 5 affiliations whose researchers have been actively engaged in research topics centred on energy efficiency and affordable housing research from 2001 to 2023. The analysis of the affiliations is important because it provides researchers with information on the locations with sufficient resources and reputational backing to not only successfully perform research on selection topics but also where researchers can engage in multidisciplinary alliances. As observed, the top 5 affiliations based on publications output are the UNSW Sydney (18), Universiti Teknologi MARA (17), Universiti Teknologi Malaysia (15), University of Sydney (15), and Universiti Malaya (13). It can be observed that Australia and Malaysia-based affiliations are among the dominant affiliations that are actively engaged in the EEAHR research landscape. The plausible reasons for this high research interest are as follows. First, their interest can be ascribed to issues linked to shared urbanization and population increase, which require active exploring for inexpensive housing. Moreover, the governments and universities in both countries have enhanced interdisciplinary knowledge in design, urban planning, economics, and engineering, promoting domestic and global cooperation.

3.2.3. Countries

Figure 7 shows the top 5 countries that have been actively involved in research topics on energy efficiency and affordable housing research across the globe from 2001 to 2023. Typically, countries provide an address (location) environment for researchers and affiliations to conduct research. In addition, countries provide funding and regulatory guidelines for conducting research and fostering innovation, which will impact their socio-economic growth and infrastructural development.

Figure 6: Top 5 affiliations on EE-AH research (2001-2023)
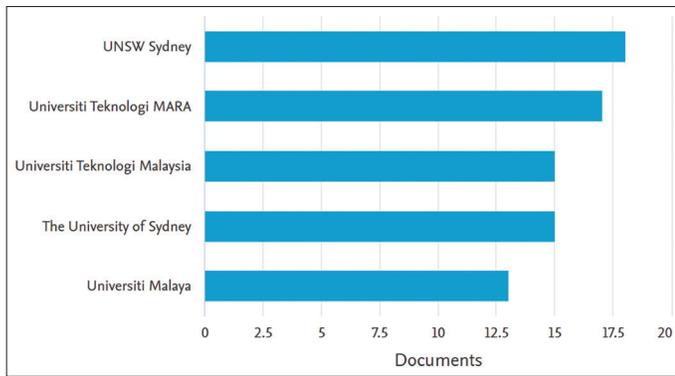
Figure 7: Top 5 countries active in EE-AH research (2001-2023)

Figure 8: Top 5 funding organizations engaged in energy efficiency and affordable housing research (2001-2023)
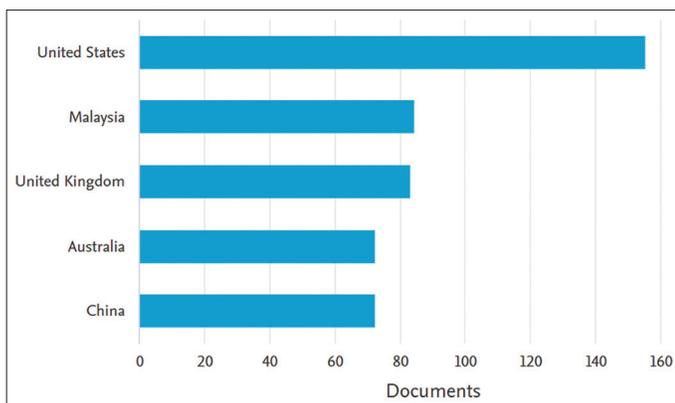
As observed in Figure 7, the most prolific nation is the United States, with 155 publications, which Malaysia follows (84), the United Kingdom (83), Australia (72), and lastly China (72). However, the findings indicate that Malaysia and Australia are the most influential countries on the topic due to the high number of its affiliations and researchers engaged in the research landscape. The dominance of these nations could be attributed to numerous factors ranging from national policies to researchers' interests and funding for research on the topic. Sub-section (d) will examine the impact of funding organizations on the productivity of the other stakeholders on the subject.

3.2.4. Funding organizations
Typically, funding organizations, agencies or institutions provide critical support for research through financial contributions (in various forms such as grants, incentives or palliatives). This support helps to fund research activities as well as shape policy priorities, and enforce accountability among stakeholders (Álvarez-Bornstein and Montesi, 2020; Smits and Denis, 2014). Figure 8 shows the top 5 funding organisations that have financed various energy efficiency and affordable housing research between 2001 and 2023. As observed, the most active funding organisation in the EE-AHR landscape is China's National Natural Science Foundation, which has 18 works to its credit. In second place is Malaysia's Universiti Teknologi Malaysia, credited with funding 8 works, whereas the Australian government comes in 3rd place with 7 publications. Other notable funders of research in the landscape are the Social Sciences and Humanities Research Council of Canada and Universiti Malaya, each with 6 publications.
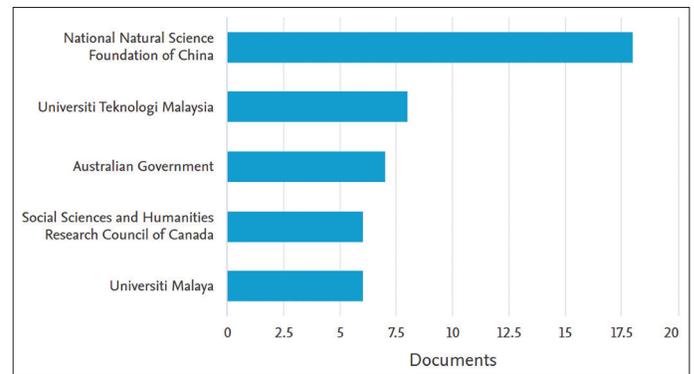
Further analysis shows that each of the stakeholders has contributed significantly to the growth and development of the research landscape. Such high productivity is often also adjudged to be due to collaborations within networks of contributors. The impact of this factor on the research landscape can be examined through co-authorship analysis. Section III presents a critical analysis of the network of authors, affiliations, and countries that have collaborated on affordable housing research over the years.

3.3. Social Network Analysis
3.3.1. Co-authorship analysis
Figure 9 depicts the network visualisation map for authors who have collaborated on publications on the EE-AHR. The data showed that 78 out of 1,398 authors had published 3 or more documents on the topic. As such, the map contains 3 clusters comprising 5 to 8 authors, with the large cluster comprising the authors Yates, Reynolds, and Milligan, among others. Further analysis shows the largest linked authors are 18 out of 78, which suggests a collaboration rate of 23.08%. This finding indicates the productivity of authors in the landscape is not solely due to collaborations but may be due to high funding and social/research impact, among others. This validates the earlier submission that funding has played a significant role in the productivity of the AHR landscape.

The rate of collaboration among organisations was also examined in this study. Figure 10 shows the network visualisation map for the various affiliations that collaborated on numerous publications in the EE-AHR landscape from 2001 to 2023. The map shows the affiliations that have collaborated on 3 or more publications. The results show that 9 out of 1062 affiliations satisfied this criterion, which resulted in 2 clusters, each with 3 affiliations. However, the computation of the rate of collaboration among affiliations shows that 6 out of 9 have collaborated on 3 or more works, which translates to an R_C of 66.67%, which is higher than reported for authors. As such, the findings show that collaboration is, in fact, a significant factor for productivity among affiliations.

Likewise, the rate of collaboration among countries that have collaborated on EE-AHR worldwide was examined in this study. Figure 11 shows the network visualisation map for countries that have collaborated on 10 or more publications on EE-AHR over the last two decades. The data revealed that 13 out of the total 68

countries satisfied the set criteria, resulting in a total of 4 clusters comprising 2 to 5 nations. The map shows a total of 37 Links and a TLS of 80. The nations with the highest TLS are the UK (26), the US (23), and Australia (21). Based on the data, the US, UK, Australia, and Malaysia are the most active countries in terms of productivity on the topic, largely based on collaborations. For example, the UK has strong collaboration links with Australia, South Africa and Malaysia, whereas the US has strong links with South Korea and China. Overall, it can be seen that collaboration

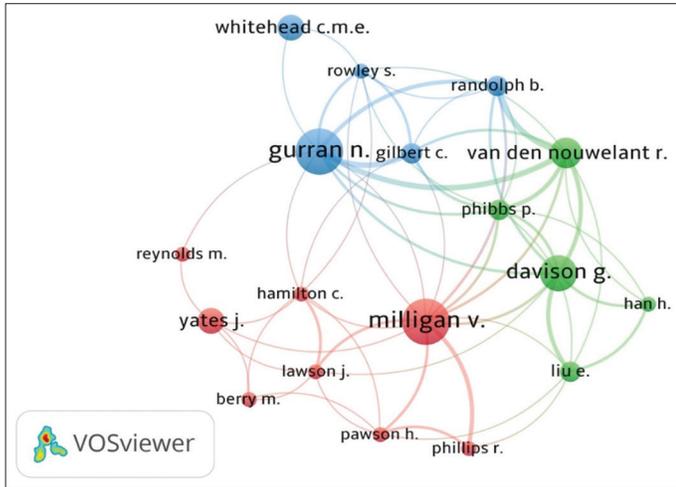**Figure 9:** Network visualisation map for collaborating authors on EE-AHR (2001-2023)

Figure 10: Network visualisation map for collaborating affiliations on EE-AHR (2001-2023)
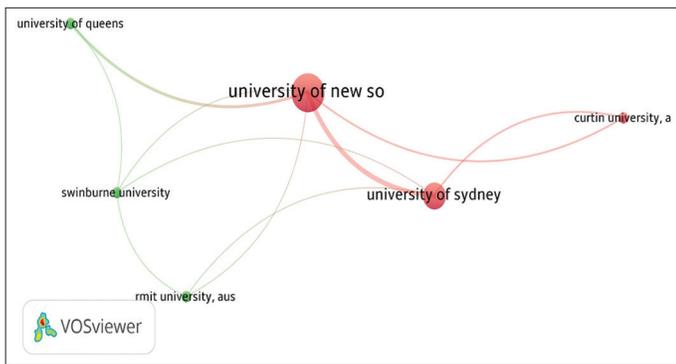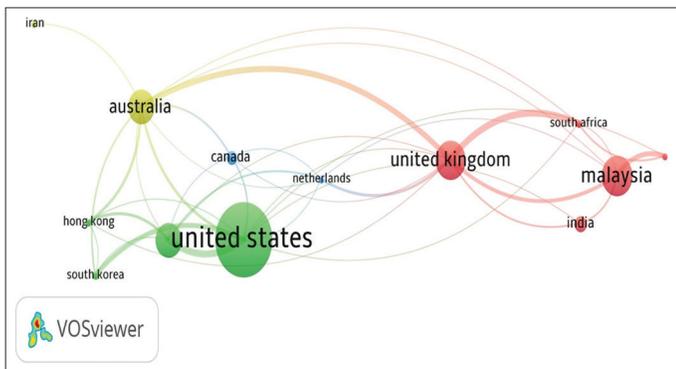

Figure 11: Network visualisation map for collaborating countries on EE-AHR (2001-2023)

has indeed played an integral role in the productivity of countries on the topic.

3.3.2. Keywords co-occurrence (KCO) analysis

The KCO analysis is typically performed to examine the current research status and predict future areas (Álvarez-Bornstein and Montesi, 2020; Wong et al., 2022). Likewise, it is used to determine the research hotspots or thematic regions on any given topic or area (Kong et al., 2024; Mokhtarpour and Khasseh, 2021; Sedighi, 2016). In this paper, the KCO feature of VOSviewer was used to analyse the co-occurrence of keywords (KW) on EE-AHR. Figure 12a and b present the network and overlay visualisation maps for KCO on EE-AHR (2001-2023), respectively. The maps reveal that 13 out of the 3,255 keywords on the topic occurred a minimum of 30 during the search. As elucidated from the KCO analysis, the top 3 KWs on the topic are Energy Efficiency, Affordable Housing, Housing, and Housing Policy. The TLS and Occurrences of each KW are Energy Efficiency (506, 231), Affordable housing (574, 713), housing (200, 316), and Housing Policy (93, 218).

Clustering analysis revealed the existence of 3 clusters comprising 3 to 6 KW, 75 Links, and TLS of 1164. Cluster 1 (Red) comprises the KW Social housing, housing policy, housing provision, housing market, China, and the United Kingdom. On the other hand, cluster 2 (Green) comprises housing, affordable housing, sustainable development, and sustainability. Lastly, cluster 3 (Blue) consists of Urban Housing, Urban planning, and the United States. Based on the preceding, the three clusters could be broadly categorised under the following thematic areas;

Figure 12: (a and b) Network and overlay visualisation maps for KCO on AHR (2001-2023)
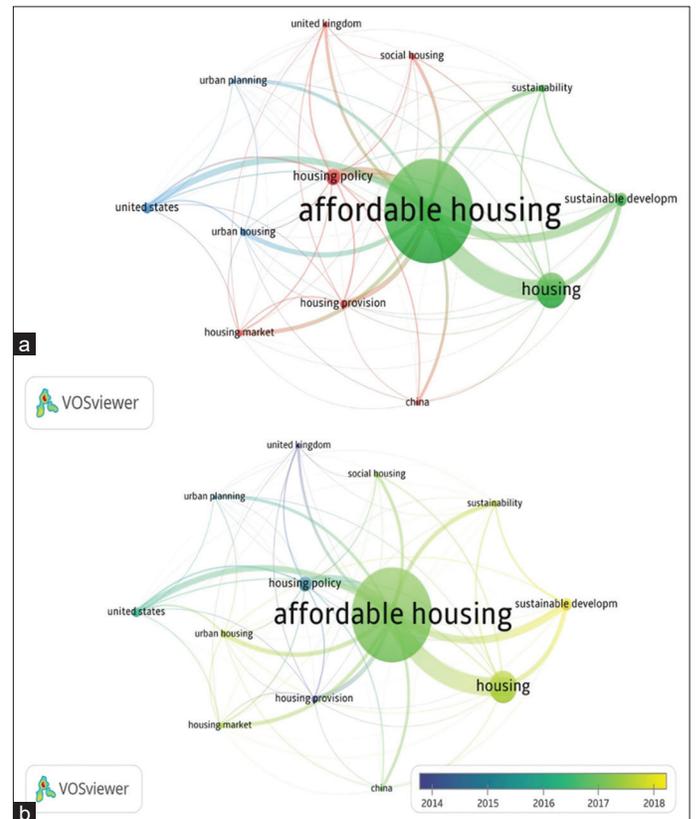
Table 2: Review of literature on energy efficiency and affordable housing research

References	Study core objective(s)	Study major findings
Crook and Whitehead (2002)	The study evaluated the effectiveness of social housing and planning gain in providing affordable housing.	The study revealed that the provision of affordable housing in the English planning system is influenced by the Planning Policy Guidance Note 3 and Circular 6/98. It also showed that these policies' creation, assessment, evolution, implementation, and goals have an impact on housing supply and prices, as well as taxation principles.
Mukhija (2004)	The study explored the challenges faced by private developers in providing AH in India.	This study, which focused on a private developer in India, evaluated the policy recommendations aimed at providing AH made by market-based actors and enabling markets. The study recommended exercising caution, acknowledging the connection between the formal and informal sectors, and addressing the influence of public support on developers.
Yeung and Howes (2006)	The study investigated the role of the housing provident fund in financing AH development in China.	The results showed that the rapid economic growth in China has resulted in housing problems in its key towns and cities. As such, the 1988 urban housing reform was devised to develop AH. However, the policy faced numerous obstacles, such as a lack of a second-hand market, underdeveloped real estate, and unclear legislation, among others.
Whitehead (2007)	The study analysed the impact of planning policies on AH in England as a successful case study.	This study discussed the success of England's approach to affordable housing production through land-use planning, highlighting the rationale and principles behind this approach. It examined the evolution of England's mechanisms, outcomes, and lessons learned, highlighting the relevance of the English experience to other advanced economies facing similar housing issues.
Mueller and Tighe (2007)	The study explored the connection between AH, health, and education outcomes.	The study showed the nature and impact of the relationship between AH housing provision and community benefits, with an emphasis on health and education. The study highlighted that analysts disagree on its net benefits or impact on neighbourhood property values.
Hoch (2007)	The study analysed the implementation of plan mandates in AH in the United States.	The impact of the AH planning mandate in Illinois (US) was examined. The findings showed that there was equal resistance and compliance among local officials. Despite 36 out of 49 suburban municipalities meeting the mandate's requirements, most failed to address prior exclusions or specific remedies.
Chiu (2007)	The study examined the planning, land, and affordable housing sectors in Hong Kong.	The paper examines Hong Kong's government's use of land and development rights to provide AH. It argued that land ownership allows the government to operate a massive public housing program, meeting half the population's housing needs at affordable rent and price levels. However, the availability of subsidized housing depends on government commitment and priority in housing problems.
Goetz (2008)	The study explored the significance of the issue framing in the context of AH.	The study investigated the impact of planners' language on public support for policies. The study performed a survey of suburban residents, which showed that using lifecycle housing instead of AH resulted in a significant difference in public opinion. This was particularly prevalent among the White, non-Hispanic respondents in the study. As such, the study suggested that proper framing can expand policy options and potentially allow for the success of previously infeasible policies under the right circumstances.
Tighe (2010)	The study analysed public opinion on AH through a comprehensive analysis of existing literature.	The study observed that public support is crucial for successful planning initiatives such as affordable housing. However, such policies can be hindered by opposition or resistance from selection sectors. More so, factors such as ideology and stereotyping can impact attitudes towards AH. Therefore, the proper understanding of such influences is essential for successful planning in AH programs.
Aurand (2010)	The study explored the use of smart tools for AH through the analysis of density, housing types, and mixed land use.	The research suggests that low-income households can benefit from neighbourhoods with various housing types and mixed land use rather than single-family homes. It suggests that planners should consider housing type goals in addition to density targets when developing future growth plans, thereby addressing the housing needs of low-income households.

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Table 2: (*Continued*)

References	Study core objective(s)	Study major findings
Wang and Murie (2011)	The study explored the new system of affordable and social housing in China, highlighting its implications for comparative housing studies.	The study showed that the government has developed policies to support affordable and social housing. Examples are the housing privatisation and commercialisation that have been developed for urban housing provision in China over the years. However, their scale and impact have been limited due to local state priorities. As such, the paper suggests a hybrid approach for policy change.
Gurran and Whitehead (2011)	The study sought to compare planning and affordable housing in Australia and the UK from a comparative perspective.	The paper highlighted that there is a divergence between urban planning and housing policy in the UK. It noted that planning is crucial for securing affordable housing and the UK's approach to housing assistance.
Wallbaum et al. (2012)	The study evaluated the sustainability of indicator-based sustainability assessment tools for AH construction technologies.	The study identified the main challenges and indicators for affordable housing production and developed an indicator-based assessment system. The final ranking showed that various technologies perform strongly, from bio-based materials to industrialized ones. Combining different technologies seems to be the most promising approach.
Welch (2013)	The paper analysed the distribution of transit access and connectivity among AH units, ensuring equity in transport.	The results showed that some subsidized housing units distribute transit connectivity and accessibility more equitably than the general population, suggesting that policies to enhance transit access have not been effective.
Nguyen et al. (2013)	The study investigated the opposition to AH in the USA, focusing on the debate framing and the responses of local actors.	The article explores the framing of AH in the USA, focusing on how race, ethnicity, class, and immigration shape opponents' views. The results showed that such opposition leads to changes in development designs and siting decisions, directing projects to specific areas.
Zou (2014)	The study examined the discrepancies in the AH policy in China, focusing on the goals and structure of the policy.	The results revealed that the division of powers between central and local governments has hindered the state's goals aimed at AH development and provision. It also examines recent government innovations to improve affordable housing policies. China's affordable housing policy, despite significant improvements, faces criticism for increasing housing inequality.
Christophers (2014)	The study explored the urban political economy, AH development, and the performative world-making of economic models in the city.	The study showed the existence of the performativity of economics in urban contexts. It is argued that economics critically influences, shapes, and remakes the urban world, particularly concepts such as AH. Additionally, it showed, using a UK case study, that economic models for assessing AH provision in residential developments since the early 2000s. The article conceptualizes these models as examples of economics 'in the wild', focusing on the work of Three Dragons, a leading commercial developer and marketer.
Austin et al. (2014)	The study explored the planning practices for AH in Australia, New Zealand, and England by examining the common culture and various mechanisms involved.	This paper reported that the effective delivery of AH depends on consistent policy articulation, government commitment, a mature housing sector, and specific market conditions.
Dang et al. (2014)	The study investigated the relationship between land-based interests and the spatial distribution of AH development in China.	The study reported that a biased distribution of AH units exists in many Chinese. It goes further to argue that this is due to the implementation of strategic policy to balance political pressure with local fiscal interests by city governments.
Scally and Tighe (2015)	The article explored the issue of NIMBY as a barrier to equitable planning in AH.	The study findings emphasized the significance of neighbourhood involvement in urban politics related to the planning and development of AH in cities. The findings further showed that local opposition can affect the building of affordable housing, and such resistance impedes the effective location of cheap housing. Hence, the authors recommended modifying local planning tactics to reduce resistance and provide more equal results.
Ren et al. (2015)	The paper analysed the performance of space heating systems in AH through data mining.	The results showed that most apartments have constant room temperature profiles, with six typical patterns during the heating season. Space heating systems cycle more frequently than anticipated due to tight thermostat settings and potentially oversized heating capacities.

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Table 2: (*Continued*)

References	Study core objective(s)	Study major findings
Copiello (2015)	The study explored the strategies for achieving AH through energy efficiency.	The study showed that public-private partnerships have helped to ensure marked progress in AH provision in Italy over the last two decades. However, challenges in accessing capital markets and rising funding costs have slowed PPP initiatives. Community needs include converting brownfields, recovering housing, and providing affordable dwellings for low to medium-income households. A case study demonstrates successful PPP and building energy efficiency in achieving social housing settlements with agreed rents higher than social rents and market rents.
Shi et al. (2016)	The paper examined the latest developments and challenges in China's AH policy.	The paper reported that China's affordable housing policy prioritizes economic growth, urbanization, and political stability by maintaining affordability. It also highlights the achievements and challenges in post-reform China and offers lessons for future policy developments.
Chegut et al. (2016)	The study evaluated the relationship between energy efficiency and economic value in the context of affordable housing.	The results showed that the Dutch AH market often lacks rental protection, which prevents landlords from charging premiums for energy-efficient dwellings. A study analysing 17,835 homes sold between 2008 and 2013 found that dwellings with high energy efficiency sell for 2.0-6.3% more, resulting in a premium of EUR 3,000 to EUR 9,700 for such housing.
Murphy (2016)	The study explored the politics of land supply and AH in New Zealand, focusing on the Housing Accord and Special Housing Areas.	This paper explored the political conflict between local government planning practices and central government policies on AH in New Zealand. The focus was on the impact of the Auckland Housing Accord and the Housing Accords and Special Housing Areas Act on AH. It highlighted that the prioritization and application of policy knowledge is intrinsically political and challenges the existing planning system aimed at ensuring affordable housing.
Hu and Qian (2017)	The study analyzed critical factors such as land-based finance, fiscal autonomy, and land supply and their impacts on AH in urban regions in China.	The paper showed that there is a spatial mismatch between cities focusing on AH and those facing affordability problems. It was observed that regions with a larger dependence on land finance and fiscal autonomy have less probability of investing in AH.
Riazi and Emami (2018)	The study employed a mixed-method approach to examine residential satisfaction with AH in Iran.	The findings showed that determinants of residential satisfaction (DRS) impact residential satisfaction, whereas ethnicity moderates the relationship between interaction with neighbours and satisfaction.
Adabre and Chan (2019)	The study identified and examined the critical success factors (CSFs) for sustainable affordable housing.	The findings showed that the efficient utilisation of resources would significantly improve the development and delivery of sustainable, affordable housing, particularly in selected markets. In addition, this approach can help to establish a relationship between CSFs and success criteria for sustainable housing.
Diamond and McQuade (2019)	The study examined individuals' preferences for affordable housing in their backyards through a balanced analysis of low-income property development.	The study showed that LIHTC development revitalizes low-income neighbourhoods, increases house prices, lowers crime rates, and attracts diverse populations, which resulted in welfare benefits amounting to USS$116 million.
Akinwumi et al. (2019)	The study explored the relationship between marine plastic pollution and affordable housing by using shredded waste plastic to stabilize soil for producing compressed earth bricks.	The study highlighted the potential of utilising shredded plastic wastes and clayey sand soil at various fractions to mould compressive earth bricks (CEB). The results showed that the highest compressive strength was obtained with 1% waste plastic, resulting in a 244.4% increase. In addition, the shredded plastic wastes with particle sizes < 6.3 mm were recommended for producing stronger and more affordable bricks for AH, provided the exterior surfaces are protected from erosion.
Adabre and Chan (2020)	The study explored the significant obstacles to sustainable, affordable housing, with a focus on the viewpoint of international construction professionals.	The study identified five key barriers to sustainable affordable housing globally, including green retrofit, land market, incentive, housing market, and infrastructural issues, providing recommendations for further research.

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Table 2: (*Continued*)

References	Study core objective(s)	Study major findings
Zheng et al. (2020)	The study investigated the potential of affordable housing programs in fostering the social integration of migrants in Chinese cities.	The results showed that migrants living in rental units in these programs have significantly higher social integration levels than those in other communities. However, owner-occupied housing does not considerably improve social integration. Inclusive living environments and neighbourhoods contribute to this difference.
Chen et al. (2021)	The study examined the social vulnerability of AH communities in Nanjing, China, with a focus on enhancing the long-term disaster resilience of low-income communities.	This paper finds that social vulnerability is affected by factors ranging from exposure and sensitivity to adaptability. As such, there is a lower risk of exposure to communities with new construction and good-built environments.
Hyde (2022)	The study adopted and explored altruism as a developer strategy for accumulation through AH policies in Canada.	The paper explores the link between altruism and profitability in private development companies in Toronto and Vancouver, challenging traditional views of developers as profit maximizers and highlighting implications for condo-ization and affordable housing privatization.
Khan et al. (2022)	The study uses a Total Interpretive Structural Modelling (TISM) method to analyze the factors influencing the adoption of modular integrated construction for affordable, sustainable housing.	This study reported that despite the rising popularity of offsite construction techniques, MiC adoption in sustainable AH is still underdeveloped. The Total Interpretive Structure Modelling (TISM) method identified eight drivers, with social factors having the highest driving and lowest dependency power. A strategic framework for boosting MiC adoption in ASH is presented, highlighting key stakeholders and strategies for transformation. This study provides a comprehensive understanding of the drivers for MiC-ASH synergy.
Czischke and van Bortel (2023)	The study explored the concepts and policies on AH in England, Italy, Poland, and The Netherlands.	The study concluded that AH is becoming a distinct field in England, Italy, Poland, and The Netherlands, paralleling developments in social housing. As a result, there has been a growing trend in the growth of innovative policies to address issues of AH and future policy developments.
Manoj (2017)	The study explores the need for an integrative approach to affordable healthcare and housing in the Kerala, India, digital economy.	The results showed a looming need for ICT for better efficiency and competitiveness in Kerala's economy. An ICT-based integrated system that ensures universal health and affordable housing is suggested, with higher government health expenditure and alternative investments in the healthcare sector through PPP mode.
Moghayedi and Awuzie (2023)	The study evaluated the sustainable performance of innovative prefabricated construction methods for AH in Southern Africa towards a net-zero carbon economy.	The study identified six innovative prefabricated construction methods (IPCMs) for affordable housing projects in Southern Africa. The findings showed that higher sustainability performance was obtainable when compared to conventional methods, with monolithic IPCMs being more suitable for net-zero carbon buildings.

- Housing sector dynamics
- Sustainable housing development
- Urban development planning.

3.4. Review of Literature

The systematic literature review (SLW) was carried out to examine the state of research developments on energy efficiency and affordable housing research based on Lotka's law. As surmised by the law, the most highly cited publications on EE-AHR were examined to identify, explore and highlight the research developments in the field. Table 2 presents an overview of the most highlighted cited publications along with their aims, objectives, and major findings.

4. RESEARCH GAP AND FUTURE RESEARCH OUTLOOK

Despite the numerous studies on the topic of energy efficiency and affordable housing (EE-AH) based on various backgrounds, there are still critical gaps that remain unaddressed in the research landscape. For example, there is an urgent need to critically identify and comparatively examine the top techniques and creative ideas for globalised applications. There is limited information on how to apply the findings from one country or region to another across the globe. Furthermore, the problems encountered by private developers in countries like India and China require practical implementation strategies. In addition, future studies will need to examine the concrete or causal links between social outcomes (e.g., health, education, and economic background) and affordable housing for deeper analysis and comprehension. The viewpoint could also give rise to research into the impartial access, transit, and spatial distribution of EE-AH. Hence, there is a need for more comprehensive research for effective as well fairer availability of selected demographics to critical amenities.

Another potential area for future research is the need for a more nuanced comprehension of the organisational frameworks and the impact of public perception on EE-AH and related initiatives

beyond various regions of the globe. It will also be necessary to examine the link between energy efficiency and economic value in AH. Based on the review of the literature, this is an inadequately investigated area or topic which necessitates integrated studies to examine the financial feasibility and environmental practicality of EE-AH. Further research is needed on the social integration of immigrants through AH programs, NIMBYism's (Not In My Back Yard) impact on equitable development, and improving social vulnerability and disaster resilience in AH communities.

Technology application in EE-AH research is another important area that needs to be explored. The exploration of EE-AH through the use of innovative, low-cost and sustainable technologies (e.g., modular and prefabricated methods) in the construction sector is required for better design, development and deployment. Such approaches are also needed to accomplish the goal of a net-zero carbon economy, which is critical to the UN-SDG 11. Lastly, the use of innovative materials (e.g., shredded waste plastic and agricultural waste residues, among others, for soil stabilization) in EE-AH construction offers promising solutions. Nonetheless, rigorous validation is needed for integrated approaches in healthcare and education.

5. CONCLUSIONS

The paper presents insights into the research landscape on Energy Efficiency and Affordable Housing (EE-AH) studies using the three-pronged approach of analyzing the publication trends, bibliometric data, and literature review of the publications on the topic indexed in the Scopus database from 2001 to 2023. The findings revealed that numerous publications have been produced by various stakeholders (e.g., authors, affiliations, and countries) actively taking part in the research topics on EE-AH. The publication trends showed that several factors, such as researchers' interests, affiliation direction, and national policy, were adjudged to have influenced the productivity of stakeholders. Notably, collaboration between affiliations was identified as critical to productivity, along with funding from various agencies and organisations. The keywords co-occurrence analysis identified three critical focus research areas in EE-AH research, namely Housing Sector Dynamics, Sustainable Housing Development, and Urban Development Planning.

The systemic literature review showed that the research landscape on EE-AH research is a broad, multidisciplinary, and impactful area with significant potential for future research, collaboration, and growth. Despite numerous studies on energy efficiency and affordable housing (EE-AH), critical gaps remain in research. These include identifying globalized application techniques, examining social outcomes, understanding organizational frameworks, and examining energy efficiency. Future research should also explore technology applications in EE-AH, using innovative materials for better design and deployment and addressing social integration, environmental sustainability, and net-zero carbon economy goals.

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