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Human factor across urban carbon neutrality case studies - A systematic literature review

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Abstract
This paper presents a systematic literature review of the urban carbon neutrality research landscape, conducted in two stages. First, a bibliometric analysis was performed on 1,769 articles sourced from the Web of Science and Scopus databases. Second, a comprehensive examination was undertaken to assess how the selected studies address the role of human behavior in achieving urban carbon neutrality. The results show that the understanding of human behavior's impact on greenhouse gas (GHG) emissions is still in its nascent stages. While much of the current research focuses on developing methodologies for measuring urban GHG emissions—a critical step toward carbon neutrality—there is a notable lack of exploration into the connection between human behavior and emissions. This gap underscores the need for future research to integrate behavioral perspectives into urban carbon neutrality strategies. Achieving carbon neutrality will require not only identifying emission sources and neutralization methods but also engaging citizens and shaping behaviors to align with the city's carbon neutral agenda.

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I. Introduction

Throughout the 20th century, populations worldwide migrated from rural areas to cities, leading to unprecedented urban growth. In 1900, only 13% of people lived in urban areas, but by the 1950s, that figure had more than doubled to 29%. This trend, rural-to-urban migration, has continued to grow into the 21st century, with projections suggesting that more than 68% of the global population will reside in cities by 2050, up from 55% in 2018 (UN, 2022). In terms of their contribution to global warming, despite occupying only 3% of the Earth's surface, cities account for over 70% of global GHG emissions, intensifying climate change (World Bank, 2019).

Recent studies have shown that one potential path to mitigating or reversing the effects of climate change is to reshape urban life and urban metabolism. By balancing human needs with sustainable practices, urban activities can cause less harm to the environment, while maintaining economic growth (Derrible, 2021 #629), and this is eventually determined by human behavior

Building on this premise, this research identifies the key drivers in projects aimed at reducing GHG emissions in cities. It then analyzes case studies that have implemented or documented policies designed to transform cities into more sustainable and healthier environments for both humans and nature. Furthermore, this study seeks to answer the following question: What common factors contribute to the success of CO_2 reduction initiatives in cities? By identifying these factors, the research also aims to highlight policies that account for human behavior and other social factors, framing them as essential elements in the transition to greener, more sustainable urban environments.

This paper provides a systematic literature review of the publications collected from both the Scopus and Web of Science databases, using bibliometrics to analyze the research landscape and evolving trends (Liu et al., 2020). In the following sections, relevant work on climate changes, GHG emissions, cities, and urban impact drivers is reviewed and organized as follows. In Section 2, the research background is provided, in Section 3, methods and data are discussed, in Section 4, the results of the systematic literature review are detailed. Finally, the relevant conclusions and future research directions are shown in Section 5. Our research sheds light on the role of human behavior as an approach for cities to reach climate neutrality aims, as well as the impact of such an approach to provide actionable insights for policymakers and urban planners striving to balance economic growth with environmental sustainability.

1. The Role of Urbanization in Global Climate

The Paris Agreement of 2015 (Council, E. 2023) and the 2030 Agenda for Sustainable Development (UN. 2015) launched a global agenda to transform the economic and social model, focusing on decarbonization and inclusive prosperity. These commitments emphasize that structural changes can only be achieved through a multilateral approach and new governance models based on equity. The Sustainable Development Goals (SDGs) address global challenges, with SDG 11 dedicated to making cities more inclusive, safe, resilient, and sustainable. Therefore, tackling the climate crisis requires coordinated action from cities and citizens, as recognized in these global agreements.

Urbanization has been one of the most transformative driving forces of the 21st century and a hallmark of modern society. According to a UN report (2022), by 2050, more than 68% of the global population will live in urban areas, a significant increase compared to the 55% recorded in 2018. Although cities cover only 3% of the Earth's surface, they account for over 70% of global greenhouse gas (GHG) emissions, significantly exacerbating climate change (World Bank, 2019; Kennedy et al., 2010; Satterthwaite, 2008). Figure 1 illustrates the trend of population and urban growth projected for 2030.

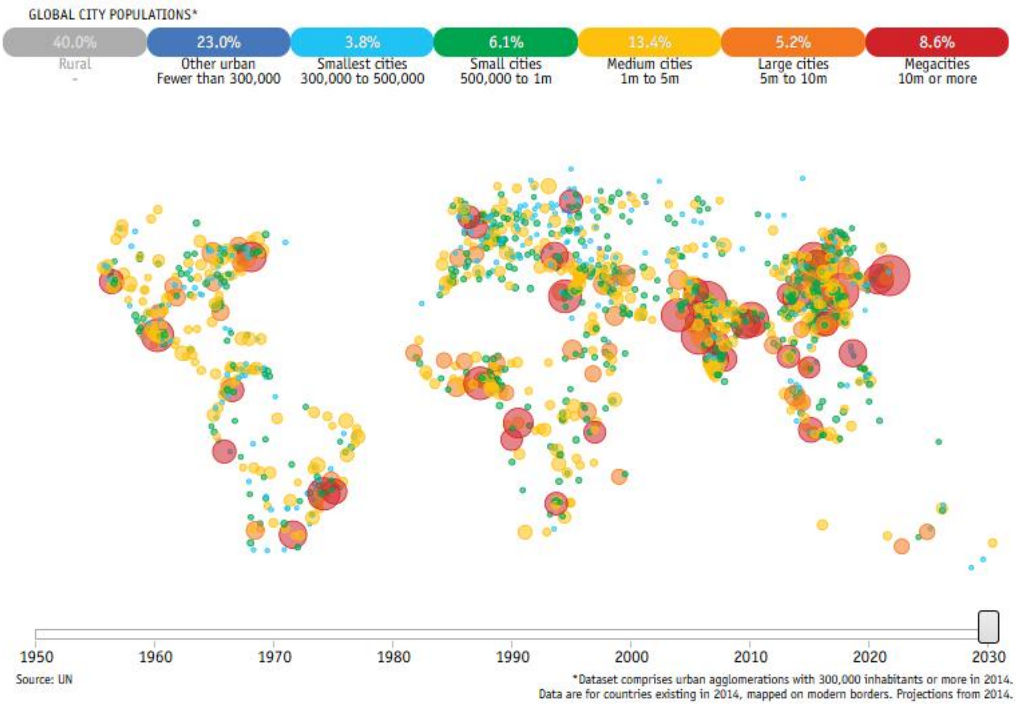

Figure 1: Urbanization and the rise of the megacity from 1950 to 2030 (Source: The Data Team (2015).

Cities are responsible for economic growth, together they generate more than 80% of the global Gross Domestic Product (GDP). However, this economic growth has resulted in significant negative environmental impacts, intensive resource consumption, and reliance on non-renewable energy sources resulting in an increasing ecological footprint of cities (Peijun, 2020; Hangna, 2023).

The urbanization process has often been characterized by significantly higher temperatures in cities compared to rural areas (Figure 2), a phenomenon known as the urban heat island (UHI). This phenomenon is caused by the high concentration of impermeable surfaces, low vegetation cover, and substantial heat generated by human activities (Hangna et al., 2023). UHI increases cooling costs, exacerbates the risks of heat waves, and harms public health, especially in densely populated cities. Additionally, GHG emissions have significantly contributed to rising temperatures in major urban centers. According to Shadnoush (2024), there are three main sources of GHG emissions in cities: energy generation, transportation, and construction activities. In Karaj, Iran, for example, power plants contribute 47% of total emissions, followed by residential and commercial units (27%) and transportation (24%) (Omranian, 2023). This pattern is consistent with other urban areas worldwide, where residential energy use and urban sprawl increase carbon emissions. Proposed mitigation strategies include comprehensive inventories and targeted policies addressing energy efficiency, transportation system reforms, and sustainable waste management (Hoda Karimipour et al., 2021), as well as creating green corridors and utilizing passive cooling technologies (Manni, 2023; Hangna et al., 2023).

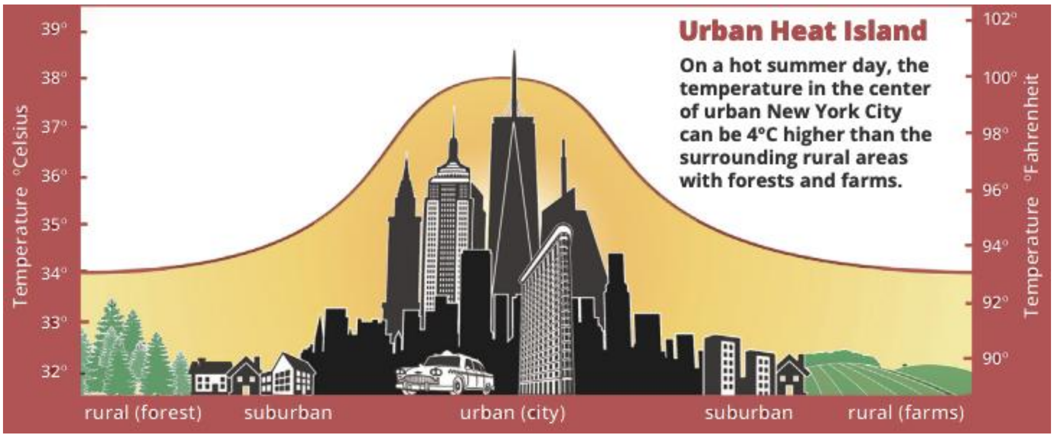

Figure 2: Urban Heat Islands. Source: My NASA Data (n.d.)

Furthermore, the generation of urban waste is another significant source of GHG emissions, especially when there is a lack of adequate infrastructure for its management. In this regard, innovative solutions have proven effective in reducing GHG emissions, enabling a more sustainable direction for cities (Fuss, 2020).

2. Urban Transformations: Towards Sustainable Cities

Despite contributing significantly to climate change, cities have enormous potential to generate innovative solutions, such as the use of renewable energy, sustainable waste management, and green infrastructures (Agnieszka, 2016; J, Bhuvana, 2023). As hubs of innovation, cities benefit from sectoral integration and access to resources and knowledge, allowing them to develop and scale new solutions. Their role in climate action is crucial. Achieving climate neutrality demands coordinated efforts across all urban subsystems and the promotion of interdisciplinary collaboration among diverse social actors in novel and effective ways.

Efforts to reduce greenhouse gas (GHG) emissions have prompted the development of various strategies and solutions worldwide. Regarding renewable energy, solar neighborhoods are emerging as an effective solution, in which projects that combine solar technologies with urban green spaces have shown significant reductions in fossil energy demand, as well as improvements in residents' quality of life (Manni, 2023; Hangna, 2023).

Green infrastructures, such as urban parks, have also been crucial in reducing the impact of cities, not only by sequestering carbon but also by mitigating heat island effects and promoting biodiversity, and studies indicate that a better distribution of green areas across neighborhoods can amplify these benefits (Hangna, 2023; Peijun, 2020). Regarding waste management, solutions such as Mechanical Biological Treatment (MBT) demonstrate that it is possible to reduce landfill-destined waste by up to 70%, significantly decreasing methane emissions while also contributing to the circular economy practices (Fuss, 2020). Furthermore, understanding the urban metabolism enables the identification of opportunities to optimize resource use and reduce environmental impacts. Tools such as emission inventories and spatial planning also are essential to achieving these goals (Omranian, 2023).

In Europe, the European Commission established the mission "Climate-Neutral and Smart Cities" aimed to transform 100 European cities into carbon-neutral ones by 2030 (Cities, E. (2022). The goal is to accelerate the implementation of the Paris Agreement and the 2030 Agenda, drive the European Green Deal, and demonstrate that climate neutrality before 2050 is achievable with social, economic, and environmental benefits.

All these initiatives are based on the premise that the transition to more sustainable cities requires integrated approaches combining technological innovation, public policies, and societal engagement. Rama et al. (2020) indicates that urban areas incorporating sustainability indicators into their planning demonstrate greater climate resilience and improved quality of life for their populations. Such solutions exemplify how cities can integrate sustainability into their infrastructure, resulting in socio-environmental benefits (Rama, 2020).

2.1: Urban Emissions: Main Causes and Scope Challenges and Opportunities

Cities contribute up to 70% of global GHG emissions, mainly due to activities related to the energy sector, transportation, land use, waste management, and buildings (Siddik et al., 2022; Yuzhuo Huang & Matsumoto, 2021). The impact of urban emissions reflects a common pattern in which human activities in cities are increasingly dependent on energy-intensive processes and natural resources, while disorganized urbanization patterns with significant gaps in good planning and sustainable infrastructure are evident (Estrada & Perron, 2021; Zhan et al., 2023). In this sense, the energy sector emerges as the major contributor to urban carbon dioxide (CO_2) emissions, with electricity and heat generation accounting for the most significant values within this sector, mainly in developing countries where rapid urban and economic growth rises energy demand, which is based on fossil fuels and where the intensive use of coal in the energy matrix substantially contributes to urban emissions (Yuzhuo Huang & Matsumoto, 2021). This is corroborated by Siddik et al. (2022), who highlight the low penetration of renewable energy sources in countries with abundant natural resources, as well as economic and structural barriers that hinder the energy transition (Siddiketal, 2022).

An important sector that also contributes to GHG emissions is transportation, particularly in cities where a large portion of the fleet is composed of vehicles powered by fossil fuels. In these cities, the lack of efficient public transportation infrastructure increases the usage of private cars, raising the level of CO_2 emissions. Additionally, the transportation and logistics of goods in cities with poor urban planning and heavy traffic is another major factor in GHG emissions. According to Zhan et al. (2023), the electrification of transportation remains limited, even in industrialized regions, which sustains the dependence on fossil fuels and restricts the potential benefits of sustainable solutions (Yuzhuo Huang & Matsumoto, 2021).

In the context of climate change, land use, and urban waste management are also important drivers of urban GHG emissions. Often, urban growth involves the conversion of forested areas into residential and/or commercial zones, reducing the soil's carbon sequestration capacity (Zhan et al., 2023). In urban areas, the use of fertilizers for maintaining gardens and lawns increases nitrous oxide (N_2O) emissions, a greenhouse gas that is approximately 273 times more potent than CO_2. Furthermore, Huang & Matsumoto (2021) and Zhan et al. (2023) point out that in cities, poor management of municipal solid waste is another significant source of emissions, particularly in countries where landfills are predominant. These landfills lead to considerable methane emissions, a greenhouse gas 28 times more potent than CO_2.

Buildings, whether residential or commercial, are also significant contributors to urban GHG emissions. Studies indicate that buildings may account for a large share of energy consumption in cities due to their needs for heating, cooling, lighting, and the operation of appliances (Zhan et al., 2023). In high-income countries, commercial buildings are major consumers of electricity. On the other hand, in low-income countries, energy inefficiency in construction results in significant reliance on fossil fuel (Huang & Matsumoto, 2021; Siddik et al., 2022)

Inadequate urban structure and planning also contribute to current GHG emission patterns (Estrada & Perron, 2021). Researchers indicate that in densely urbanized regions, the heat island effect can amplify emissions by up to 15% compared to suburban areas. However, larger cities with low population density are more dependent on vehicles, resulting in higher per capita transportation emissions (Huang & Matsumoto, 2021). In this sense, it is important to highlight the interconnection between these sectors and their emissions (Table 1), such as the increase in individual transportation use, which is often a response to inefficient urban planning and transportation systems. Meanwhile, the rise in energy demand from buildings is directly related to economic growth and changes in urban consumption patterns. These relationships point to the need for integrated approaches rather than isolated and purely technical solutions, where the transition to renewable energy, promotion of public transport, sustainable buildings, and proper waste management are addressed as a whole. Finally, although these structural drivers are the core of discussions on GHG, human behavior is an essential factor in understanding the issue. Individual and collective decisions directly affect energy consumption, transportation choices, recycling practices, and other factors.

Study area	Authors	Considerations
Energy Sector	Siddik et al., 2022; Yuzhuo Huang & Matsumoto, 2021	The energy sector is the major contributor to urban CO_2 emissions. Electricity and heat generation are key drivers, especially in developing countries with high reliance on fossil fuels like coal.
Transportation	Zhan et al., 2023; Yuzhuo Huang & Matsumoto, 2021	High CO_2 emissions due to fossil-fueled vehicles and lack of public transportation infrastructure. Limited electrification of transportation in industrialized regions sustains dependence on fossil fuels.

Land Use and Waste Management	Zhan et al., 2023; Huang & Matsumoto, 2021	Urban growth reduces soil carbon sequestration. Poor waste management, especially in countries with landfills, results in methane emissions.
Buildings	Zhan et al., 2023; Huang & Matsumoto, 2021; Siddik et al., 2022	Buildings are significant energy consumers for heating, cooling, and lighting. Construction materials like concrete and steel are major CO_2 emitters.
Urban Heat Island Effect and Planning	Estrada & Perron, 2021; Huang & Matsumoto, 2021	Urban heat islands increase energy demand for cooling, amplifying emissions. Inefficient planning increases dependence on transportation.
Individual and Collective Decisions	Multiple references in the text	Human decisions affect energy use, transportation choices, recycling, and urban consumption patterns.

Table 1: Summary of the main authors and their considerations regarding urban emissions.

3. The Role of Human Behavior in Urban Emissions

Urban emissions arise from multiple causes and drivers strongly connected by human behavior, which has the potential to either amplify or mitigate them. Whether in transportation choices, energy habits, waste management, or other actions, individual and collective behaviors directly influence emission patterns. Researchers indicate that individual and/or collective behavior accounts for a significant fraction of GHG emissions, especially in cities where population density intensifies the effects of daily choices (Stankuniene et al., 2020).

Human behavior not only directly contributes to several drivers of urban emissions but also impacts the effectiveness of policies and interventions to mitigate them. According to Acharjee & Sarkar (2021), in the context of urban mobility, preferences for private rather than public transportation are deeply based on social and psychological perceptions. The authors also point out that car ownership is often associated with convenience and social status, while public transportation can be perceived as less reliable or comfortable. Even in cities with well-developed public transport networks, cultural and social barriers continue to limit its adoption. Models such as Mobility as a Service (MaaS), which integrate different transport options into a single platform, show potential to transform these perceptions, encouraging the use of more sustainable mobility like bicycles, ride-sharing, and public transportation (Ozpinar, 2023).

In the context of buildings, energy consumption patterns are strongly influenced by individual and daily decisions. Thus, the choice of appliances, lighting, heating, and cooling habits, as well as the adoption of energy efficiency technologies, reflect behavioral factors of people such as knowledge, economic status, and social norms. Studies indicate that small habit changes can significantly reduce emissions associated with urban buildings (Stankuniene et al., 2020). Additionally, "energy literacy" combined with financial incentives and educational programs has shown good results in reducing energy consumption in urban buildings (Pestana et al. 2021). Similarly, political incentives that raise public awareness of environmental impacts, such as the choice of more sustainable building materials like low-carbon concrete and efficient insulation, have also proven effective (F Antoniou, 2022; J.M., Taylor, 2011).

Human behavior also plays a fundamental role in urban waste management due to the culture of consumerism and conveniences such as food delivery services, that has fostered a significant increase in the volume of plastic and/or organic waste. Demographic characteristics, such as income and occupation, also greatly influence waste generation patterns. Thus, Tan et al. (2021) point out that interventions tailored to local specificities are necessary, as well as the creation of public policies that encourage the use of more sustainable resources, contributing to the reduction of the impacts. However, such policies require profound changes in population habits and attitudes. All these examples highlight the strong connection between human behavior and drivers of GHG emissions, but addressing these issues demands a holistic perspective that must consider not only direct impacts but also the subjective motivations and barriers that shape individual and collective decisions.

However, despite the existing consensus on the importance of human behavior related to GHG emissions, as illustrated in Table 2, many researchers treat behavior merely as data, without understanding its underlying motivations, neglecting the social sciences (Victor, 2015), and focusing on technological changes (Creutzig et al 2016). reveling gaps in understanding human behavior. These gaps in the understanding of barriers can hinder greater adoption of more sustainable practices, for example, psychological barriers in which aspects such as social norms and risk perceptions are often ignored, they are essential to changing the consumption habits of people (Katar, Ihab. 2022). Also, cultural barriers, such as engagement with new modes of transportation, such as bicycles and electric vehicles, are limited by perceptions of comfort (Luh et al., 2022).

Thus, the use of behavioral models, such as those proposed in the Self-Determination Theory, can help align public policies with the intrinsic needs and motivations of citizens (Stankuniene et al., 2020). Finally, human behavior can be considered a central factor in urban emissions, but it also offers a powerful pathway for mitigation. To achieve climate neutrality, it is essential for cities to systematically address behavioral motivations and barriers.

Study Area	Source	Considerations	Considering Human Behaviors
Urban (households)	Stankuniene et al., 2020	Individual and collective behaviors account for a significant fraction of urban GHG emissions. Population density intensifies the effects of daily choices. Behavioral models align policies with citizen motivations.	Yes
Mobility	Acharjee & Sarkar (2021)	Preferences for private vehicles over public transportation are driven by social and psychological perceptions. MaaS models show the potential to encourage sustainable mobility.	Yes
Mobility	Luh et al., 2022	Small habit changes in energy consumption can significantly reduce emissions. Psychological barriers are often ignored, they are essential to changing the consumption habits of people	Yes
Buildings	F Antoniou, 2022; J.M., Taylor, 2011	Public awareness and incentives can promote sustainable building materials like low-carbon concrete and efficient insulation.	Yes
Energy	Tan et al., 2021	Public policies encourage sustainable changes in the population. However, such policies require profound changes in population habits and attitudes	Yes
Human Behavior (Social Science)	Victor, 2015; Creutzig et al., 2016	Researchers often neglect the underlying motivations of human behavior, focusing more on technological changes than social sciences.	Partially
Energy	Pestana et al., 2021	Psychological barriers, such as social norms and risk perceptions, hinder the adoption of sustainable practices.	Yes
Mobility	Katar, Ihab. 2022	Gaps in the understanding of barriers can hinder greater adoption of more sustainable practices.	Yes

Table 2: Summary of the main authors and their considerations regarding Human Behavior.

4. Material and methods

4.1. Search strategy

This study was conducted in two stages. The first stage involved a bibliometric analysis, which summarizes the bibliometric and intellectual structure of a field by examining the social and structural relationships between various research constituents (e.g., authors, countries, institutions, topics) (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Accordingly, this bibliometric analysis aimed to identify key elements across multiple documents by analyzing the most frequently used words in their abstracts.

In the second stage, following the identification of the elements, a systematic literature review was carried out with a more specific focus on the human behavior factor, to understand how the human factor has been taken into account in those studies. Then, a systematic literature review, using classic methods, requires a narrower scope of study and thus tends to include a lesser number of papers for review and fit better for confined or niche research areas (Donthu; Kumar; Mukherjee; Pandey; Lim, 2021). This procedure was aligned with the second strategy stage of this study.

There are many databases of peer-reviewed literature, digital libraries, web-based academic search engines, and preprint servers. Among them, Web of Science and Scopus are the two world-leading and competing citation databases as they index high-quality peer-reviewed publications and have a large coverage of different literature topics and studies across all domains (Benita, 2021). This study, in the first stage, focused on the Scopus database, as based on Singh, Singh, Karmakar, Leta, and Mayr (2021) “34% of journals indexed in Scopus overlap with Web of Science and that Scopus has about 66% of its journals exclusively covered as compared to Web of

Science". Afterward, in the second part, both the most recognized data sources - the Web of Science and Scopus databases were added. From the Scopus database, the research retrieved full-text articles using the following terms: Cit* OR urban, "greenhouse gases" OR GHG OR "carbon neutrality", and "case stud*" to be connected by the boolean operator "AND" to filter the documents. From this initial search, 2072 documents were obtained. Thus, only English-language documents and publications from conference proceedings and journals were selected, resulting in a total of 1769 (Figure 3).

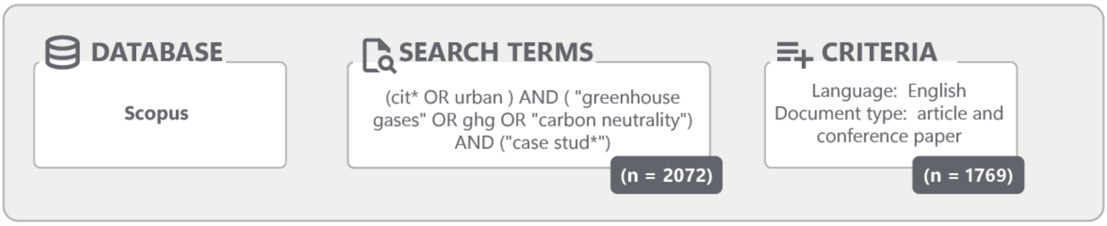

Figure 3: Article screening stage 1.

In the 1769 selected documents, the following parameters were analyzed: the annual evolution of publications, the main authors, subject areas involved within, the countries, and finally, the verification of the main elements or terms found in the abstracts. This parameter aimed to detect and understand possible patterns in the analyzed research.

In the second part of the study, the term 'human' was added to the search, filtering documents that addressed the human factor among their research topics. As previously mentioned, this search was conducted using the Scopus and WoS databases, gathering a total of 210 documents (155 from Scopus and 55 from WoS) where 16 documents were identified as duplicates between the databases. Therefore, after removing the duplicates, a total of 194 articles were selected. However, after focusing on those that used the term 'human.', aiming to filter those documents in which the term 'human' appeared in the titles, abstracts, or keywords, the total of articles was reduced to 35, which were selected to be analyzed in depth (Figure 4)

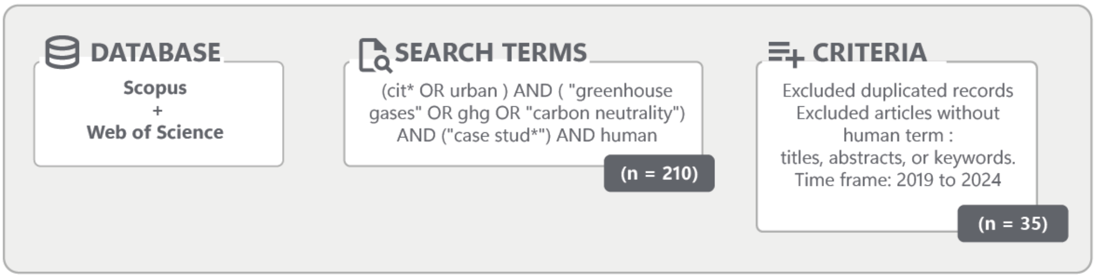

Figure 4: Article screening stage 2.

4.2. Methods of analysis

Due to the volume of documents found in the first part of the study (1239 papers), for the Scopus database analysis, the data visualization tool VOSviewer software was used to extract common subjects and topics addressed by the selected articles. As stated by Van Eck and Waltman (2009), 'VOSviewer is a program that we have developed for constructing and viewing bibliometric maps - the program is freely available to the bibliometric research community (see www.vosviewer.com) - offering a viewer that allows bibliometric maps to be examined in full detail.'

In the second part of the study, no analytical tools were used, and an in-depth articles reading strategy was conducted.

5. Results

5.1. Bibliometrical analysis

Yearly evaluation of publications reflects the development status, knowledge accumulation, and even the maturity of this field. The variation curves of the article's publication are presented in Figure 5. A preliminary search found that the first published paper regarding greenhouse gases appeared in 1993 and was under the theme of Energy and discussed the benefits of using natural gas compared to the fossil fuel industry. Later in 1994, a case study from Sri Lanka addressed the problem of greenhouse gas emissions in the transportation sector, but then again, it was only one publication. Only then, in 1998 the topic started to receive more scholarly interest, with three more publications engaged with this subject.

Furthermore, in the first 15 years after 1993, no more than 10 publications addressed this theme per year. Nevertheless, it is clear that from 2008 onwards, there began to be an increase in publications and research on the subject. From 2016 onwards, however, the number of publications on the subject grew considerably (surpassing 100 publications per year).

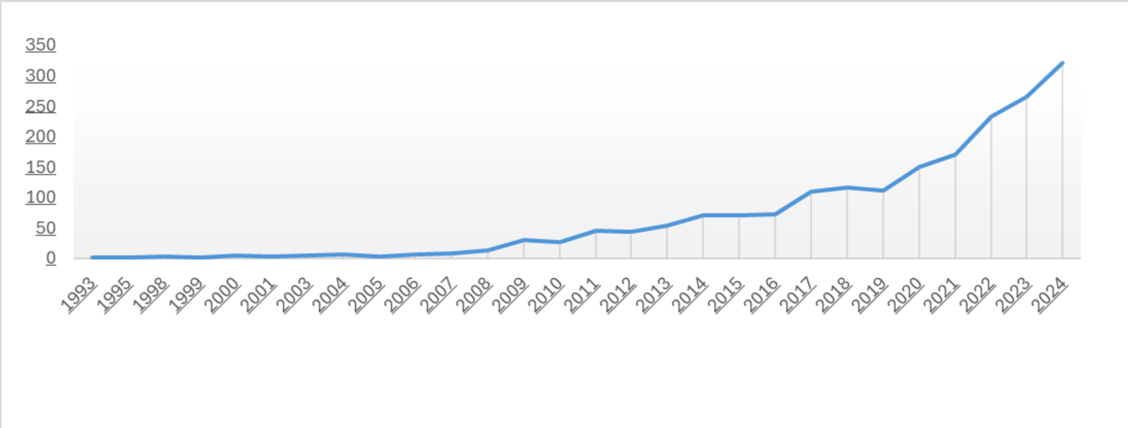

Figure 5: Evolution of publications

The number of publications was plotted in the chart illustrated in Figure 6 to identify the productive and influential countries involved in GHG research. There are as many as 100 countries/territories that are involved in this realm. Ranking the top 10 countries/territories, China stands out as the most productive in terms of publications (354 publications - 20%). Achieving more than double that of the second-ranked the United States of America (151 publications 8,54%), followed by Italy (5%), the United Kingdom (5,48%), Germany (4,47%), Spain (3,62%), Canada (3,11%), India (2,54%), Iran (2,15%), and Australia (2,9%).

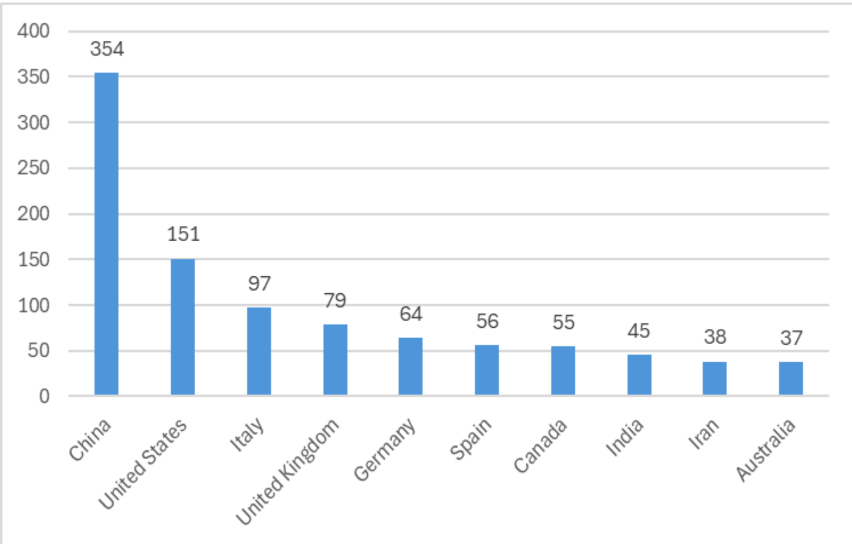

Figure 6: Influential countries involved in GHG research

Analyzing the authors' contributions, and comparing them with the number of publications per author on the topic of GHG (Table 3) and with the total of publications per author, we observe that publications about GHG are minimal concerning the total number of publications, with no author dedicating more than 6.3% of their work to the subject. Moreover, the author with the highest number of publications allocated less than 2% to this area.

Author name	**Documents about GHG within the publications per author**	**Total of publications**	**Country**
Horvath, A.	10 (5.7%)	175	USA

Geng, Y.	9 (1.8%)	483	China
Rieradevall, J.	8 (4.6%)	172	Spain
Heinonen, J.	7 (6.3%)	110	Iceland
Chester, M.V.	7 (4.7%)	148	USA
Brattebø, H.	6 (5%)	119	Norway
Crawford, R.H.	6 (4.7%)	126	Australia
Dong, L.	6 (4.3%)	137	China
Creutzig, F.	6 (3.8%)	157	Germany
Eicker, U.	6 (2.3%)	258	Canada

Table 3: Publications per author on the topic of GHG.

About the subject area, twenty-five areas of knowledge were identified. As illustrated in Figure 7, the top 10 most predominant subject areas identified are environmental science, engineering, energy, social sciences or computer science.

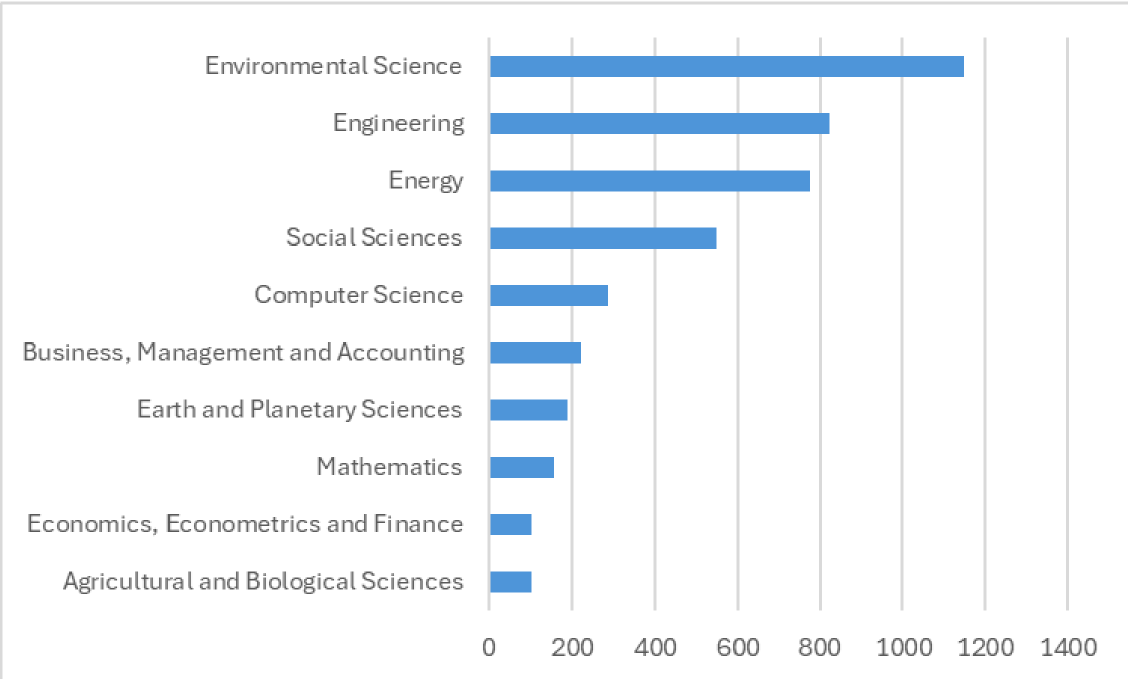

Figure 7: Top 10 areas of knowledge identified.

The analysis of the 1769 papers resulted in the network cloud generated, represented in Figure 8, which makes complex data accessible, allowing for an interpretation of trends and focus areas aside from importance and relevance topic evaluation, providing evidence-based insights (Joseph et al., 2024).

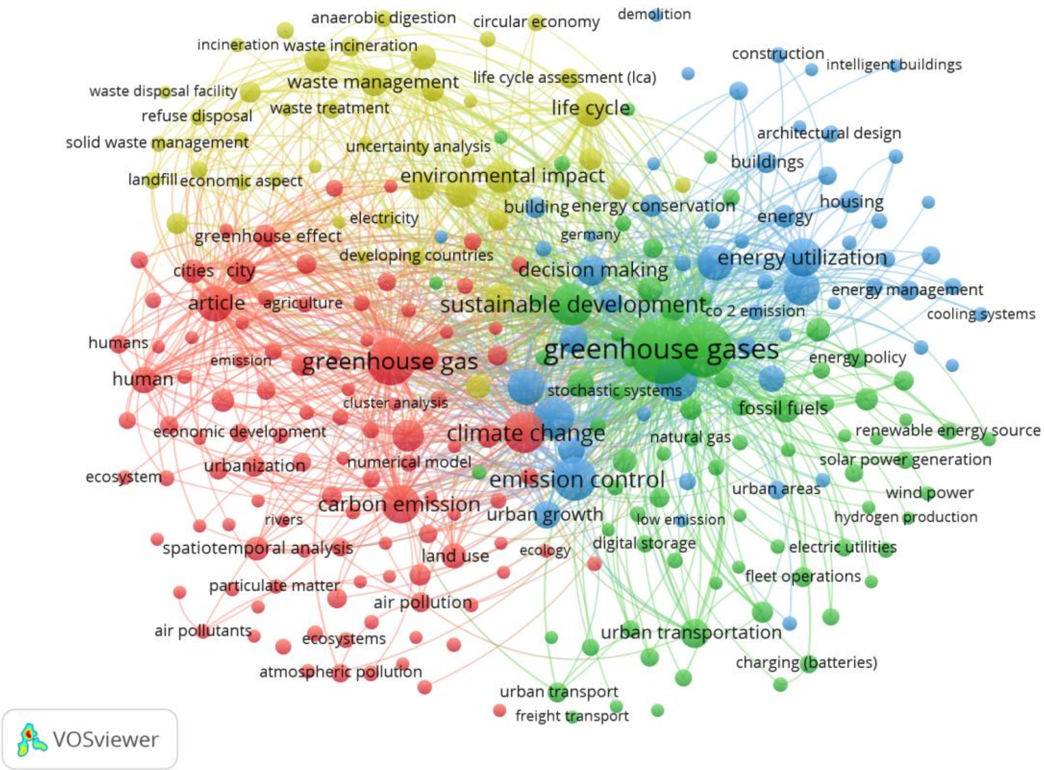

Figure 8: Network cloud generated with Vos.

Analyzing the nouns shown in the network cloud generated with the Vos application, most of the studies seem to be driven by four main themes, which were separated by color for the software (Greenhouse gas - in red; Greenhouse gases - in green; Energy utilization/Emission control - in blue; and Life cycle - in yellow). Moreover, the few nouns associated with the "Human factor" shown for this chart are: human and humans (being part of the red cloud on the far left). Notably, this situation highlights an interesting observation, since this might suggest that "human action" might not be treated as an origin of the GHG, but as a mere component of the system.

This perspective—organizing "humans and human activities" alongside urban transport, electricity, and cities—reflects a phenomenological approach to experiencing any subject, where technology and humans are viewed as a unified entity (Merleau-Ponty, 2010). In this case, citizens (humans) and cities (a collective of technologies) were unified within an "urban space." This unification not only defined the subject of the study but also shaped the research lens, integrating both elements into a single analytical framework.

Therefore, this embodiment of the way of interpreting humans of one more component of static and closed systems (cities), implies that researchers may have overlooked the role of human behavior in driving urban emissions. Instead, such emissions are often treated as isolated data points to be collected and analyzed, rather than as outcomes intricately linked to human actions. This statement can also be supported after the second stage of the study of deep analysis of articles.

5.2. Second Stage of study

To understand and document the state of the art on case studies of carbon-neutral cities, a comprehensive analysis was conducted on 35 articles that included Human Factors in their abstracts and/or keywords. This analysis revealed a significant lack of data on implementing strategies to influence behavioral change. Additionally, it also highlighted a gap in understanding the human factors that determine how citizens can actively participate in the transition toward carbon-neutral urban spaces.

This resolution became evident after applying the initial screening method to the 35 articles, categorizing them into three distinct groups, represented in Table 4 and Figure 9 based on their level of "Integration of Human Factors" (IHF). To enhance visualization, each category was assigned a specific color. Articles that integrated human behavior or other human-related data into their analysis or results were classified as having a HIGH level of IHF and were marked with the color GREEN. Articles that mentioned human factors but did not analyze the underlying reasons behind such behaviors or explore their relationships with GHG emissions were classified as having a MODERATE level of IHF, represented by the color YELLOW. Lastly, articles that referenced human factors in their abstracts or keywords but did not incorporate them into their analysis were categorized as having NO IHF, associated with the color RED.

Level of IHF	Articles	Percentage
No IHF	10	28,57%
Moderate IHF	14	40,00%
High IHF	11	31,43%

Table 4: Distribution of Articles by Levels of IHF

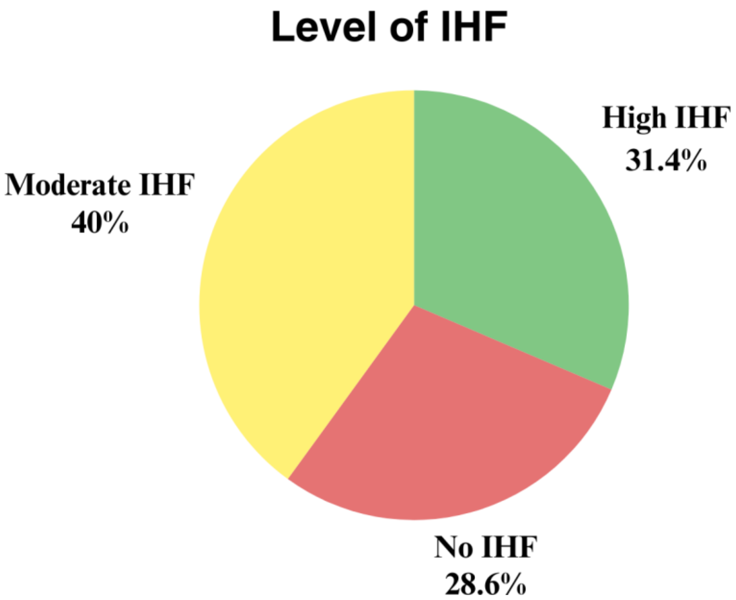

Figure 9: Distribution of Articles by Levels of IHF

Therefore, articles marked as RED (28.5%) focused almost exclusively on technological changes, such as replacing fossil fuel applications with alternative electric solutions, while barely addressing human participation in the urban transition towards carbon neutrality. These articles were vague regarding the human factors involved in the value chains of such transitions, even though they had mentioned human factors in their abstracts or had human factors as one of their keywords. Those marked as YELLOW (40%) included some level of human behavior, typically analyzing the consequences of urban activities and exploring alternatives to mitigate their impacts. Finally, less than one-third of the articles were marked as GREEN (31.4%), as they effectively incorporated human factors in their data and considered people integral to promoting carbon neutrality urban transitions. Articles marked as GREEN received additional attention during the analysis, as they offered valuable insights into effectively addressing the human factor within the context of urban carbon neutrality.

Since more than half of the articles (RED + YELLOW = 68.5%) did not prioritize human factors as their primary research focus, they appeared to concentrate on the initial phase of the transition process. This phase involved developing methods to measure the environmental impacts of urban human activity and identifying the aspects of urban life that contribute most significantly to environmental degradation (Foliente et al., 2007). However, it is also notable that 71.4% (YELLOW + GREEN) considered human factors as a metric or point of interest in building carbon-neutral cities. Nevertheless, most of these articles (40% YELLOW) did not explore the topic in depth beyond acknowledging the influence of human behavior on carbon emissions or the transition to carbon neutrality.

Nevertheless, it is worth saying that this initial data-gathering phase is essential for creating strategies to support the carbon neutrality transition effectively. It includes exploring solutions to better engage citizens by determining how to optimize their time and efforts in this process (Skarlatidou et al, 2021)

This resolution is further supported by additional data from the categorization of the articles. Such as only 34.2% of the studies were conducted by multidisciplinary teams of researchers, while 65.7% were not. Moreover, only 5.7% of the research teams included contributions from Human Science departments (Table

5)(Figure 10). This finding highlights that most of the collected data and methods were focused on measuring GHG emissions and other pollutants.

Multidisciplinary	Number of articles	Percentage	Human Science Collaboration
Yes (Y)	12	34,29%	2 (5,71%)
No (N)	23	65,71%	0

Table 5: Multidisciplinarity.

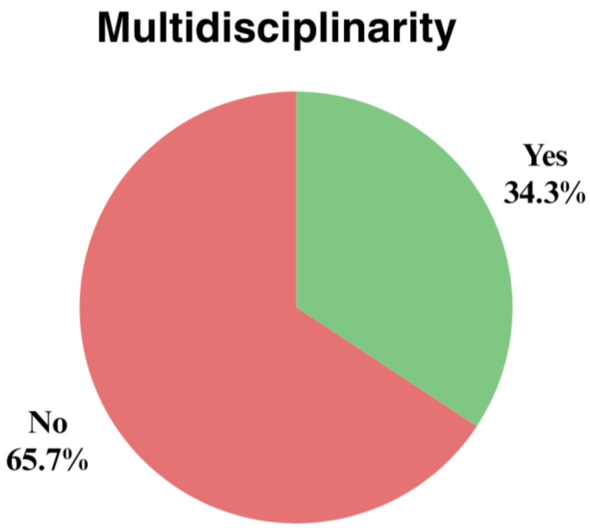

Figure 10: Multidisciplinarity.

Lastly, regarding how the articles approached their themes, quantitative data collection was present in 60% of all 35 articles (Figure 11) (Table 6).

Articles	Number of articles	Percentage
Qualitative	5	14,29%
Quantitative	21	60,00%
Semiqualitative	9	25,71%

Table 6:Total Research type (RED + YELLOW + GREEN)

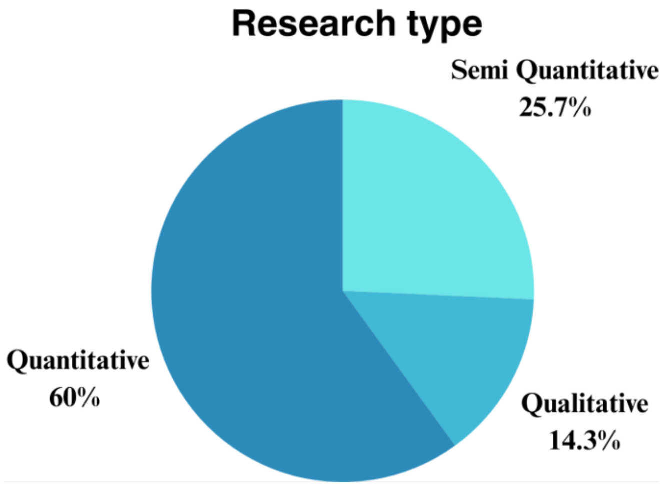

Figure 11:Research type (RED + YELLOW + GREEN)

When focusing exclusively on the YELLOW and GREEN-ranked articles, the percentage of quantitative studies remained the same at 60%. Semi Quantitative studies, which combined qualitative and quantitative research methods, ranked second in both datasets (Bertin, 1978) (Table 7) (Figure 12).

Articles	Number of articles	Percentage
Qualitative	3	12,29%
Quantitative	15	60,00%
Semiqualitative	7	28,00%

Table 7: Research type (YELLOW + GREEN)

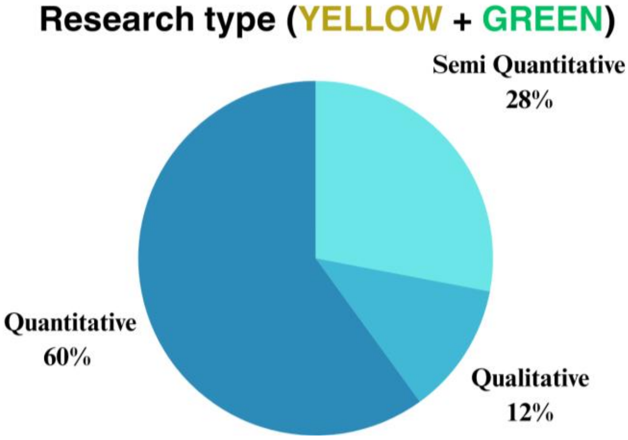

Figure 12: Research type (YELLOW + GREEN)

Thus, Semi Quantitative research accounted for 25.7% of all articles and slightly increased its proportion to 26% when excluding the RED-ranked articles. Qualitative research emerged as the least applied method, comprising 14% of the general dataset and dropping to 12% in the focused dataset. While the predominance of Quantitative research does not inherently indicate a bias toward natural or physical sciences—given that human sciences also extensively employ quantitative methods—the broader context suggests a lack of sufficient emphasis on questions such as how perceptions of climate change influence human behavior. Thus, this disparity supports this paper's thesis of the lack of human-centered inquiries in the urban carbon-neutral case study research realm.

5.3 Content analysis

The following analysis aimed to examine the distribution of publications based on various factors: the time of publication, the regions where case studies were conducted, the scope of the journals, the domain of the case studies, the variables analyzed, the research methods implemented, and the main objectives identified across all 35 deeply analyzed articles. All those variables explored in this section have contributed, to a greater or lesser extent, to the analysis of the previous section.

A significant majority (68.5%) of the articles were published after 2022 (Figure 13), with 2023 standing out as the year.

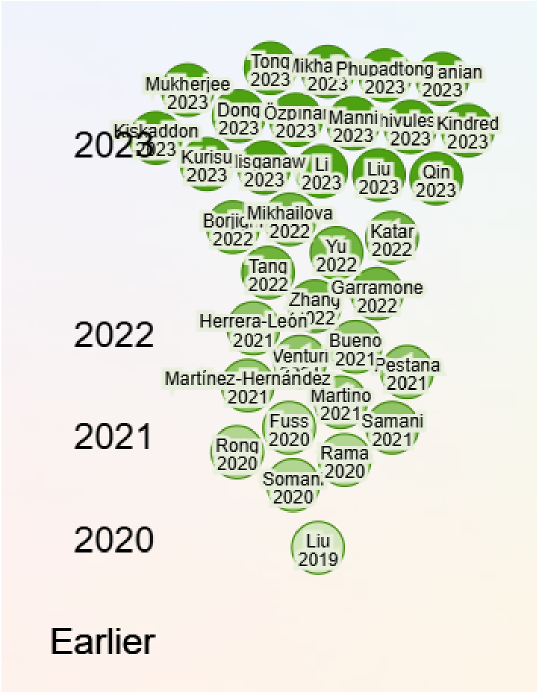

Figure 13: Distribution of articles over time (image generated with researchrabbitapp.com)

As shown in Table 8, the highest publication frequency was observed across all three main categories (RED, YELLOW, and GREEN). Although the initial research excluded articles published before 2019, it is noteworthy that only one article (3%) dates back to that year. Furthermore, there is a clear trend of increasing publication frequency in recent years, with nearly half of the articles (45.7%) published as recently as 2023. This trend may indicate the growing novelty of addressing GHG emissions at the city scale rather than ranking emissions at the national level.

Publication Year	All Articles (n= 35)	NO IHF (n=10, RED)	MODERATE IHF (n=14, YELLOW)	HIGH IHF (n= 11, GREEN)
2019	1 (3%)	-	1 (7,14%)	-
2020	4 (11,43%)	-	4 (28,57%)	-
2021	6 (17,14%)	2 (20%)	1 (7,14%)	3 (27,27%)
2022	7 (20,00%)	2 (20%)	1 (7,14%)	4 (36,36)
2023	16 (45,71%)	6 (60%)	7 (50%)	3 (27,27%)
2024	1 (2,86%)	-	-	1 (9,09%)

Table 8: Distribution of articles over time.

Nevertheless, since some regions of the planet show more GHG emissions than others, it is important to understand where the researchers have documented and studied those emissions. Thus, regarding where the case studies were conducted, Asia (40%) and Europe (28,5%) were the regions where most of the studies were conducted, but China has also stood out as a big focus of interest during the data gathering, being 25,7% of all the cases studied as represented in Table 9 and Figure 14. This variable was included in this research because sustainability globally demands a global effort since the effects of environmental negligence do not restrict itself to where it is caused.

Country	Number of articles	Percentage
Asia	14	40,00%
Middle east	3	8,57%
North America	3	8,57%
Europe	10	28,57%
South America	2	5,71%
Africa	1	2,86%
Other	2	5,71%
City	**Number of articles**	**Percentage**
China	9	25,7%

Table 9: Case study Region

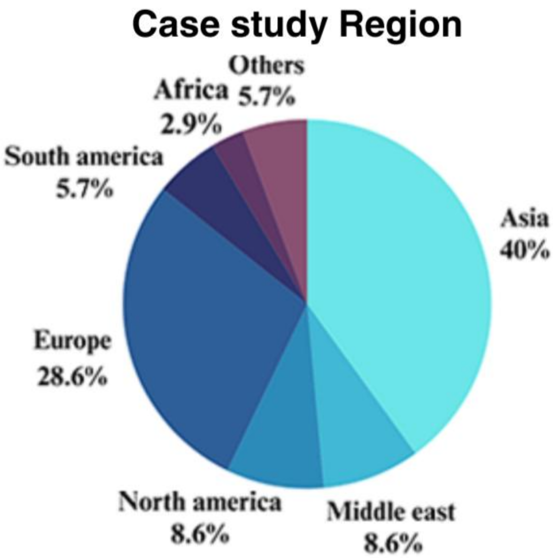

Figure 14: Case study Region

This trend of China's strong presence persisted when the analysis was not limited to articles categorized as YELLOW and GREEN combined (32%) (Table 10, Figure 15) but was also evident when focusing solely on GREEN articles (27.2%) (Table 11, Figure 16). This is particularly notable because China has been identified as the world's largest GHG emitter since 2006 when it surpassed the United States in annual emissions (Ding et al., 2017). However, this finding is not surprising, given that China, besides being the world's largest carbon emitter, also produces substantial research on carbon neutrality (Miao et al., 2024). Additionally, as previously noted in Figure 6, China's strong interest in the topic is reflected in its high volume of publications. Alongside China, Europe has also demonstrated a significant commitment to carbon neutrality through its number of publications, suggesting a shift in its internal policies regarding GHG emissions.

Country	Number of articles	Percentage
Asia	11	44,00%
Middle east	3	12,00%
North America	2	8,00%

Europe	5	20,00%
South America	1	4,00%
Africa	-	-
Other	2	12,00%
City	**Number of articles**	**Percentage**
China	8	32,00%

Table 10: Case study Region (YELLOW + GREENS)

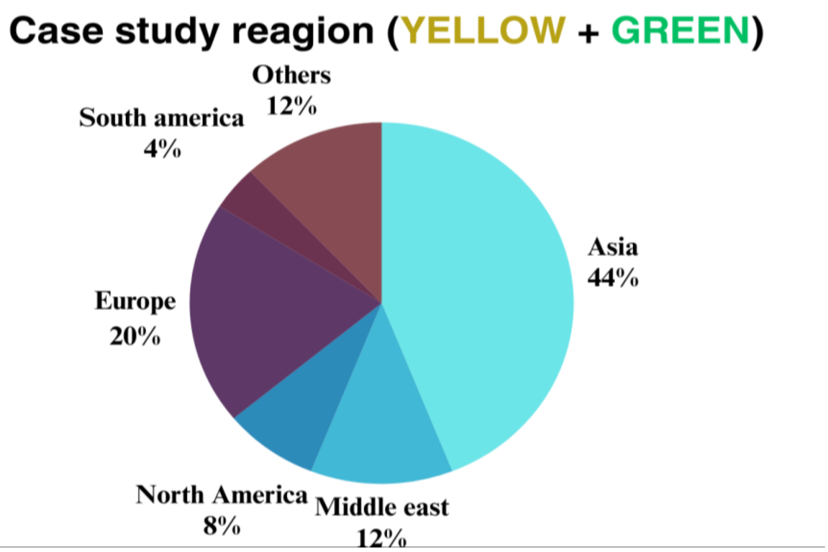

Figure 15: Case study regions (YELLOW + GREEN)

Country	Number of articles	Percentage
Asia	4	36,36%
Middle east	1	9,09%
North America	2	18,18%
Europe	3	27,27%
South America	-	27,27%
Africa	-	-
Other	1	9,09%
City	**Number of articles**	**Percentage**
China	3	27,27%

Table 11: Case study Region (GREEN)

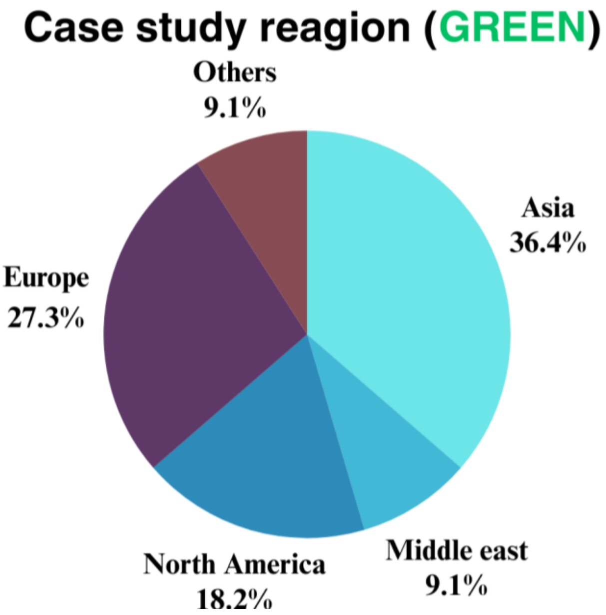

Figure 16: Case study Region (GREENS)

Regarding the periodic focus where the articles were published, most of the articles came from environmentally focused journals (60%) (Table 12) (Figure 17).

Type of scope	Number of articles	Percentage
Environment	21	60,00%
Energy	2	5,71%
Transport	2	5,71%
Urbanism	2	5,71%
Tech	2	5,71%
Public policies	2	5,71%
Others	4	11,43%

Table 12: Jornal's Scope

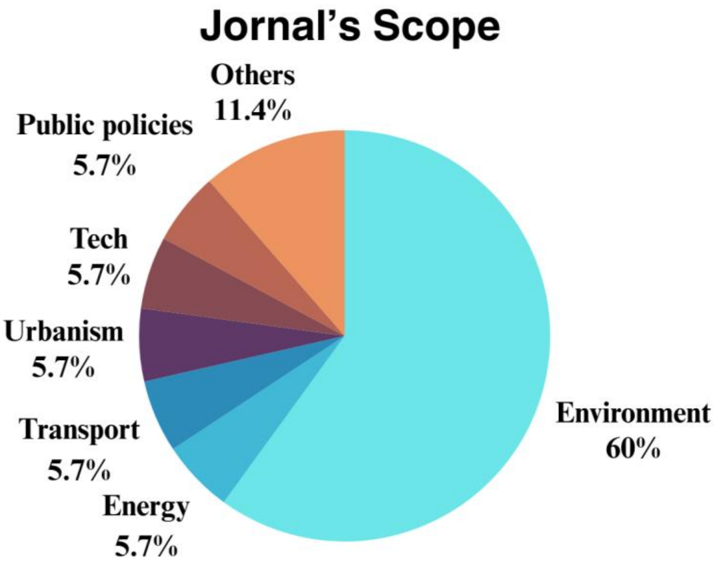

Figure 17: Jornal's scope

This tendency also was maintained after excluding the RED articles (72%) (Table 13) (Figure 18).

Type of scope	Number of articles	Percentage
Environment	18	72,00%
Energy	1	4,00%
Transport	2	8,00%
Urbanism	-	-
Tech	1	4,00%
Public policies	1	4,00%
Others	2	8,00%

Table 13: Jornal's Scope (YELLOW + GREEN)

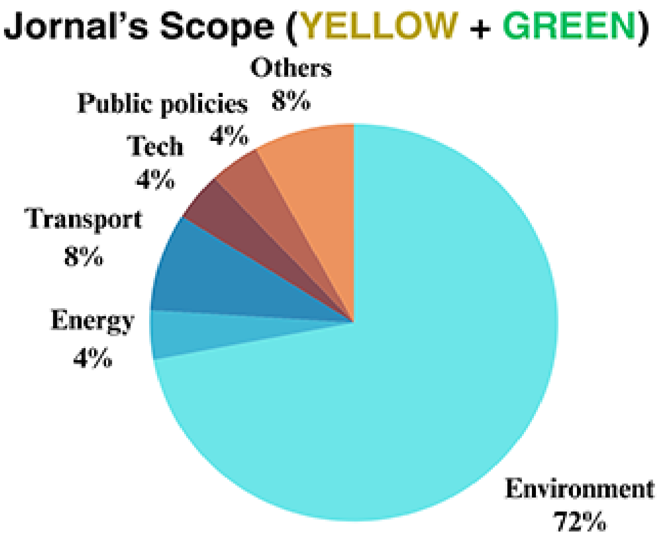

Figure 18: Jornal's scope (YELLOW +' GREEN)

The same was observed when focusing solely on the GREEN articles" (63,6%) (Table 14) (Figure 19). None of the analyzed papers were published in journals or presented at conferences dedicated to human sciences, reinforcing the thesis that carbon neutrality remains predominantly confined to the realms of physical and natural science.

Type of scope	Number of articles	Percentage
Environment	7	63,64%
Energy	1	9,09%
Transport	1	9,09%
Urbanism	-	-
Tech	1	9,09%
Public policies	-	-
Others	1	9,09%

Table 14: Jornal's Scope (GREEN)

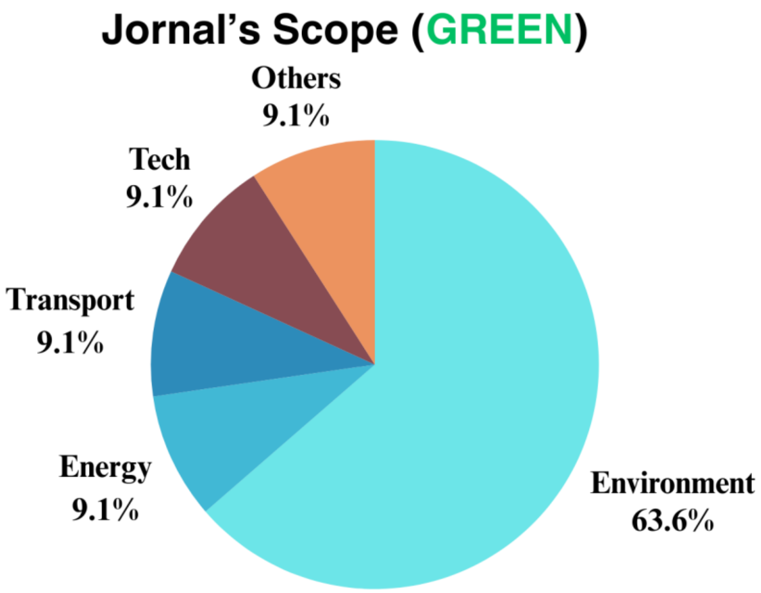

Figure 19: Jornal's scope (GREENS)

Regarding the themes addressed by the studies analyzed (Table 15)(Figure 20), Mobility (20%) and Carbon Emission Reduction (14.2%) were among the most frequently studied topics. Additionally, a significant portion of the articles (25.7%) focused on developing methodologies to measure urban environmental impacts.

Case Study Focus	Number of articles	Percentage
Methodology	9	25,71%
Mobility	7	20,00%
Energy	5	14,29%
Carbon reduction	5	14,29%
Solid Waste	3	8,57%

Building	1	2,86%
Others	5	14,28%

Table 15: Case Study Focus

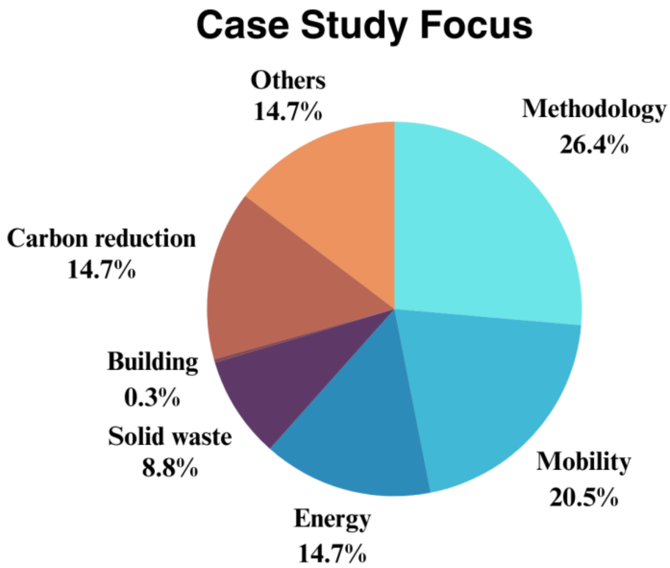

Figure 20: Case Study Focus

This data reveals an overlap between the themes identified as urban impact drivers (Table 1) and the thematic domains addressed in most of the analyzed articles. Mobility (a broader category encompassing transportation) accounts for 20%, Energy for 14.29%, Solid Waste for 8.67%, and Buildings for 2.86%. Since these themes appear in both contexts, it can be concluded that 45.82% (Mobility + Energy + Solid Waste + Buildings) of the article has addressed urban impact drivers as their main theme when addressing the transition to Urban Carbon Neutrality. Nevertheless, the predominance of methodology (25,71%) supports this article's initial claim - the state of the art in urban carbon neutrality focuses heavily on developing reliable methodologies.

These methodologies are essential for assessing urban environmental impacts, given the complexity of the urban carbon neutrality issue. As an illustration of this cross-sectoral framework at multiple levels, research conducted by Miao et al. (2024) aims to map the landscape of carbon-neutral cities. Among the numerous domains cited in the articles were city construction, technological innovations, industrial transformation and upgrading, public transportation development, the promotion of new energy vehicles, urban governance, urban agriculture, low-carbon behaviors and attitudes, and many others.

This pattern of complexity and methodological development is also evident when analyzing the main objectives of the articles (Table 16, Figure 16), considering that a single study could have multiple objectives. Nearly half (43.1%) of the studies aimed, either partially or entirely, to monitor some form of environmental impact, while 25% focused on evaluating the potential for decarbonization across different economic sectors. The latter category includes studies that simulated decarbonization processes by replacing fossil fuels with renewable energy sources.

Notably, only 22.7% of the analyzed articles incorporated human factors as part of their research focus. Most of these studies addressed human factors in terms of comfort or discomfort related to sustainability—an aspect that undeniably falls within the broader scope of human behavior. However, only a small portion of this subset explored how feelings and subjective perceptions can motivate individuals to adopt sustainable practices.

Objectives	Number of articles	Percentage
Monitoring	19	43,18%
Human behavior	10	22,73%
Descarbonixation valuation	11	25,00%

Proposing actions	2	4,55%
Others	2	4,55%

Table 16: Objective types

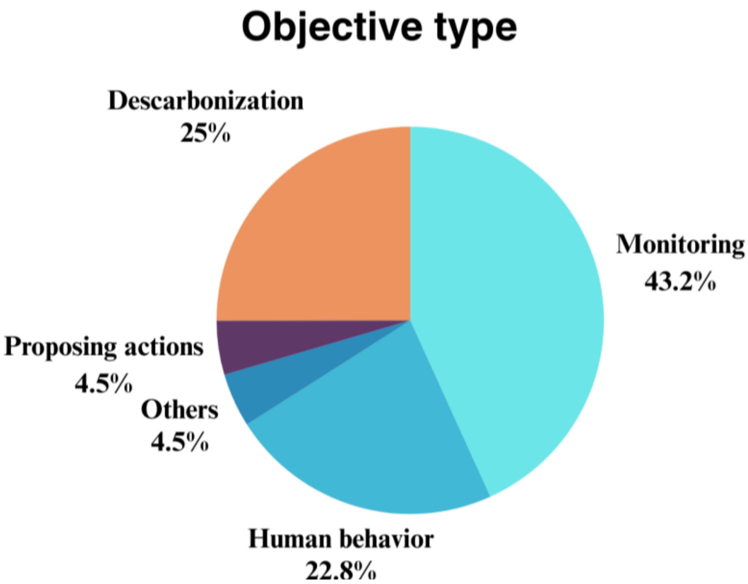

Figure 21: Objective types

6. Discussion

Taking into consideration the results, there is a significant gap and also an opportunity to explore how and which human factors play a substantial role in the transition of urban spaces towards carbon-neutral cities. This study revealed that a considerable portion of the articles analyzed (68.5%, RED + YELLOW) did not prioritize human factors, leaving out the analysis of the impacts and solutions brought by human behavior on GHG emissions of their analyses. Focusing instead on technological changes like replacing fossil fuels with electric solutions, even though almost two-thirds (71,4% YELLOW and GREEN) recognize the human factor as an important component for achieving urban carbon neutrality. Nevertheless, only 31.4% of the articles (GREEN) effectively included human factors, demonstrating that the role of human behavior in urban carbon neutrality still needs to be explored.

For what it's worth, significant progress has been made in tracking pollutants from urban activities. Approximately 25.7% of the articles focused on developing methodologies to measure urban environmental impacts, including pollutant monitoring. Additionally, 25% of the studies concentrated on decarbonization, often through simulations of replacing fossil fuels with renewable energy sources. This focus indirectly contributed to pollutant tracking, marking a notable advancement in understanding and mitigating urban environmental degradation.

Nevertheless, although it is accepted that promoting urban carbon neutrality will require not only understanding every city emission's peculiarities, but the behavior of its population as well, therefore there is still a significant gap in the scientific literature to explore this critical driver. As explained by Blake, J. (1999) "policy must be sensitive to the everyday contexts in which individual intentions and actions are constrained by socioeconomic and political institutions", in a few words - shaping a carbon neutrality policy will require much more than only identifying where the emissions come from and how to neutralize it, but also how to convince the citizens to behave accordingly to the new city's carbon neutral agenda. Blake, J. (1999) also warns about the risk of alienating the citizens' needs from the urban carbon neutrality guidelines, according to Blake policy shifts to actively encouraging sustainable behaviors, often requiring lifestyle changes, thus, tensions between national and local dimensions of sustainability initiatives reveal that bridging the "value-action gap" cannot be achieved solely by addressing an "information deficit" model of engagement.

This indicates that more attention should be given to fostering partnerships that are adaptable to these variations, ensuring a fairer allocation of responsibility among diverse environmental stakeholders (citizens. local businesses, policymakers, and local authorities).

7. Conclusion

This analysis underscores a critical gap/opportunity to explore and integrate the role of human factors in the transition of urban spaces toward carbon neutrality. While the prevailing focus of current research emphasizes technological solutions, the influence of human behavior remains a pivotal element in achieving urban sustainability goals. Policymakers and researchers must move beyond prioritizing the measurement of GHG emissions—although essential—and actively design strategies that engage citizens in adopting sustainable behaviors and participating in a new paradigm of urban sustainability.

The reviewed literature predominantly focuses on methodologies for measuring GHG emissions, highlighting the early stage of this research field. Furthermore, the frequent neglect of the relationship between unsustainable human habits and GHG emissions reveals a gap in understanding the causal impact of citizen behavior on urban emissions. Addressing this oversight requires a paradigm shift that integrates both physical and social sciences to deepen our understanding of how human factors influence the transition to urban carbon neutrality.

Therefore, to advance this field, future studies should prioritize investigating how citizens perceive their role in achieving carbon neutrality and, critically, how urban infrastructures and policies can effectively influence and engage citizen behavior. Fostering collaborative partnerships among stakeholders will be essential to bridging the "value-action gap", promoting an inclusive and equitable approach to urban sustainability. By addressing these dimensions, cities can build a robust foundation for achieving carbon neutrality through a holistic integration of technological advancements and human-centric strategies.

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