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Review

Transition to Sustainable Energy System for Smart Cities—Literature Review

Magdalena Krystyna Wyrwicka [1,*], Ewa Więcek-Janka [1,*] and Łukasz Brzeziński [2]

[1] Faculty of Engineering Management, Poznan University of Technology, 60-965 Poznan, Poland
[2] Faculty of Management and Logistics, Poznan School of Logistics, 61-755 Poznan, Poland; lukasz.brzezinski@wsl.com.pl
* Correspondence: magdalena.wyrwicka@put.poznan.pl (M.K.W.); ewa.wiecek-janka@put.poznan.pl (E.W.-J.)

Abstract: The article will contain a scientific analysis, showing thematic links between publications and consist of searching the data in the Scopus database. The timeframe of the searched publications will be 2010–2022. The parameters should also be narrowed down by selecting the following indexes: Science Citation Index Expanded (SCI-E), Social Science Citation Index (SSCI) and Emerging Sources Citation Index (ESCI), which was intended to eliminate abstracts of books and conference materials, leaving only reviewed works with the highest level of relevance for furthering knowledge. An additional limit of five minimum citations will be introduced. The analysis included 342 articles. Texts cited at least 100 times were highlighted. The research showed that authors focus piecemeal on selected aspects or problems, so an attempt was made to show thematic connections of keywords, illustrating the complexity of the transformations underway. The discussion identifies the most active authors and countries, especially exploring the topic of a transition to a sustainable energy system for smart cities. The authors have employed scientometric analysis to provide an objective and data-driven exploration of the transformation of sustainable energy systems for smart cities. This approach offers valuable insights into the research landscape, trends, and relationships within the field, which can guide future scientific research and contribute to a deeper understanding of the subject matter. As an additional element of this conclusion, the authors proposed supplementing the scientometric analysis with the foresight methodology. The authors' research approach is distinguished by the following stages: problem formulation, data collection, choice of scientometric methodology, analysis of advantages and limitations of scientometrics, clustering analysis, data analysis, and presentation of results. Our systematic literature review systematizes the existing literature on the sustainable energy systems for smart cities, isolates main research interests, identifies future research avenues, and provides several important hints for researchers.

Keywords: energy system; transition; smart city; sustainable energy system for smart cities; scientific analysis with VOSviewer

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1. Introduction

Transformation is a deliberate, carefully planned, complete reconstruction, the effects of which will be used in the long term. It usually concerns economic infrastructure, and its implementation requires a multifaceted approach for the solutions created. Nadler's concept of an ideal system, developed in the 1960s, assumed that an ideal model would be created which should be verified by existing conditions in reality, which would enable the preparation of a holistic improvement of the system's functionality that can be realized in practice [1]. The integrating element of the system is the function (mission, goal, task), the realization of which requires technical systems (fixed assets), as well as a group of competent contractors (executing the project), all of which should be selected deliberately, in the context of the technologies necessary to support the processes. Such a system requires sources of supply (input elements) and distribution of products (including undesirable

ones—waste) at the output. The whole function is in the environment, hence the system's interaction with the environment and reciprocally—the environment with the system.

The one-size-fits-all view of the system described here also applies to energy systems, which in the past were analyzed primarily from the perspective of economic efficiency. Today, significant changes are evident due to different priorities. In 1987, the Gro Harlem Brundtland Our Common Future report [2] presented the concept of sustainable development in its broadest sense, in which development was defined as meeting the needs of both present and future generations, determining to a large extent the quality of life (the social aspect) by appropriately and consciously shaping the relationship between economic growth (the economic aspect) and respect for the environment (the environmental aspect). In the late 1980s, the concept of the creative city (creative city) emerged [3], and a practical implication of the application of the idea of sustainable development is the concept of the compact city or city of short distances [4]. The main thrust of this concept is to strive to reduce energy consumption, including reducing vehicular transportation, shortening the routes and transmission networks of various utilities, and solving the problem of so-called urban sprawl [5].

The term smart city is associated with the words livable, green, intelligent, low carbon, sustainable, digital, information, knowledge, resilient, eco, and ubiquitous [6]. The modern concept of a smart city includes the following [7–11]:

- Smart economy—a highly efficient economy due to the use of ICT;
- Smart mobility (smart transportation networks) using clean energy;
- Smart environment; the sustainable use of resources. A smart city manages its natural resources frugally; aims to increase the use of renewables; controls power and water networks, street lighting, and other public amenities in a manner allowing for the optimization of environmental and financial costs of their operation; measures, controls, and monitors pollution on an ongoing basis; renovates buildings to reduce their power needs;
- Smart people (social capital creating an engaged, diverse, innovative, and tolerant society);
- Smart living (high quality of life) means a safe and healthy life in a city with rich possibilities and infrastructure that enables the creation of various ways of life or lifestyles;
- Smart governance, where social participation in making decisions, of a strategic nature, plays an important role in the transparency of actions, quality, and availability of public services; intelligent public governance facilitates the organization and integration of the remaining elements of a smart city;
- Smart cities are becoming technological havens [12]. Transportation, healthcare, entertainment, agriculture, municipal infrastructure, and administration, provide smart solutions and effectively create smart-city resources to improve the overall quality of life of its residents. Recognizing the interactions of these elements is possible through system analysis [10,11]. With regard to the smart city, the main assumptions concern the use of modern, environmentally friendly technologies, and the improvement of the quality of life. Hence, one of the manifestations of the smart-city concept is investment in renewable energy sources (RES), which is currently a popular direction of urban transformation. Systemic thinking and action will certainly support such projects [12]. However, it is worth emphasizing the need to create dedicated solutions that also take into account the human factor.

Taking this into account, the preferences of the local community are for public consultation, as well as the necessary inclusion of various stakeholder groups in creating the future, and such opportunities are offered using the foresight methodology. The concept of foresight was first defined by Joseph F. Coates in 1985. It is the process of recognizing the forces shaping the distant future, which should be taken into account when formulating strategies. [13] The objectives of foresight are to identify and assess future needs, opportunities, and threats related to social, economic, and technological development, as well as to prepare appropriate anticipatory measures that take into account more general

social, economic, and technological conditions. Such analyses are already being carried out both for energy systems [14] and for the creation of smart cities [15]. The transformation, implemented based on foresight studies, envisions eight stages [16]:

(1) Preliminary—revealing the rationale, scope and purpose of the changes;
(2) Scanning—related to identifying and analyzing trends;
(3) Recruitment—identifying project stakeholders and field experts;
(4) Generating knowledge—revealing the relevant factors and causal mechanisms that shape the state of the government in a given area;
(5) Anticipatory—creating visions of the future and scenarios for action;
(6) Executional—related to carrying out the transformation;
(7) Evaluation—assessing the effects;
(8) Reinforcing—resulting from feedback, providing a rationale for improvement activities, or subsequent changes.

Targeting sustainable energy systems is now an integral element of smart-city operation. While on the one hand it brings many benefits, at the same time a number of challenges or risks can be pointed out, e.g., related to the unpredictability of weather conditions for RES, energy crises, cyber-security threats, and political orientation of the implementation of specific solutions in energy supply. These are currently key issues for a functioning human society. Therefore, conducting research aimed at predicting the possible directions of these transformations, by following the range of publications, geographical analyses of their appearances, etc., we can fill knowledge gaps and add value to science.

The solutions to these identified challenges may be based on the use of various research methods. Approaches such as the research method that focuses on business-process modeling and service selection [17], protecting data privacy by adjusting model outputs to equal probability-density distributions [18], constructing a user risk-assessment model for identifying potential underground industry users [19], deep learning, autoencoders, and transformer layers for traffic classification and improved model performance [20], formalization of privacy, time, and energy evaluation indicators, and the use of Markov decision processes (MDP) for optimal task offloading decisions [21].

In the context of the provided approaches, scientometric analysis could be valuable for assessing the influence and evolution of research in areas such as data privacy, deep learning, and smart cities. By employing scientometric methods, researchers can gain a deeper understanding of research trends, interdisciplinary connections, and the impact of different research approaches. This can help guide future research and policy decisions in these domains.

Among the advantages and features of the scientometric method the following can be highlighted:

- Scientometrics is a quantitative-research approach that provides a data-driven analysis of scientific publications. It allows researchers to measure and evaluate the impact and productivity of research.
- Scientometric methods provide objective and standardized measures to evaluate research quality, impact, and influence. This reduces subjectivity in research evaluation.
- Scientometric analysis can identify trends in research areas, including the emergence of new concepts and the evolution of existing ones, as seen in the historical evolution of the smart-city concept.
- Researchers can use scientometrics to compare research outcomes, methodologies, and results between different institutions, fields, and time periods.
- Scientometric tools, like VOSviewer, enable researchers to visualize complex relationships between authors, publications, and keywords, allowing for a more comprehensive understanding of the research landscape.
- Scientometrics can reveal interdisciplinary connections and collaborations, which are particularly valuable in areas like smart cities where diverse domains intersect.

The integration of available solutions into an optimal energy system tailored to future needs can be linked to different variants of urban-development scenarios built in respect for place, people, and climate, emphasizing localism and sensitivity to social needs. The above considerations provided the rationale for undertaking a scientometric analysis. Carrying out research using the developed scientometric-research methodology allows for conducting qualitative research in a transparent and replicable manner using bibliometric automation (which allows for minimizing human errors). Thanks to this approach, interdisciplinary research or research conducted in different fields can be discussed and compared between researchers.

The aim of the study is to identify thematic areas related to the issue of transformation of sustainable energy systems for smart cities.

The following research questions were formulated:

RQ1: What are the characteristics of a transition to a sustainable energy system for smart cities?

RQ2: What thematic clusters can be created as part of the transition to a sustainable energy system for smart cities analyses?

The structure of the article consists of five parts: introduction, analysis of the literature on the subject (in particular aspects of sustainability of the energy system for smart cities), description of the methodological assumptions of the study, analysis of research results, discussion (in-depth analysis of research results), and conclusions.

2. Literature Review

2.1. The Concept and Scope of Smart Cities

The importance of smart cities in enhancing sustainability is widely recognized in the literature and practice. However, it's crucial to acknowledge that the actual implementation and impact of smart-city initiatives can vary significantly from one city to another. The success of smart-city projects depends on various factors, including governance, technology adoption, and community engagement.

Smart cities represent an innovative concept aimed at enhancing the sustainability and quality of life for urban populations [22]. Furthermore, initiatives focused on digitization and the development of smart cities are essential to bolster ecological and economic sustainability. Nevertheless, a more direct way to articulate this added value is by initially deducting the benefits from the efforts [23]. The notion of a smart city is relatively recent, emerging as a product of an evolutionary process [24]. It is important to highlight that the concept of a smart city gradually took shape from various perspectives as a means of characterizing technological transformations within urban environments. The earliest reference to such a concept can be traced back to 1997, when it was introduced as a virtual city, denoting local ICT network initiatives facilitating the emergence of local cybernetic (virtual) communities [25]. These virtual cities were dependent on the World Wide Web (WWW) and functioned as digital counterparts to tangible urban spaces [24]. Subsequently, the term 'digital city' emerged, signifying the presence of infrastructure conducive to the formation of virtual communities [26].

In the year 2000, the smart-city concept was formally defined as a city that systematically oversees and integrates the state of its entire critical infrastructure, encompassing elements such as roads, bridges, tunnels, railways, subways, airports, seaports, communication networks, sanitation systems, energy resources, and even buildings. This comprehensive approach aimed at optimizing resource utilization, planning preventive maintenance operations, and ensuring safety while maximizing the quality of services for its residents [27]. A decade later, it was emphasized that a smart city is one that harmoniously blends physical infrastructure, information technology infrastructure, social infrastructure, and business infrastructure to harness the collective intelligence of the city's inhabitants [28]. In essence, the concept of a smart city revolves around the idea of viewing it as a collection of initiatives designed to enhance the efficiency of urban centers through the utilization of data, information, and information technologies (IT). This, in turn, leads

to the provision of more efficient services for citizens, as well as the monitoring and optimization of city functions, fostering collaboration among various economic entities, and encouraging the adoption of innovative business models within both the private and public sectors [29].

As a matter of fact, we observe a progression starting from the inception of the virtual city, with the establishment of ICT networks, a concept that gained prominence in the literature after the 1990s [30]. This evolution continued with the widespread adoption of ICT throughout the entire urban infrastructure, facilitating intelligent management of energy consumption, transportation, and building systems [31]. Subsequently, the notion of a 'smart city footprint' emerged, quantified through indicators reflecting the city's capacity across various dimensions, including society, economy, mobility, and governance. This phase involved large-scale experimentation, effectively treating the city as a dynamic living laboratory [24]. In the most recent approaches, the primary focus has shifted towards enhancing the everyday quality of life for residents, promoting sustainable development, prioritizing environmental concerns, optimizing mobility, and expanding green spaces and smart energy systems [32,33].

The historical evolution of the smart-city concept reflects the changing technological landscape and the growing recognition of the need for integrated urban planning. However, it's important to note that the definition and understanding of smart cities can vary among scholars, practitioners, and policymakers. This can lead to challenges in implementation and measurement. Metropolitan regions are responsible for approximately 70% of worldwide CO_2 emissions and account for two-thirds of global energy consumption. In this respect, governments worldwide have pledged to cooperate in addressing global energy, climate, and environmental challenges [22]. Therefore, the role and importance of energy systems and the transformation towards their sustainability should be emphasized. From the point of view of the "green transformation" of urban areas, this is a key aspect driving these changes.

2.2. Sustainable Energy Systems for Smart Cities

Energy-generation systems are engineered to transform primary energy sources like heat, electricity, and cooling into alternative secondary energy forms. Common methods for generating renewable energy include the use of wind turbines, hydroelectric dams, and multi-generational power plants. In a typical smart energy system, renewable energy takes precedence over fossil fuels. However, to ensure year-round system reliability, fossil fuels may be used as an additional energy source [34].

Management systems play a multifaceted role in fostering effective interaction between household residents and the management framework. They include functions such as monitoring and logging, along with the use of various predefined risk alerts to enhance home security through a management system. Homeowners have the flexibility to control household appliances based on their preferences using Smart Home Energy Management Systems (SHEMS), mobile applications, or manual methods [35].

As indicated in the reference [36], numerous studies have demonstrated that the Internet of Things (IoT) offers significant advantages compared to other communication networks. The IoT is gaining popularity due to its user-friendliness and compatibility with diverse communication protocols [37]. Building Energy Management Systems (BEMS) find applications across a range of building types, including residential, industrial, administrative, and commercial structures. Moreover, the integration of intermittent renewable energy sources with an appropriate energy-storage system within the building is essential to ensure the reliability and efficiency of BEMS, addressing a critical requirement [36].

Consequently, the assessment of a specific area within a building is ascertained through the deployment of sensors. The definition of a 'zone' can vary based on architectural considerations and the manner in which sensors are incorporated into the building; it could encompass a single room, an entire floor, or even the entire structure. These sensors play a pivotal role in monitoring indoor-comfort parameters, including occupancy, CO_2 levels,

temperature, and humidity. Additionally, sensors are capable of detecting critical situations such as fire hazards, flooding, or unauthorized intrusion [38].

Many authors and organizations have introduced and put into practice the concept of the 'smart city,' which remains relatively new [39]. Smart cities are specifically designed to tackle or mitigate the challenges posed by rapid urbanization and population growth. These challenges encompass various aspects such as energy provision, waste management, and transportation, all with the aim of maximizing efficiency and resource utilization. The existing energy classification categorizes areas of intervention within smart cities in diverse ways. However, a limitation of these classifications is their exclusive focus on the smart grid when addressing energy concerns, overlooking essential elements like transportation and infrastructure [40].

Cities' energy demands are both intricate and multifaceted. Consequently, contemporary cities should harness the synergies among different energy solutions to improve their existing systems and implement new ones using a cohesive and optimized approach. Challenges such as volatile energy supply-and-demand, the imperative of more energy-efficient transportation, and various other energy-related issues necessitate collective solutions rather than isolated approaches [41].

In a city that prioritizes the well-being of its residents and is mindful of environmental concerns, the foremost consideration is meeting the needs of its inhabitants. Sustainable development is centered on the city's holistic advancement, promoting fairness and conservation. In contrast to the focus of smart cities, it involves integrating green spaces and eco-friendly practices into the urban landscape to mitigate pollution, reducing carbon emissions, and safeguarding natural resources [42]. By leveraging advanced technologies like ICT and other cutting-edge methods, a city can enhance the quality of life for its residents, optimize operational efficiency, and bolster competitiveness, while also addressing the present and future generations' needs. Cities must evolve to become more intelligent and environmentally sustainable to reduce CO_2 emissions. Key benefits encompass advancements in renewable energy, efficient waste management, and improved traffic conditions. Many smart-city initiatives revolve around the implementation of efficient grid- and watershed-management systems [43].

A system for ensuring human safety and monitoring energy consumption can be established through the utilization of water-level-monitoring devices. Initiatives and activities aimed at conserving resources are regarded as sustainable practices. Sustainable development is built upon five core pillars: ecological preservation, social progress, cultural conservation, and economic growth [44]. These encompass various aspects, such as intelligent streets, smart lighting, efficient parking facilities, and intelligent traffic signals, which collectively enhance navigation efficiency and expedite transfers. By utilizing these environmentally friendly technologies, individuals can reduce their carbon footprint and enhance their social capital [44]. In addition to improving public services, infrastructure, and sustainability, smart cities strive to create a more advanced social environment for their residents [45]. These concerns and the reinvigoration of cities as pivotal economic hubs, both nationally and globally, have emerged in response to urbanization and global economic shifts [46].

In smart cities, both new and existing structures are designed to be more energy-efficient and operationally effective. The optimization of power generation, which encompasses various energy sources and has distributed generation, relies on a detailed analysis of energy-consumption patterns [47]. Precise metering is an essential component of effective energy management. Managing energy resources within these urban areas poses significant challenges due to their intricate nature and critical importance. To enhance corporate social responsibility and mitigate greenhouse-gas emissions, it becomes essential to closely monitor operational costs and prepare accurate budgets based on utility bills. Reducing dependency on unreliable supply chains is a key objective. The approach outlined below facilitates discussions on energy utilization and, consequently, contributes to the economic development of a sustainable smart city [48].

As an alternative, there is the option of an urban-construction group. This small, intelligent community can utilize an Internet of Things (IoT) platform comprehensively, allowing its members to collaborate effectively in enhancing their energy-generation capacity with the goal of reducing the city's CO_2 emissions. In line with our proposed energy-management system's approach, buildings equipped with Renewable Energy Sources in Society (RESS) can be synchronized to reduce their reliance on the primary distribution grid [49]. This strategy, centered on renewable-energy adoption, contributes to a reduction or elimination of greenhouse-gas emissions. Wind and solar energy sources are currently recognized as the most cost-effective, based on global research. Our objective is to pioneer a novel method for assessing the optimal capabilities of RESS, which takes into account building usage patterns, seasonal variations, energy expenses, and carbon-emission taxes [50].

Based on the literature review, it can be indicated that issues related to energy systems—in the context of the implementation or functioning of smart-city assumptions—are extremely complex. Production, distribution, and effective energy management at the building or city level constitute a significant challenge. Additionally, new solutions, technologies, innovations, and systems are systematically created to streamline or improve the functioning of energy systems. This is fundamental from the point of view of reducing greenhouse-gas emissions or implementing the concept of sustainable development. This also shows the importance of scientometric analyses for the analyzed issues.

Recognizing the role of energy systems in urban sustainability is crucial. However, achieving sustainable energy systems in cities requires comprehensive planning, investment in renewable energy sources, and policy support. It's also essential to consider the broader implications of energy transformation on economic and social aspects. In conclusion, the provided literature excerpts offer valuable insights into the evolution and importance of sustainable energy systems for smart cities. While the concept holds promise for addressing various urban challenges, its successful implementation requires careful consideration of technological, social, economic, and environmental factors, as well as ongoing evaluation and adaptation to local contexts.

3. Materials and Methods

This study uses a scientometric analysis of the topic, which will help guide future scientific research conducted by the authors of this article [51,52]. Scientometrics-based methodology involves analyzing metadata from academic-research databases published in the Scopus Science Database, one of the most influential sources of scientific information.

Metadata consists of key factors such as source titles, abstracts, keywords, authors, references, and number of citations for publications. This makes it possible to identify collaboration between researchers' works (co-authorship), impact (bibliographic coupling), level of collaboration between countries or organizations, and common keywords to determine whether they belong to a particular area of knowledge [52]. It is possible to create a network of relationships over a selected time period and subject area [53,54]. The analysis can also be used to classify journals by determining the equal size of the productivity zone, which makes it possible to identify the most specialized journals [55].

The research methodology is based on scientistic analysis [56]. It is exploratory in nature and consists of five phases: formulation, identification, selection, confirmation, analysis, and thematic synthesis [51,52,54]. Formulation is based on posing research questions [57,58], taking into account the most important issues related to the topic being addressed.

In the case of the analysis presented here, the aim of the study is to identify thematic areas related to the issue of transformation of sustainable energy systems for smart cities.

The following research questions were formulated:

RQ1: What are the characteristics of transition to a sustainable energy system for smart cities?

RQ2: What thematic clusters can be created as part of the transition to a sustainable energy system for smart cities analyses?

The choice of the method of scientometric study was dictated by several issues, which at the same time represent the advantages of scientometric analysis:

- High objectivity of the research, since such a study provides a set of metrics and statistical tools that allow an objective assessment of the quality and impact of research in the studied area [59];
- Tools for scientometric analysis allow processing and analysis of large data sets, which is difficult to achieve using other methods [60]; advanced tools, such as, for example VosViewer, allow the graphical representation of complex relationships, such as co-authorship networks, which facilitates their analysis [61];
- Scientometrics enable the rapid collation of various aspects of scientific activity, such as the number of publications and the number of citations or international collaborations [62];
- Trend recognition by identifying the most important papers, authors, institutions, and countries in a given research area, which is helpful for research management and planning [63];
- These methods allow analysis of scientific networks, which can be useful in understanding how different fields are developed and how they are interrelated [64];
- Established metrics and tools allow the comparison of results between different institutions, fields, and time periods [65];
- The ability to track how often and in what context publications are cited provides some insight into their impact on a given area of research.

Despite maintaining full research transparency and a methodological regime, this method also has its drawbacks, which include the following:

- Errors in metadata, missing data, or differences in standards can affect the results;
- The selection of parameters for analysis can be time-consuming and complicated;
- Incomplete analysis—VosViewer and similar tools often focus on one aspect of the scientific network, such as co-authorship and keywords or citations, which may not capture the full picture;
- These analyses focus mainly on quantitative measures (e.g., number of publications, number of citations), leaving out qualitative aspects (e.g., significance of discovery, societal impact);
- The choice of metrics and parameters is often a subjective decision, which can affect the objectivity of the analyses [66];
- Tools such as VosViewer are more useful for nomothetic analyses of large datasets, and may not be as effective in analyzing unique, idiographic aspects of individual scientific papers [67];
- The post-tenure incompleteness of databases, which update from day to day, hence the pre-presented results will be an analysis of the status on a given day; in addition, there is a probability of not "reaching" important articles due to their absence in the selected publication database;
- Differences in the notation of the names of authors of publications depending on the journal, which causes a number of problems in classifying authors into clusters and searching for relationships between them.

Clustering according to specific metrics gives direct insight not only into the internal layout of a cluster but also insight into the relationships between clusters, which in turn allows one to see the development of scientific problems in the studied area both thematically and temporally.

The study was conducted 28 December 2022–1 July 2023 and consisted of a search of data in the Scopus database. The expert consultation method listed the following keywords: transition, energy system, sustainable energy system, smart city, energy system for smart city. The timeframe of the searched publications was 2010–2023. The search parameters were also narrowed by selecting the following indexes: Science Citation Index Expanded (SCI-E), Social Science Citation Index (SSCI), and Emerging Sources Citation Index (ESCI),

with the aim of eliminating book abstracts and conference proceedings, leaving only peer-reviewed papers with the highest level of relevance to further knowledge [52,54,68,69]. An additional restriction of a minimum citation count of five was also introduced.

The search yielded 342 articles, published in the Scopus database between 2010 and 2023. The next step was to confirm that the data matched the search terms. The following were analyzed: number of publications, citations, authors, categories, institutions, countries, and keywords. Scientometric-mapping analysis was also carried out, as well as studies presenting networks of relationships, presented in the form of graphs and highlighted clusters, using VOSviewer, version 1.6.16 [53,54,61,70].

4. Results

4.1. Characteristics of Publications Regarding Transition to a Sustainable Energy System for Smart Cities

The research process included two phases: preparation of the publication database for analysis and the scientometric analysis phase. Phase one consisted of three stages: identification, screening, and inclusion. Table 1 shows the course of the first phase.

Table 1. Phases of the research process.

	Previous Studies	**Identification of New Studies on Database**	
Identification	Study included in previous version of review (n = 0)	Records identified from SCOPUS (n = 494) →	Records removed before screening: Duplicate records (n = 3)
		↓	
Screening		Record screened (n = 486) →	Records excluded: Records not in English (n = 47)
		↓	
		Records assessed for eligibility	Records excluded: Unrelated to energy (n = 4) Unrelated to smart cities (n = 8)
		↓	
Inclusion		New studies included in review (n = 432)	
		↓	
		Total studies included in review (432)	

The second scientometric phase determined the relationships between the identified publications. For this purpose, the publicly available VosViewer tool was used. The results of the research are presented in graphical and tabular form in the rest of this report. From the scientometric analysis, 27 were cited more than a hundred times and were extracted (Table 2). The most cited article as of 2012 is "Smart Cities of the future" by Batty and his team [71] and is cited 12,210.

The total number of citations of all articles identified in the Scopus database by June 2023 was 24,418 (Figure 1).

Table 2. Popularity of scientific articles on the topic of smart cities.

Year	Document Title	Authors	cit	Journal Title
2012	Smart cities of the future	Batty M., Axhausen K.W., Giannotti F., Pozdnoukhov A., Bazzani A., Wachowicz M., Ouzounis G., Portugali Y. [71]	12,210	European Physical Journal: Special Topics
2015	Smart Energy Systems for coherent 100% renewable energy and transport solutions	Mathiesen B.V., Lund H., Connolly D., Wenzel H., Ostergaard P.A., Moller B., Nielsen S., Ridjan I., KarnOe P., Sperling K., Hvelplund F.K. [72].	1317	Applied Energy
2017	Smart energy and smart energy systems	Lund H., Østergaard P.A., Connolly D., Mathiesen B.V. [73]	803	Energy
2019	Reinforcement learning for demand response: A review of algorithms and modeling techniques	Vázquez-Canteli J.R., Nagy Z. [74].	580	Applied Energy
2018	Information and communications technologies for sustainable development goals: State-of-the-art, needs and perspectives	Wu J., Guo S., Huang H., Liu W., Xiang Y. [75]	360	IEEE Communications Surveys and Tutorials
2020	Internet of things (IoT) and the energy sector	Motlagh N.H., Mohammadrezaei M., Hunt J., Zakeri B. [76]	353	Energies
2016	Meta-principles for developing smart, sustainable, and healthy cities	Ramaswami A., Russell A.G., Culligan P.J., Rahul Sharma K., Kumar E. [77].	305	Science
2018	A Comprehensive Study of Implemented International Standards, Technical Challenges, Impacts and Prospects for Electric Vehicles	Habib S., Khan M.M., Abbas F., Sang L., Shahid M.U., Tang H. [78].	213	IEEE Access
2019	Smart energy systems for sustainable smart cities: Current developments, trends and future directions	O'Dwyer E., Pan I., Acha S., Shah N. [79]	194	Applied Energy
2019	Review of blockchain-based distributed energy: Implications for institutional development	Ahl A., Yarime M., Tanaka K., Sagawa D. [80].	192	Renewable and Sustainable Energy Reviews
2021	Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process	Hoang A.T., Pham V.V., Nguyen X.P. [81].	181	Journal of Cleaner Production
2017	Towards the next generation of smart grids: Semantic and holonic multi-agent management of distributed energy resources	Howell S., Rezgui Y., Hippolyte J.-L., Jayan B., Li H. [82]	179	Renewable and Sustainable Energy Reviews
2020	Blockchain for Internet of Energy management: Review, solutions, and challenges	Miglani A., Kumar N., Chamola V., Zeadally S. [83]	179	Computer Communications
2018	Integrating a hydrogen fuel cell electric vehicle with vehicle-to-grid technology, photovoltaic power and a residential building	Robledo C.B., Oldenbroek V., Abbruzzese F., van Wijk A.J.M. [84].	161	Applied Energy

Table 2. *Cont.*

Year	Document Title	Authors	cit	Journal Title
2021	Recent advances on nanofluids for low to medium temperature solar collectors: energy, exergy, economic analysis and environmental impact	Said Z., Hachicha A.A., Aberoumand S., Yousef B.A.A., Sayed E.T., Bellos E. [85].	158	Progress in Energy and Combustion Science
2021	Large-vscale hydrogen production and storage technologies: Current status and future directions	Olabi A.G., bahri A.S., Abdelghafar A.A., Baroutaji A., Sayed E.T., Alami A.H., Rezk H., Abdelkareem M.A.. [86]	146	International Journal of Hydrogen Energy
2020	Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries	Vanegas Cantarero M.M. [87].	145	Energy Research and Social Science
2019	A review on overall control of DC microgrids	Kumar J., Agarwal A., Agarwal V. [88].	139	Journal of Energy Storage
2019	Towards future infrastructures for sustainable multi-energy systems: A review	Guelpa E., Bischi A., Verda V., Chertkov M., Lund H. [89].	138	Energy
2017	Reduced graphene-oxide acting as electron-trapping sites in the friction layer for giant triboelectric enhancement	Wu C., Kim T.W., Choi H.Y. [90]	129	Nano Energy
2018	Prosumer communities and relationships in smart grids: A literature review, evolution and future directions	Espe E., Potdar V., Chang E. [91].	129	Energies
2019	Sustainability perspectives- a review for solar photovoltaic trends and growth opportunities	Choudhary P., Srivastava R.K. [92].	125	Journal of Cleaner Production
2020	Smart energy cities in a 100% renewable energy context	Thellufsen J.Z., Lund H., Sorknaes P., Ostergaard P.A., Chang M., Drysdale D., Nielsen S., Djorup S.R., Sperling K. [93].	121	Renewable and Sustainable Energy Reviews
2021	Technology evolution from self-powered sensors to AIoT enabled smart homes	Dong B., Shi Q., Yang Y., Wen F., Zhang Z., Lee C. [94]	120	Nano Energy
2019	Flexible Carbon Capture and Utilization technologies in future energy systems and the utilization pathways of captured CO_2	Mikulcic H., Skov I.R., Dominkovic D.F., Wan Alwi S.R., Manan Z.A., Tan R., Duic N., Hidayah Mohamad S.N., Wang X. [95]	118	Renewable and Sustainable Energy Reviews
2021	A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities	Kim H., Choi H., Kang H., An J., Yeom S., Hong T. [96].	105	Renewable and Sustainable Energy Reviews
2019	Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK	Brown D., Hall S., Davis M.E. [97].	104	Energy Policy

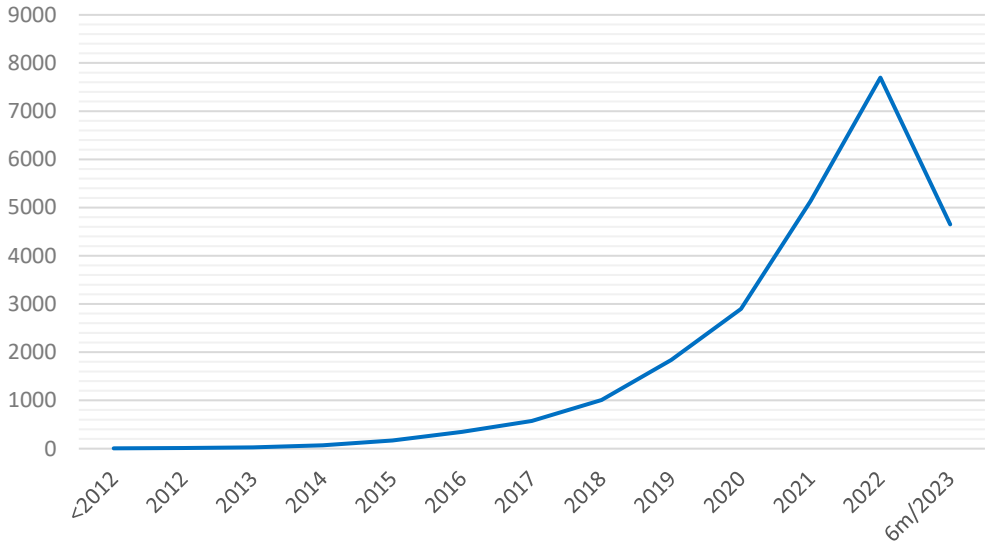

Figure 1. Number of cited publications thematically related to "smart city", "energy", "smart power grid", etc.

An identification of authors who are most involved in research on the topic of a transition to a sustainable energy system for smart cities was also conducted. The most publications in this field are by Kamyab, Hesam (Engineering Department, Razak Faculty of Technology and Informatics, University Teknologi, Malaysia (9 publications), Klemeš, Jirii (University of Technology, Brno, Czech Republic (7), and Østergaard, Poul (Aalborg University, Department of Planning, Denmark (7). Other researchers' names are listed in Table 3 along with their citation rates.

Table 3. Names of researchers with the highest number of publications in the surveyed collection.

Author	Affiliation	Region	Field-Weighted CI	Citation Count
Barone, Giovanni	University of Naples Federico II	Italy	47.21	20
Buonomano, Annamaria	University of Naples Federico II	Italy	47.21	20
Forzano, Cesare	University of Naples Federico II	Italy	47.21	20
De Felice, Fabio	University of Cassino and Southern Lazio	Italy	23.09	64
Parmentola, Adele	University of Naples Parthenope	Italy	23.09	64
Petrillo, Antonella	University of Naples Parthenope	Italy	23.09	64
Tutore, Ilaria	University of Naples Parthenope	Italy	23.09	64
Friedler, Ferenc	Széchenyi István University	Hungary	14.01	11
Losada, Jean Pimentel	Budapest University of Technology and Economics	Hungary	14.01	11
Orosz, Ákos	University of Pannonia	Hungary	14.01	11
Chong, C. T.	Shanghai Jiao Tong University	China	11.13	36
Fan, Yee Van	Brno University of Technology	Czech Republic	11.13	36
Lee, Chewtin	Universiti Teknologi Malaysia	Malaysia	11.13	36

An analysis of research communities and universities that are involved in smart-city research was conducted. The results of the analysis, along with the number of affiliated publications, are shown in Table 4.

Table 4. Affiliated research institutes and universities.

Institution	Country/Region	Field-Weighted CI	Citation Count
Qingdao University of Technology	China	9.9	31
Universiti Teknologi Malaysia	Malaysia	8.57	83
Aligarh Muslim University	India	7.34	23
Universiti Teknologi Petronas	Malaysia	7.34	23
Brno University of Technology	Czech Republic	6.93	70
Shanghai Jiao Tong University	China	6.08	43
King Fahd University of Petroleum and Minerals	Saudi Arabia	5.15	32
University of Sharjah	UA Emirates	5.02	32
National University of Sciences and Technology Pakistan	Pakistan	5	32
University of Béjaïa	Algeria	4.58	12
University of Newcastle	Australia	4.35	1
University of Minho	Portugal	4.21	22
South Ural State University	Russian Federation	4.19	27

4.2. Thematic Clusters Related to the Issue of Transition to a Sustainable Energy System for Smart Cities

The identified publications merge into clusters related to the included content. Of the 342 publications analyzed, 119 include energy systems. The term energy system links thematically to five areas (Figure 2; Table 3). The "red" area concerns the development of the "energy" and "smart" approach and is related to "smart power grids" and "smart grid" [97–101]. The "blue" cluster, although very dispersed, is related to the topics of "sustainable development" and "sustainable energy system" [87,102–108]. Meanwhile, the yellow cluster is related to publications on "smart energy system", "optimization" and "integrated energy system" [109–117]. The purple area emphasizes "renewable energies" and "renewable energy resources" [87,108,118–129]—Table 5.

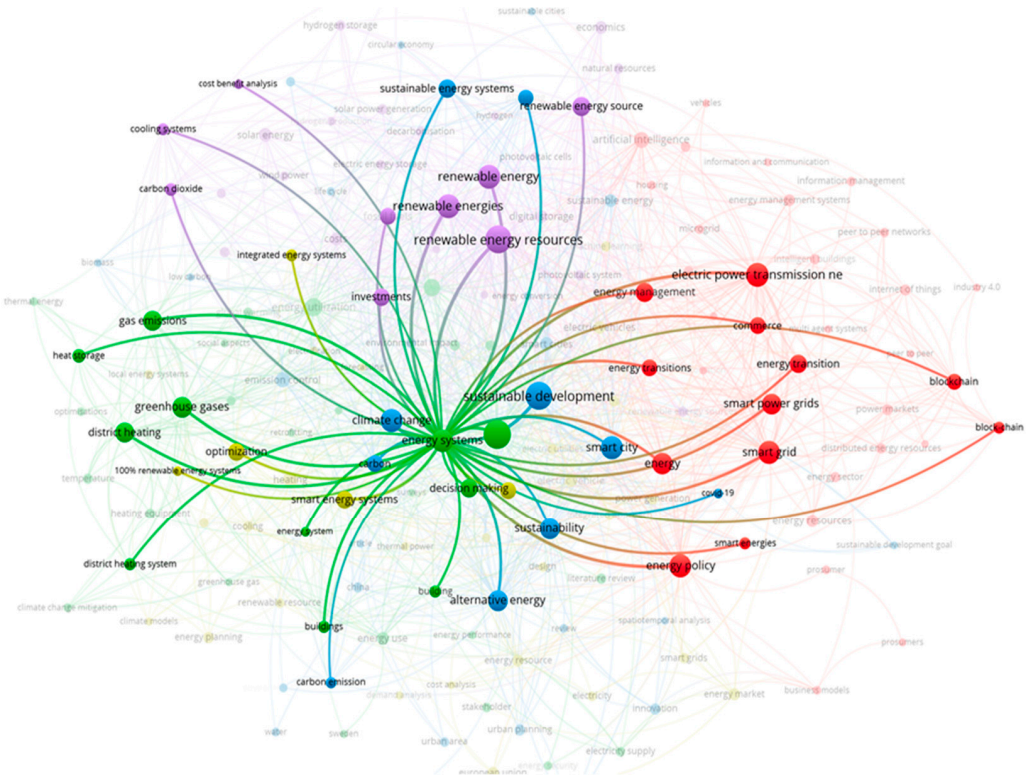

Figure 2. Topic links for the keyword "energy system".

Table 5. Clusters for energy systems.

Keyword	Energy Systems			
red cluster	blue cluster	purple cluster	green cluster	yellow cluster
energy policy	carbon emission	cost-benefit analysis	decision making	integrated energy systems
smart energies	alternative energy	cooling systems	building	optimization
energy	carbon emission	renewable energies	energy efficiency	100% renewable energy systems
energy transitions	climate change	renewable energy	buildings	smart energy systems
energy management	sustainable development	carbon dioxide	energy system	energy storage
electric power transmission ne	smart city	investments	district heating system	
energy transition	COVID-19	renewable energy resources	district heating system	
smart power grids	sustainable energy systems	renewable energy source	greenhouse gases	
commerce	planning	fossil fuels	heat storage	
smart grid			gas emissions	
block chain				

The consideration of sustainability requirements for the "energy system" was noted in 18 publications. The analysis made it possible to distinguish four clusters and one separate factor—"heating" (Figure 3). The "red" cluster indicates links to "energy policy", "smart grid", and "energy-management systems", which can be referred to as structural solutions [130,131]. The "blue" cluster groups "climate change", "sustainable development", "smart city", and "sustainable energy" and indicates the area that has relations with the natural and social environment [132,133]. The "purple" cluster combines "economics" and "cooling systems" with "renewable energies", indicating local conditions. The "green" cluster links "energy utilization", "efficiency", "energy", and "energy conservation" and can be associated with the need for process-appropriate technological solutions.

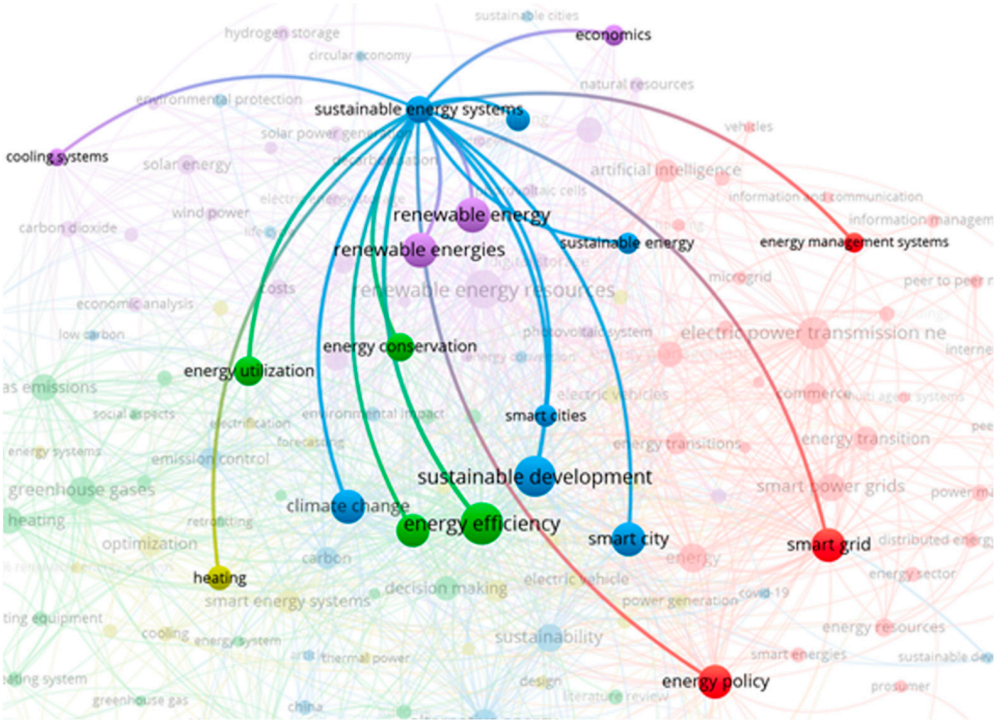

Figure 3. Thematic links for the term "sustainable energy systems".

There are five thematic areas associated with the smart-city concept (Figure 4; Table 6) The area highlighted in "red" deals with "energy", "electric power", "transmission", "smart grid", "smart power grids" and "artificial intelligence". The scattered "blue" color combines "smart city" with such issues as "sustainable development" and "climate change", "sustainability", "carbon", "alternative energy", "urban planning", "urban development", "innovation", "sustainable cities", and "sustainable energy systems". In the "green" area are concepts such as "energy", "efficiency", "energy utilization", and "energy conservation" [95,126,134].

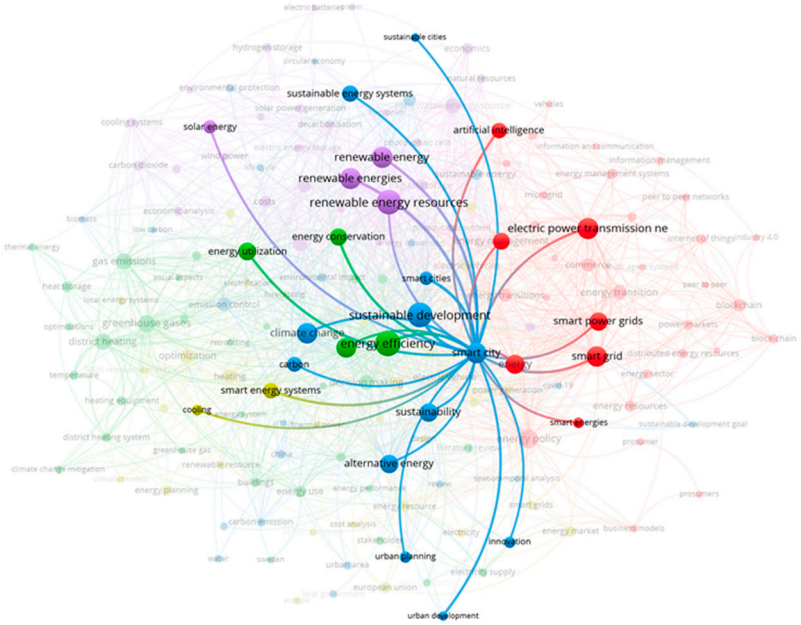

Figure 4. Thematic links for the term "smart city".

Table 6. Clusters for smart city.

Key Word	Smart City			
red cluster	blue cluster	purple cluster	green cluster	yellow cluster
energy	innovation	solar energy	energy conservation	cooling
smart energies	urban development	renewable energy resources	energy utilization	smart energy systems
smart grid	urban planning	renewable energies	energy efficiency	
smart power grids	alternative energy	renewable energy	energy systems	
energy management	sustainability			
electric-power transmission	carbon			
artificial intelligence	climate change			
	sustainable development			
	smart cities			
	sustainable energy systems			
	sustainable cities			

The purple cluster indicates the links between "smart city", "renewable energies" and "renewable energy sources" themes [97–100]. The fifth (small yellow) topic area exposes "smart energy systems" and "cooling". Figure 4 is the result of analyses based on the keywords "smart cities". The survey did not reveal the "red" area, seen in Figure 5 (and Table 7). The remaining clusters are consistent with the analyses performed for the keyword "smart city".

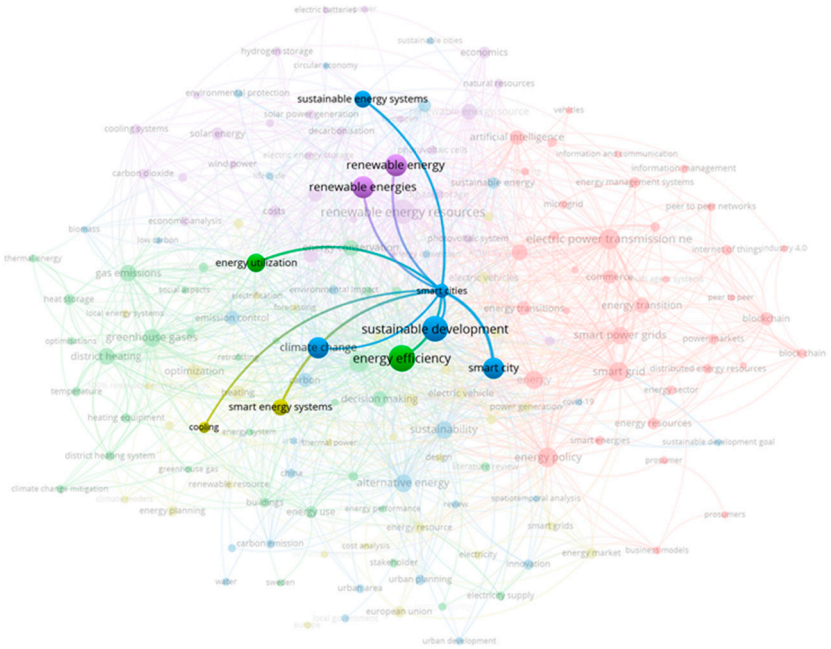

Figure 5. Thematic linkages for the term "smart cities".

Table 7. Clusters for smart cities.

Key Word	Smart Cities		
yellow cluster	blue cluster	purple cluster	green cluster
cooling	smart city	renewable energies	energy utilization
smart energy systems	sustainable development	renewable energy	energy efficiency
	climate change		
	sustainable energy systems		

Selection of the selected set based on the occurrence of the term "smart city" identified 27 publications. Eight of them dealt with "energy systems for smart city or managing energy in cities" [81,118,135–140]; Seven discussed the relationship between technology and urban planning [110,135,141–145]; five dealt with "creation of smart city" [79,96,146–148]; four of them focused on "smart city architecture" [71,149–151]; and three presented applications of the smart-city concept [152–154].

The linkages between the topics addressed in the study are reflected holistically in Figure 6, where numerous connections can be seen. The various clusters intermingle, which demonstrates the systemic dependencies that exist with regard to the topic of a sustainable energy system for smart cities and indicates the need for very careful preparation of transformational changes. The distinguished areas of study can be recognized using their dominant points. Thus, in the green cluster "energy efficiency", "gas emission", "energy utilization", and "greenhouse gasses" are particularly evident. In the purple area, "renewable energy resources", "renewable energy sources", and "renewable energy" are particularly prominent. The red cluster is dominated by "energy", "energy policy", "smart grid", "smart power grids", "energy transition", "electric power", "transmission", and "artificial intelligence (AI)". The blue area exposes "sustainable development", "smart city", "sustainability", "alternative energy", "sustainable energy system", and "climate change". The yellow cluster—the smallest—groups concepts such as "optimization", "heating", and "smart energy".

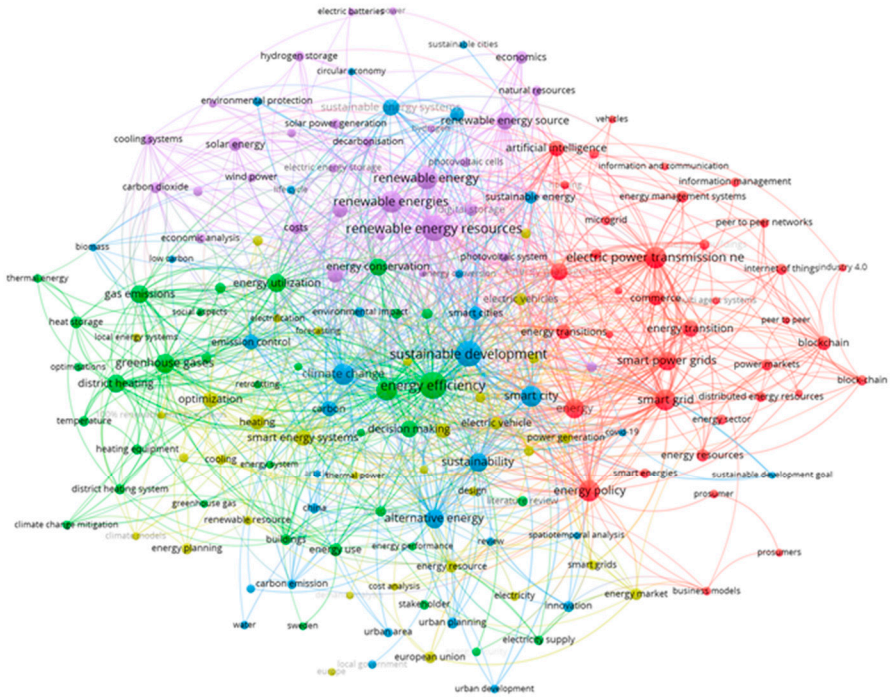

Figure 6. Detailed map of thematic links.

The network relationships in Figure 6 reveal noteworthy, relevant topic areas like biomass-gas and thermal-energy harvesting, electric batteries, industry 4.0, prosumer, water, emissions, etc.

Analyzing the "watch" of the issues covered by the research, it can be noted that the most undertaken research is on "renewable energy resources", "energy efficiency", "energy policy", and "electric power transition". Each of these scientific problems is directly or indirectly connected with the issues of "smart", "smart cities", and "sustainability". The linkage analysis shows that in the last five years, more and more interdisciplinary research results have been published, covering energy management, RES, cities, all using a sustainability approach. The presented maps of linkages and thematic relationships provide an answer to the research question posed and indicate the need to create model solutions that can be situationally adapted to the actual conditions of a specific city, based on already existing research results.

5. Discussion

The analysis of the identified publications has revealed several clusters of related content, each offering insights into various aspects of sustainable energy systems for smart cities. The key dependencies and relationships include the following:

- **Energy systems**:
  - This cluster, marked in red, primarily focuses on the development of the "energy smart" approach, including topics such as "smart power grids" and "smart grid".
  - The blue cluster covers a broad spectrum of topics related to sustainability, including "sustainable development", "sustainable energy systems", and "sustainable cities".
  - The yellow cluster is centered around the themes of "smart energy systems", "optimization", and "integrated energy systems".
  - The purple area highlights "renewable energies" and "renewable energy resources", "cooling systems", and "renewable energies", indicating local conditions.
  - The red subcluster links to "energy policy", "smart grid", and "energy management systems".

- The green subcluster interconnects "energy utilization", "efficiency", "energy", and "energy conservation", highlighting the need for technological solutions.

- **Smart city**:
  - In the case of the "smart city" concept, the analysis identifies five thematic areas.
  - The red area deals with "energy", "electric power", "transmission", and "smart grids".
  - The blue cluster combines "sustainable development", "climate change", and "sustainable energy systems".
  - The purple cluster links "renewable energies" and "renewable energy sources".
  - The green cluster focuses on "energy utilization" and "energy conservation".
  - The yellow cluster covers "smart energy systems" and "cooling".

Overall, these clusters reveal the intricate interdependencies between various aspects of sustainable energy systems, sustainability, and the smart-city concept. The network relationships highlight emerging topics like biomass gas, thermal-energy harvesting, electric batteries, industry 4.0, prosumer models, water management, and emissions reduction. This holistic view underscores the complexity of transforming urban areas into sustainable smart cities and emphasizes the need for careful planning and integrated solutions.

The results of the research provide a comprehensive overview of the transformation of energy systems within the context of sustainable smart cities. The following can be described as important transformation assumptions:

1. **Energy system thematic clusters**: The identified clusters related to energy systems highlight the multifaceted nature of energy management in smart cities. These clusters encompass various aspects, such as smart-grid development, sustainable energy systems, optimization, and renewable energy resources. This suggests that the transformation of energy systems in smart cities is a complex endeavor that involves multiple dimensions.
2. **Sustainability integration**: The presence of sustainability-related clusters, such as "sustainable development" and "sustainable energy systems", underscores the importance of integrating sustainability principles into the transformation of energy systems. This indicates a shift toward eco-friendly and socially responsible energy solutions.
3. **Structural solutions**: The association of certain clusters, like "energy policy", "smart grid", and "energy management systems", with structural solutions suggests that policy frameworks and technological advancements play a crucial role in reshaping energy systems for smart cities.
4. **Natural and social environment**: The presence of clusters related to "climate change" and "sustainable development" within the blue cluster signifies the interconnectedness of energy systems with the natural and social environment. It implies that energy transformations need to consider broader environmental and societal implications.
5. **Technological solutions**: The green cluster, which includes terms like "energy efficiency", "energy utilization", and "energy conservation", emphasizes the need for technological solutions to enhance the efficiency and sustainability of energy systems.
6. **Smart-city themes**: The thematic areas associated with the smart-city concept highlight the centrality of energy within smart-city frameworks. These themes encompass various dimensions, including energy management, sustainability, alternative energy sources, and urban planning. It suggests that energy is a fundamental pillar of smart-city development.
7. **Interconnectedness**: The network relationships depicted in Figure 6 demonstrate the intricate web of connections between different aspects of sustainable energy systems for smart cities. This interconnectedness highlights the need for a holistic approach to planning and implementing energy transformations.
8. **Emerging topics**: The presence of emerging topics like biomass gas, thermal-energy harvesting, electric batteries, industry 4.0, prosumer models, water management, and

emission reduction indicates the evolving nature of energy systems in response to technological advancements and environmental challenges.

In summary, the research findings indicate that the transformation of energy systems in smart cities is a multifaceted process that requires careful consideration of sustainability, policy, technology, and their interplay with the natural and social environment. The results provide valuable insights for policymakers, urban planners, and researchers working towards the development of sustainable and efficient energy systems in the context of smart cities.

6. Conclusions

The in-depth scientometric analysis conducted based on data from the Scopus database has identified leading scientific centers engaged in research on the broad concept of smart cities, as well as top researchers. Furthermore, it has been observed that there are strong connections between research on smart cities and sustainable development, energy efficiency, climate change, etc. Regardless of the research center, a pattern of conducting research can be identified. Researchers recognize smart-city indicators in their regional environment and subsequently carry out increasingly detailed studies on prosumer attitudes, smart grids, smart power grids, and artificial intelligence in various development contexts.

The analyses have confirmed that the energy system for a smart city is a highly complex system that requires careful preparation for transformation towards sustainability. The concept of Nadler's ideal system can be utilized to create a vision for the future of a specific city and take actions to realize it. A smart city can also be considered through the lens of a system model, where the elements include the following:

(1) City function (including goals, tasks, or functional priorities);
(2) Infrastructure (including energy infrastructure);
(3) Local community and its needs, preferences, competencies, culture, and structure;
(4) Processes (including energy acquisition and delivery processes), where technologies should be deliberately selected considering the existing infrastructure and residents' competencies;
(5) Input elements are tangible and informational (including energy supply);
(6) Output elements are tangible, informational, and surplus (offered services, including the acquisition of excess energy from prosumers);
(7) Interactions with the immediate and broader environment (economic, ecological, social).

Integrating these elements, in the context of local conditions, can result in gradual, flexible, and acceptable changes towards sustainable development of both cities and their associated energy systems. Transformations related to the implementation of sustainable-development priorities require a situational, holistic approach. Local conditions can be taken into account using foresight methodology, which not only predicts social debates and stakeholder involvement in preparing a shared vision of the future but also methodically prepares transformation scenarios. Our study reflected the guidelines and recommendations of Kraus [155], although there were some limitations. Using a single database (Scopus) may have resulted in the inclusion of irrelevant articles in the sample [156], especially since, as Mongeon and Paul-Hus [56] noted, the social sciences are underrepresented on Scopus. The use of other databases (such as EBSCO or CEJSH) could enrich the study. As with any similar research process, subjectivity cannot be completely excluded from our review. Nevertheless, we identified research gaps and potential directions for future research. They indicate the development trend of the topic under study, which, in addition, in the context of artificial intelligence, autonomous vehicles, the use of "smart "in every field of urban development, seems to be a rationale for continuing scientometric research, on more specific topics. This will accelerate the possibility of comparing new energy solutions and smart cities.

The limitations of the research process apply in particular to the quantitative analysis of the published articles, through keywords. For further research and the possibility of referring to the future, qualitative analyses are necessary, taking into account market trends,

as well as expert opinions. The authors regard the results of the study as a premise for undertaking further, exploratory, in-depth research for the identified clusters in qualitative terms. Future research should include validation of the adopted metrics for finding publications and how they correlate with other measures of impact and research quality in the topic. Nevertheless, the above shortcomings do not significantly affect the quality of our study.

In conclusion, our analysis of publications has illuminated the intricate web of interdependencies within sustainable energy systems for smart cities. These clusters have revealed the multifaceted nature of energy management, sustainability, policy, technology, and their interconnection with the natural and social environment. This holistic view underscores the complexity of transforming urban areas into sustainable smart cities, emphasizing the need for careful planning and integrated solutions. As we move forward, there are numerous opportunities for future research, in particular related to emerging topics of exploration and further application of foresight methodology in the transformation of broadly understood smart-city concepts based on scientometric analyses. In light of these potential research directions, our study serves as a valuable foundation for further exploratory investigations and provides a comprehensive overview of the complex landscape of sustainable energy systems in the context of smart cities. The findings have significant implications for policymakers, urban planners, and researchers working toward the development of sustainable and efficient energy systems within smart cities.

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