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Review

Understanding Sustainable Energy in the Context of Smart Cities: A PRISMA Review

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Abstract: In the context of smart cities, sustainability is an essential dimension. One of the ways to achieve sustainability and reduce the emission of greenhouse gases in smart cities is through the promotion of sustainable energy. The demand for affordable and reliable electrical energy requires different energy sources, where the cost of production often outweighs the environmental factor. This paper aims to investigate the ways smart cities promote sustainability in the electricity sector. For this, a systematic literature review using the PRISMA protocol was employed as the methodological approach. In this review, 154 journal articles were thoroughly analyzed. The results were grouped according to the themes and categorized into energy efficiency, renewable energies, and energy and urban planning. The study findings revealed the following: (a) global academic publication landscape for smart city and energy sustainability research; (b) unbalanced publications when critically evaluating geographical continents' energy use intensity vs. smart cities' energy sustainability research outcomes; (c) there is a heavy concentration on the technology dimension of energy sustainability and efficiency, and renewables topics in the literature, but much less attention is paid to the energy and urban planning issues. The insights generated inform urban and energy authorities and provide scholars with directions for prospective research.

Keywords: sustainable energy; renewable energy; energy efficiency; smart grid; smart building; smart city; climate change; urban planning; sustainable development goals; urban policy

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1. Introduction

The United Nations' (UN) projections suggest the world population will reach about 9.7 billion inhabitants by the mid-century, where this figure is to exceed 11 billion by the end of the century [1]. Along with this rapid population growth, urbanization levels across the globe are also on the rise due to accelerated migration from rural to urban areas. In 1960, the world population residing in urban centers was only 33.6%; in 2018, this number increased to 55.7% [2]. The UN estimates that by 2050, 60% of the world's population will reside in urban areas [3]. In many developing and developed regions of the world, such as Latin America and Europe, this number has already exceeded 75% [4,5].

Along with population growth and urbanization, cities face problems such as sprawling urban expansion, inequitable distribution of infrastructure and amenities, environmental degradation and pollution, urban immobility, increased demand for energy, uneven distribution of water and food, and lack of basic sanitation, among others [6–8]. Given the current situation and future projections, the need for cities to seek smart and sustainable solutions to deal with these challenges is eminent, especially in the era that gave rise to smart cities [5], where these offer an urban development blueprint in line with sustainable and knowledge-based urban development principles [9–11].

Energy, sustainability, and smart cities are associated concepts that require an integrated approach in promoting the quality of life and sustainability for the world's population that today lives concentratedly in cities [12–14]. For humanity to continue to develop and prosper into the next generations, sustainable urban development with increased energy efficiency is necessary [15]. In this context, energy efficiency can be understood as the rational and efficient use of energy in all stages of the process, from primary form to final consumption [16]. It is an essential tool with a relevant impact to reduce energy costs, but it depends on implementing public policies with fiscal and financial incentives for its application in local management [17].

In the world energy perspective, energy consumption is an essential indicator of development for countries. However, a significant constraint on the economic development of smart cities is the cost of electricity [18], where the demand for energy increases as the population and its living conditions increase. The global energy consumption trend, between 1990 and 2017, is illustrated with data from the International Energy Agency (IEA) [19] in Figure 1. The financial crisis caused by the COVID-19 pandemic showed us how financial factors influence access to energy [20]. The IEA [19] estimated that, in 2020, 592 million people across the world did not have access to electricity. In 2019 (just before the beginning of the pandemic), this figure was 572 million, which shows a significant increase in inequality, going against the UN's Sustainable Development Goals (SDGs) [20,21]. This situation shows that the supply of affordable electricity is a requirement for cities' socioeconomic development [18,22].

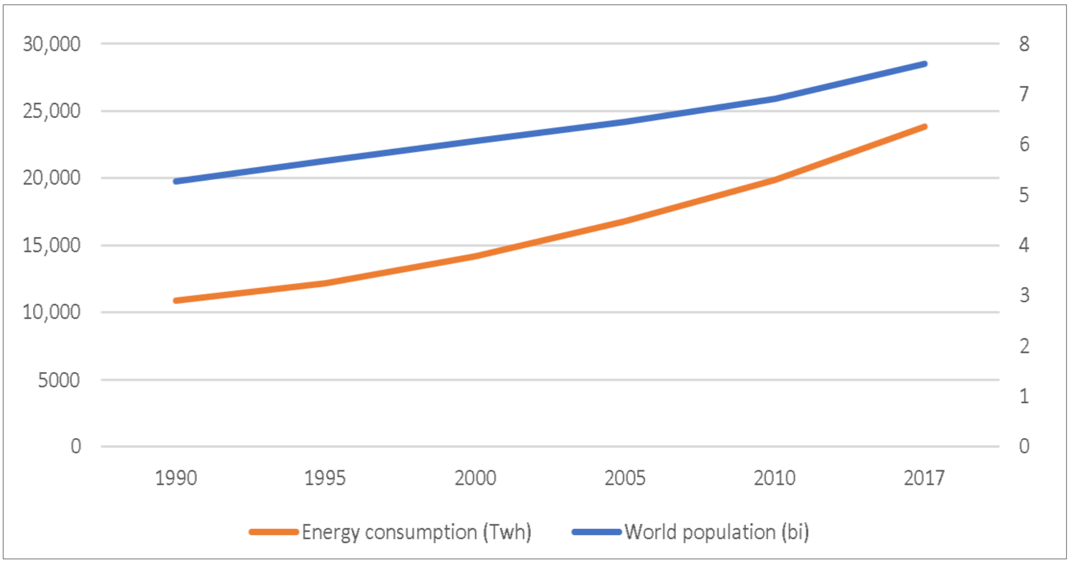

Figure 1. Global population (billion) and energy consumption (TWh) by year (1990–2017), derived from [19].

The solution to this imminent increase in the demand for electric energy cannot be given only by expanding energy production from the traditional fossil fuel resources. UN's SDG 7 deals with access to different energy sources, especially renewable, efficient, and non-polluting ones. SDG 7 highlights that development requires electricity to be clean and affordable [21]. In addition to being affordable, electricity needs to be sustainable [23,24]. The COP 26 (2021 United Nations Conference on Climate Change) proposed reducing 50% of greenhouse gas emissions by 2030 [25]. One of the industrial sectors that requires attention in this emission reduction plan is the energy production sector, which currently accounts for more than a quarter (27%) of total carbon equivalent emissions [18,25], illustrated in Figure 2.

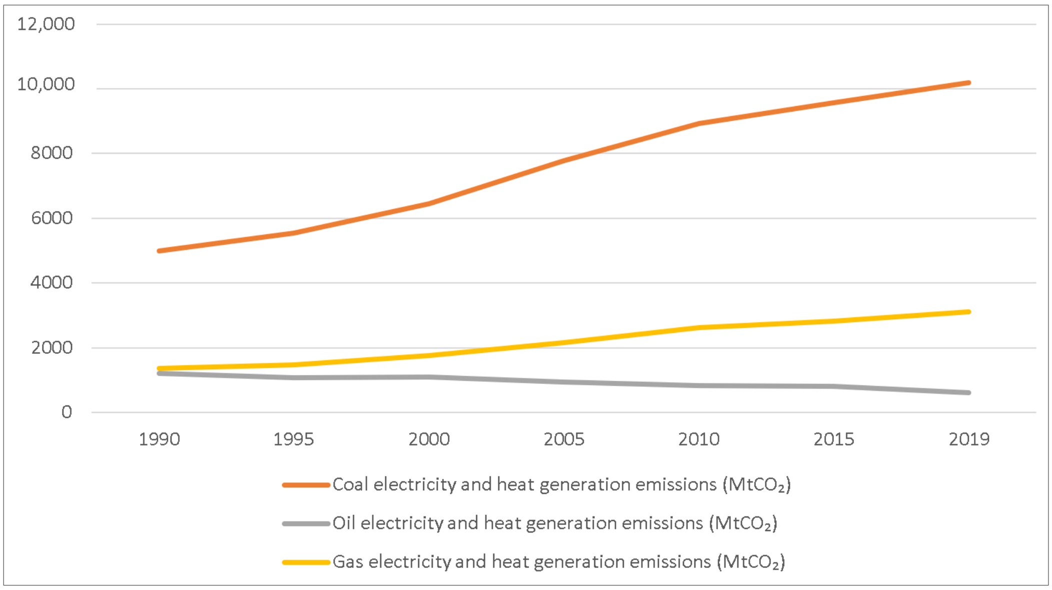

Figure 2. Global CO_2 emissions ($MTCO_2$) from electricity and heat by energy sources and year (1990–2019), derived from [19].

1.1. Theoretical Background

The sixth report of the Intergovernmental Panel on Climate Change (IPCC) disclosed the increase in the planet's temperature caused by the emission of greenhouse gases, also highlighting the relationship of this warming with extreme climatic events [26]. Scientific evidence alerts the public to the need to seek sustainable and less polluting solutions. One of the actions to reduce emissions in the energy production sector is to accelerate the replacement of coal, which represents 36% of the world energy matrix, with clean energy, such as solar, wind, tidal, etc., [25].

Replacing traditional fossil fuel with sustainable resources is not the only proposal to reduce the emission of greenhouse gases [25,27]. Another way of promoting energy sustainability is by applying technological resources to obtain energy efficiency [28], a technique that does not change production but improves how energy is handled and utilized. These techniques also reduce losses in the distribution of electric energy, smart grids, the Internet-of-things, and energy reduction for heating and cooling of buildings [28,29].

The relationship between smart cities and sustainability has been examined recently. One of the leading studies for the topic answered the question "can cities become smart without being sustainable?" and revealed that cities cannot be truly smart without being sustainable in the first place [30]. On a higher level, sustainability or its varied forms can become key indicators for measuring cities' smartness, such as conservation of natural resources [31] and environment impact from energy use [32]. Smart cities are designed to promote sustainability, ensuring access to essential human development and well-being [30]. Smart cities and sustainability are intertwining concepts that can be infused in many aspects of urban living, such as in urban mobility [24], urban planning [33], and energy management [34].

1.2. Aim and Contributions

Considering the growing demand for electric energy accompanied by the tremendous environmental impacts caused by its production, this study aims to seek the ways smart cities promote sustainability in the electricity sector. For this purpose, the study employed the systematic literature review method to map the scientific knowledge produced so far on the topic [35].

The main contributions of this study include:

- Being a pioneering systematic review that focuses on energy sustainability in smart cities;
- Offering the depiction of the academic publication landscape for smart city and energy sustainability research (Section 3.1);
- Providing a critical evaluation of geographical continents' energy use intensity vs. smart cities' energy sustainability research outcomes (Section 3.2);
- Identifying major research gaps in energy and urban planning areas (Section 3.2.3).

Following this introduction, Section 2 details the methodological approach of the paper. Next, Section 3 reveals the results and offers a discussion on the results. Lastly, Section 4 presents the key findings and contributions of the study.

2. Methodology

In this study, a systematic literature review method is used to tackle the question of "How do smart cities promote sustainability in the electricity sector?" [35]. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol is adopted to offer the replicability of the study [36]. The review is structured in three stages according to the methodology suggested by Yigitcanlar et al. [30] and Regona et al. [37]. The three stages are: (a) planning for developing the research aim, question, and search criteria; (b) conducting the review; and (c) reporting and dissemination stage.

The review study used the Web of Science and Scopus databases to collect documents, as they are the two databases with the most significant number of indexed journals on the subject studied [38]. In the first stage, the study made a review planning by creating the inclusion and exclusion criteria. The keywords "smart cities" and "energy" were defined (considering all the terms with and without plural inflection) to construct the search expression to collect the materials. In this step, the inclusion criteria were defined: only complete articles, available online, written in English, and relevant to the study. Finally, the exclusion criteria were defined: as described in Table 1, books, conference reports, editorials, articles in languages other than English, and gray literature (government documents, industrial reports, non-academic documents, or any other material that did not pass the inclusion criteria).

Table 1. Inclusion and exclusion criteria.

Primary Data		**Secondary Data**	
Inclusionary	Exclusionary	Inclusionary	Exclusionary
Journal articles	Duplicate records	Energy in smart cities	Not related to energy sustainability
Peer-reviewed	Books and chapters	Energy sustainability	Not related to cities
Full-text available online	Industry reports	Relevant to the research objective	Irrelevant research objectives
Published in English	Government reports Conferences		

In the second stage, the study conducted a systematic literature review by following the PRISMA protocol. In this step, the materials were collected from the selected search bases, for which the keywords gave rise to the search expression (Title or Publication Title contains the terms ("smart city" OR "smart cities") AND ("energy" OR "energies")). For the collection of materials, the authors did not establish an initial date so that all materials published until 31 December 2021, were collected. The results of this search were tabulated; this initial sample contained 928 documents. After removing documents duplicated, in languages other than English, and non-academic documents, a sample of 226 articles was identified. The abstracts of the articles in this sample were read to separate only the articles that had elements capable of contributing to the answer to the guiding question according to the criteria in Table 2.

Table 2. Selection criteria.

Selection Criteria
▪ Identify which continents promote energy sustainability.
▪ Determine how energy sustainability is promoted.
▪ Quantify the methodological approach of the analyzed works.
▪ Analyze whether the theme is promising through a temporal analysis.
▪ Relevant categories are distributed and selected under the most pertinent categories.

After the above step, 154 articles were selected (listed in Appendix A Table A1) to compose the final sample, which were read in full and had their information tabulated, and the articles were grouped according to their objective/central theme. The process for literature screening and selection is illustrated in Figure 3 following the PRISMA model [36].

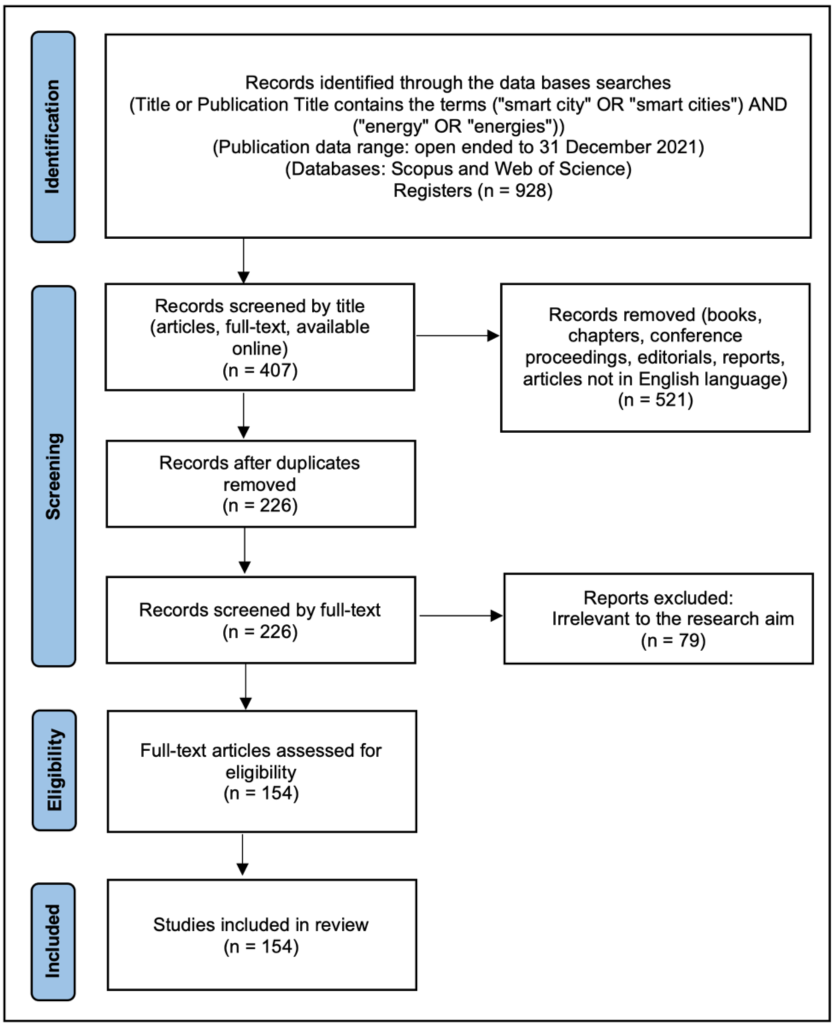

Figure 3. The PRISMA selection process of relevant literature.

The results were presented in a literature review format in the third stage. In addition to the articles that made up the sample used in this work, complementary materials were selected for the composition, introduction, contextualization, discussion, and conclusion. The results of this review are presented and discussed in Section 3.

3. Results and Discussion

3.1. General Observations

The research showed that despite being a relatively new topic, it continues to proliferate in academia, showing a scientific drive to seek solutions and innovation in the energy sustainability sector in cities. The initially selected literature pieces contained 928 documents. After applying the inclusion and exclusion criteria, a final list was created containing 154 articles in English published in scientific journals for analysis. The final list showed that 81% of the studies on energy sustainability in smart cities were published in the last four years (13% in 2018, 16% in 2019, 20% in 2020, and 32% in 2021). It was also notable that in 2012, there were two publications on the topic and that the cumulative distribution of these publications until the end of 2016 was only 11%, as shown in Figure 4.

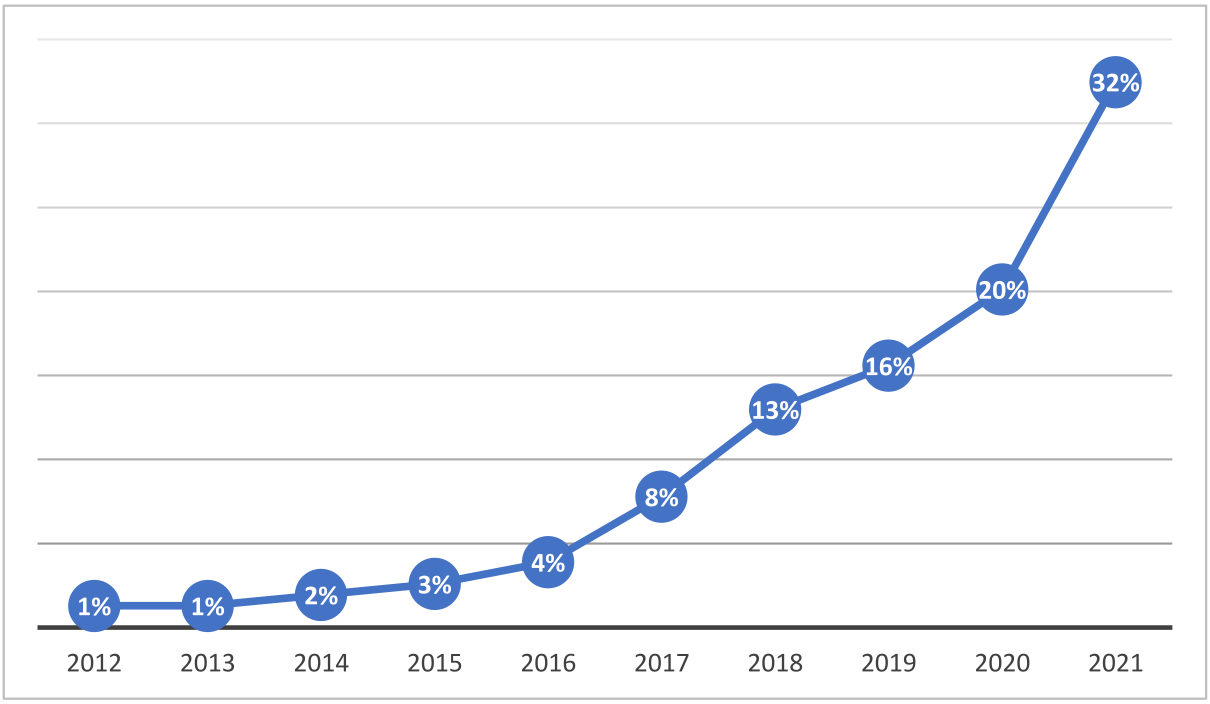

Figure 4. Distribution of publications by year (2012–2021).

The analysis disclosed that the 154 selected articles are distributed among 97 journals, of which only 20 have two or more publications on the topic, grouping 51% of these articles, as shown in Table 1. Of these works, 13.6% were published in the journals "Sustainable Energy Technologies and Assessments" and "Energies" followed by the journals "Sustainability" and "Sustainable Cities and Society" with 5% and 4%, respectively. The journals "Smart Cities", "IEEE Access", "Sensors", "IEEE Transactions on Industrial Informatics", "Applied Energy", "Journal of Cleaner Production", and "Green Energy and Technology" published together 16% of the articles found on the theme. Despite having a distribution of materials in 97 journals, the research showed that the topic is still segmented with greater concentration in only 13% of the sample journals (12 journals with three or more articles about the subject since 2012) as shown in Table 3.

Table 3. Distribution of publications by journals and years.

Journal	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Energies	1	0	0	0	0	0	1	1	3	5	11
Sustainable Energy Technologies and Assessments	0	0	0	0	0	0	0	0	0	10	10
Sustainability	0	0	1	0	0	0	0	0	3	3	7
Sustainable Cities and Society	0	0	0	0	0	0	0	0	1	4	5
Smart Cities	0	0	0	0	0	0	0	0	2	2	4
IEEE Access	0	0	0	0	0	0	1	1	2	0	4
Sensors	0	0	0	0	2	1	0	0	0	0	3
IEEE Transactions on Industrial Informatics	0	0	0	0	0	1	3	3	0	0	7
Applied Sciences	0	0	0	0	0	0	0	0	1	1	2
Journal of Cleaner Production	0	0	0	0	0	0	1	1	0	1	3
Green Energy and Technology	0	0	1	0	1	1	0	0	0	0	3
Techne-Journal of Technology for Architecture and Environment	0	0	0	0	0	0	3	3	0	0	6
Energy and Buildings	0	0	0	0	0	0	0	0	1	1	2
Techne	0	0	0	0	0	0	1	1	0	1	3
Future Generation Computer Systems	0	0	0	0	0	0	0	0	1	0	1
Energy Policy	0	0	0	0	0	1	0	0	0	0	1
IEEE Communications Magazine	0	0	0	0	0	1	0	0	0	0	1
Energy, Sustainability and Society	0	0	0	0	1	1	0	0	0	0	2
Applied Energy	0	1	0	0	0	0	0	0	0	0	1
Expert Systems	0	0	0	0	0	0	0	0	1	1	2
Other	1	1	1	4	2	6	10	14	16	21	76
Total	2	2	3	4	6	12	20	24	31	50	154

To understand whether the amount of academic scientific production is associated with the energy demand of a specific region, the number of publications per region was determined. This indicator was related to each continent's amount of electricity consumed [19]. This analysis showed that Asia, the continent with the highest energy consumption, is the second continent that most produces scientific research on the subject, behind Europe in terms of scientific production, representing 44% and 45% of the total sample each. Next in energy consumption comes North America. However, the number of academic publications on the continent on the subject represents only 5% of the sample, and only a little more than half of these studies are of practical content. Europe is the continent that ranks third in terms of energy consumption. Next comes Oceania, Latin and Central America, and Africa, in that order. The energy consumption of these continents together represents less than the total consumption of North America, and the sum of the academic publications of these continents on the subject represents only 5% of the sample, as shown in Table 4 electricity consumption figures are gathered from IEA statistics [19].

3.2. Classification of Categories

With the increase in urbanization and population, the energy demand also grows. Estimates from the UN predict that by 2050, the world population will reach 9.7 billion [39]. This challenge demands the implementation of urban planning considering three categories built from this systematic literature review: the energy issue [40–42], adoption of renewable energy sources [43,44], and actions on energy efficiency [40,45,46] for better handling and utilization of available energy.

Table 4. Number of publications by continent, methodology, and energy consumption.

Continent	Number of Studies	Empirical	Theoretical	Electricity Consumption (TWh)
Asia	69	49	20	11,985.5
Europe	70	38	32	3837.9
North America	7	4	3	5056.2
Africa	3	2	1	732.4
Latin and Central America	3	3	0	1109.5
Oceania	2	1	1	1912.7

During the systematic literature review, the articles are grouped and analyzed according to their central theme and research question, resulting in the construction of three categories. Together, these three categories are an integral part of energy and urban planning. Figure 5 illustrates the union of these categories, where energy sustainability is the central theme and underlines the main theme of this paper, i.e., urban energy sustainability. This theme is connected to the three observed categories: (a) energy efficiency; (b) renewable energy; and (c) energy and urban planning. Figure 5 represents the connection between the central theme, energy sustainability, followed by the three themes that appeared the most in the articles, which, for categorization, were treated as categories, together with their subcategories converging towards the established objective.

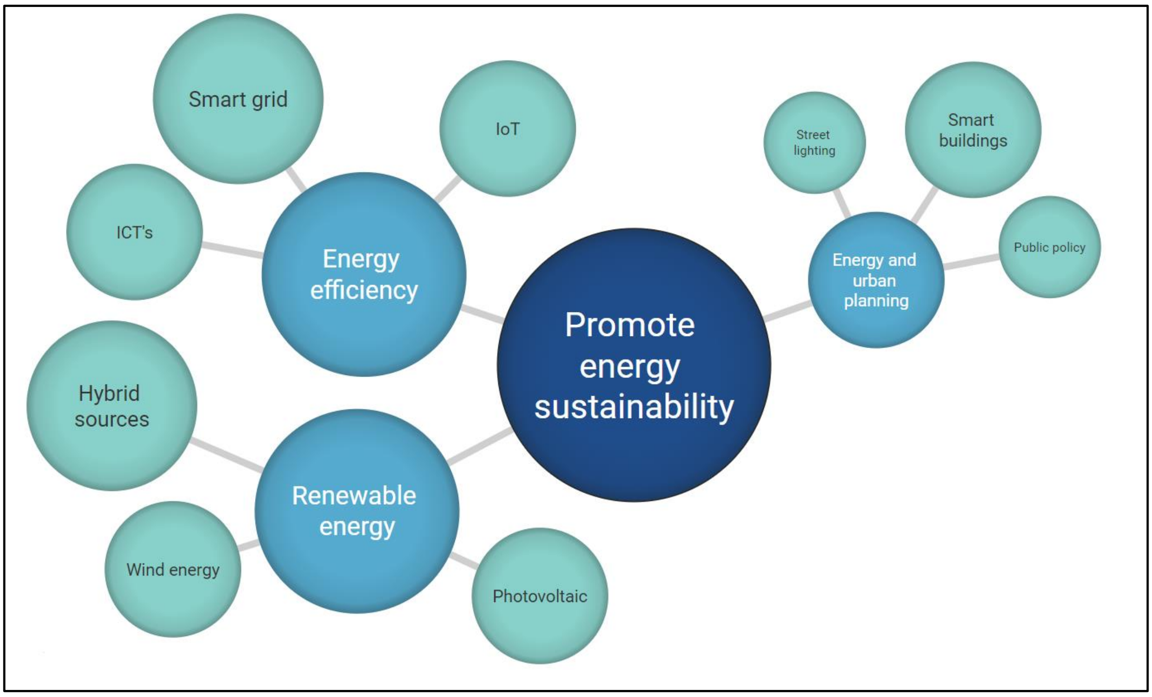

Figure 5. Main categories concerning sustainable energy in the context of smart cities.

Figure 5 represents the proposition of UN, which declared the decade from 2014 to 2023 as the decade of "Sustainable energy for all", contemplating universal access to energy, renewable energy, and energy efficiency as primary objectives [47]. The stimulus is intense to expand the supply of renewable energy in the world energy matrix and ensure that energy promotes economic development in all countries. In this sense, sustainability and energy are directly related topics, and, as most of the world's population live in cities, this research agenda integrates with the challenges within the scope of smart and sustainable cities [48].

3.2.1. Energy Efficiency

From reading the articles, the review sought to understand the focus that each one had. The first category identified was "Energy efficiency" due to the number of articles published (86 documents), equivalent to 55.8% of the selected literature pieces. Energy efficiency is characterized by actions and projects that use technology to reduce energy consumption or make this consumption process more efficient [49,50].

Technology stands out as one of smart cities' leading and central dimensions [51,52]. This dimension is also a protagonist in the energy efficiency category. Some of the main topics identified in these studies are smart grids, the Internet-of-things (IoT), and information and communication technologies (ICTs).

Smart grids use technological resources for the efficient production and distribution of electricity, promoting energy security and diversifying production sources, enabling the use of more than one source of energy production in the same distribution network [53,54]. In addition to promoting energy efficiency, smart grids have emerged as elements for creating resilient cities, as they ensure diversity in energy production sources and diversification of distribution routes [55].

Due to the wide range of power transmission and distribution lines, IoT resources emerge as vital allies in promoting energy efficiency, enabling the monitoring of quality of service, and assisting in decision-making [56,57]. Associated with the use of IoT, the use of ICTs also appears as a necessary resource for the implementation of IoT [58,59]. The emergence of 5G technology favors the use of IoT in the energy efficiency sector, enabling the connection of the resource in more remote areas and with better connection quality and speed [60,61].

An IEA [19] survey pointed out a jump in electricity consumption in the world, which went from 2.1 MWh/per capita in 1990 to 3.3 MWh/per capita in 2018, an increase of 57% in just 28 years. With the population increase projected for the next decades [22], there is an imminent need to produce more electricity to meet this demand—energy consumption figures are illustrated in Figure 6.

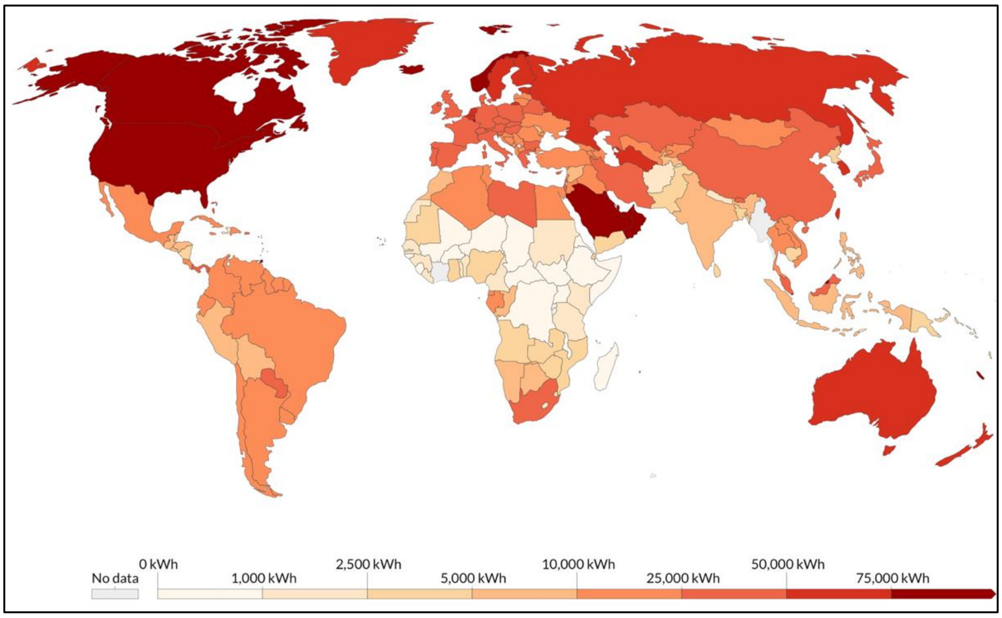

Figure 6. Per capita global energy consumption (kWh) in 2019, derived from [19].

This research unveiled that the continent with the highest per capita consumption is not necessarily the most advanced academic research on the subject. North America, a continent with an average consumption of 10.3 MWh/capita, published only seven articles in this category, representing 5% of the total sample. On the other hand, Asia and Europe, which occupy the second and third position of the continents with the highest consumption of electric energy per capita, are the ones that produced the most research on the subject. Asia published 70 articles, representing 45% of the total sample. Europe appears to be tied with Asia in the number of publications. Most of the works developed by Asian and European authors are of an empirical, methodological nature, representing 71% and 54%, respectively, whereas 57% North American publications are of an empirical nature.

On the energy efficiency issue, on the one hand, energy efficiency has contributed to the promotion of sustainability in smart cities through its innovations and the use of technology; on the other hand, its specific actions and independent projects alone are not sufficient to guarantee significant changes in the consumption patterns or behavior of the entire society. Another critical point of this category is the concentration of studies on the technology dimension, which demonstrates that smart cities remain "stuck" in their stereotype without considering socioeconomic issues that directly affect the life and behavior of the population.

In sum, promoting energy sustainability is possible by applying appropriate technological solutions to improve energy efficiency, but this should be implemented along with other measures, such as investing on renewable energy resources.

3.2.2. Renewable Energy

The second category is "Renewable energy", which is present in 36 documents, equivalent to 23.3% of the selected literature. Renewable energy corresponds to natural energy sources; they regenerate naturally in each cycle [62,63]. Despite being a global commitment established in international agreements [25,64,65], the production of scientific research on renewable energy in smart cities is still limited. Asia is the continent that produced the most research on the topic, with 23 articles in the sample, followed by Europe with 15 and North America and Oceania, with only one article each.

Sustainability is one of the structuring axes of research on smart cities [51,52,66]. In this context, environmental sustainability has been the focus of discussions and commitments by several countries due to the urgency of measures to restore ecosystems and mitigate climate change [39]. Renewable energy contributes significantly to environmental sustainability. Among the main topics identified in the sample, studies are mainly in the areas of solar energy, wind energy, tidal energy, and biomass energy.

The world energy matrix is composed of different resources to produce electric energy, using the most viable resource for each region and the combination of these resources [18,67,68], as illustrated in Figure 7. Despite a growth in the use of renewable resources such as photovoltaic and wind energy, the electricity generated from fossil fuels is still the majority in the world. They are also the ones that release the most greenhouse gases into the atmosphere, as illustrated in Figure 8 [19].

In this category, most studies refer to hybrid systems, which use two or more sources for energy production. This predominance occurs due to the natural variation of renewable resources, such as fluctuations in solar irradiance and wind speeds [18,67,68]. With the increased installation of photovoltaic panels at homes and buildings, locally generated renewable electricity has been increased for local use, making it possible to adopt a renewable source of energy without depending solely on utility and network companies responsible for the supply of electricity [69]. With the popularization of electric vehicles, the concern of some cities also arises in providing clean energy for recharging these vehicles [70].

On the renewable energy issue, we consider this category the most urgent and promising of all. Nonetheless, renewable energies still lack investments for their development and expansion. Likewise, the results show that research on this topic is still incipient. Even in smart cities, the lack of investments, incentives, and public policies makes switching to renewable energies very slow. Another critical point related to this category is the economic aspect, traditional companies in the energy sector that use polluting sources represent true economic powers and profit a lot from inefficient and destructive energy generation.

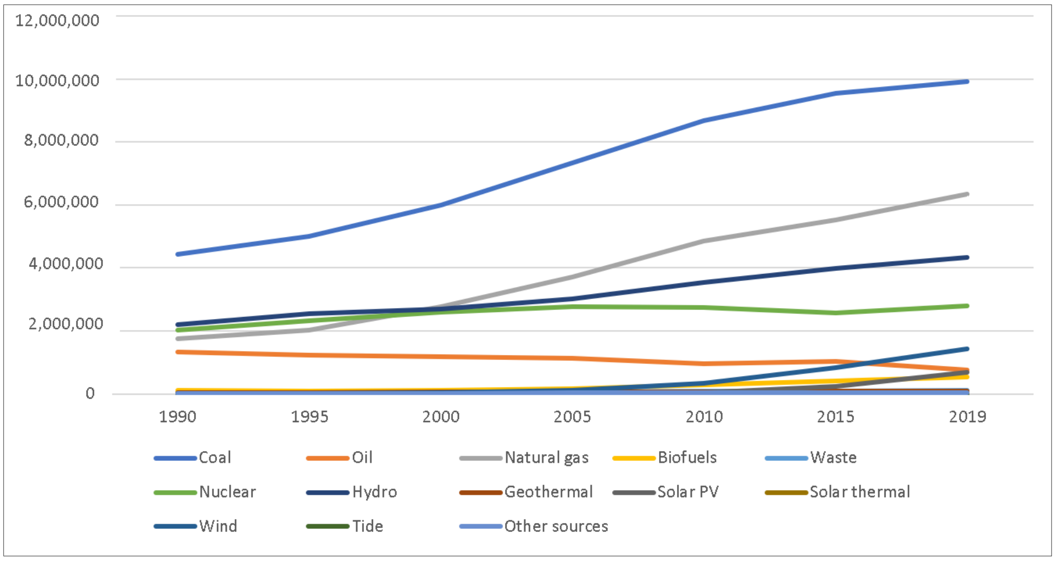

Figure 7. Global electricity generation by source (GWh) and year (1990–2019), derived from [19].

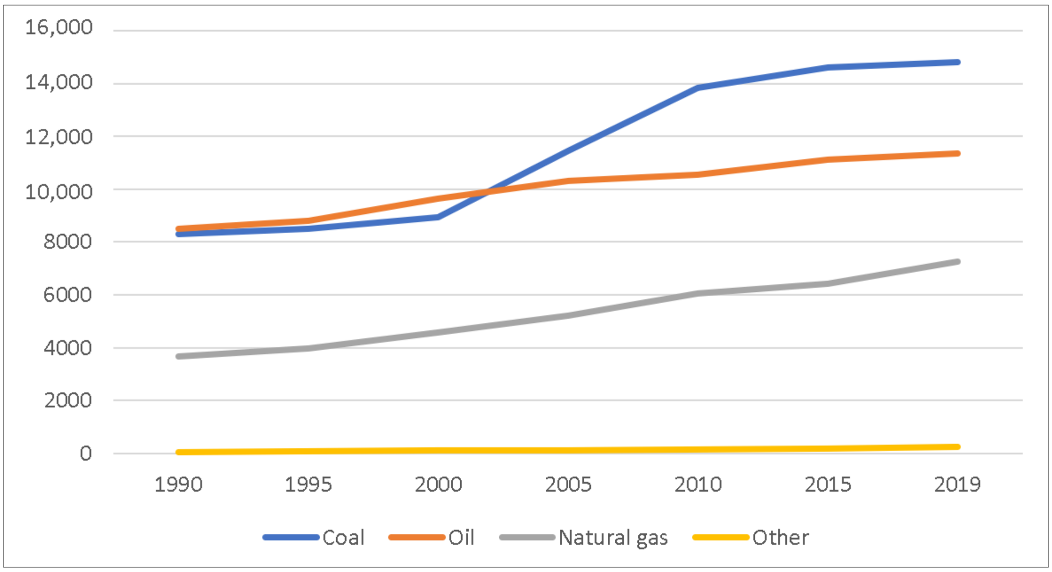

Figure 8. Global CO_2 emissions in electric energy production by source and year (1990–2019), derived from [19].

In sum, the generation of clean energy from renewable energy resources has been gaining popularity in recent years. Renewable energy is a critical and integral part of the smart and sustainable cities agenda. Nonetheless, renewable energy with respect to urban planning is still an area for further growth for smart cities to deliver their desired sustainable energy goals.

3.2.3. Energy and Urban Planning

The "Energy and urban planning" category was the third identified and consisted of planning, management, creation, and development of public policies, actions, and strategies focused on the development of urban energy sustainability [40,41,71].

The issue of energy and urban planning was identified as a significant gap in this study, present in 32 of the studies analyzed, representing 20.7% of the sample. With only a few studies as a reference, this category should be the basis or the starting point for energy sustainability in smart cities. Without adequate planning, SDGs and the agreements signed at the COP26 in 2021 on the energy matrix would be lost in goals and promises that will not be achievable for several countries [39].

Promoting energy sustainability also comes from creating public policies for urban planning, sustainable urban development, and management instruments. These policies should focus on access to electricity and energy security, ensuring the availability and reliability of the resource, and sustainability in production [72,73]. For this, urban planning must consider elements such as efficient and sustainable public lighting [74] and the construction of smart homes, buildings, and neighborhoods capable of promoting energy efficiency and renewable energy sources.

One of the essential strategies to reduce energy consumption and increase efficiency is to implement technological innovation, such as automation of lighting systems using presence sensors and timers, materials with thermal comfort consideration, and automation of temperature control systems for air conditioners. In new constructions, this discussion needs to become mandatory in the design phase. Furthermore, retrofitting is an effective and economical option to combine innovation and sustainability for existing and old buildings [48].

On the energy and urban planning aspect, we consider that smart cities demand the improvement of the energy systems, regarding production, distribution, and consumption in public urban planning policies to achieve significant changes and proceed with the behavioral transformation of the whole society to a sustainable model [75]. The great challenge is how to maintain energy supply and promote energy sustainability in these cities to allow continued economic development, ensuring an ecologically balanced environment [44]. Another critical point for this change is the integration and commitment of different actors in the society, such as governments, public institutions, non-governmental institutions, private companies, and civil societies [76].

In sum, energy, sustainability, and smart cities are associated concepts and require an integrated approach in promoting urban sustainability and quality of life of the world's population that today live concentratedly in cities. Urban planning could provide such integration. Nevertheless, there is a high concentration on the technology dimension of energy sustainability and efficiency, and renewables in the reviewed literature, but much less attention is paid to the most needed symbiosis between energy and urban planning [77].

3.3. A Conceptual Model and Further Discussion

Based on the systematic literature review discoveries, a conceptual model for energy sustainability in smart cities was developed and the model is presented in Figure 9. Furthermore, this section extends the discussion and presents potential implications for researching energy sustainability in smart cities.

As shown in Figure 9, energy efficiency, renewable energy, and energy and urban planning are pillars of energy sustainability in smart cities. They are integral components and together support sustainable development of smart cities. Energy efficiency runs through the whole energy cycle, from generation to distribution to utilization at users' end. Renewable energy supports sustainability by generating clean and sustainable energy for smart cities. In the context of smart cities, energy and urban planning can be enabling and overarching factors to ensure energy sustainability. Implications and examples of the three components are discussed in the following paragraphs.

Implications for energy efficiency in smart cities: Energy efficiency is often of the highest priority in terms of resource conservation because it often has permanent impact and cuts down the need to use energy, hence reducing the need to consume resources [78,79]. When sustainability becomes an inherent part of smart cities, urban energy efficiency would also become a key enabler and indicator for smart cities, for example, passive design for buildings [79] and innovative technology implementation for urban environment [80]. However, as Section 3.2.1 revealed, energy efficiency may not be the silver bullet for all energy sustainability needs. There is a need to enable more renewable energy in smart cities. This is critical as the forecasts are for the future of urban mobility being electric, hence there is investment needed for clean energy fed electromobility [81].

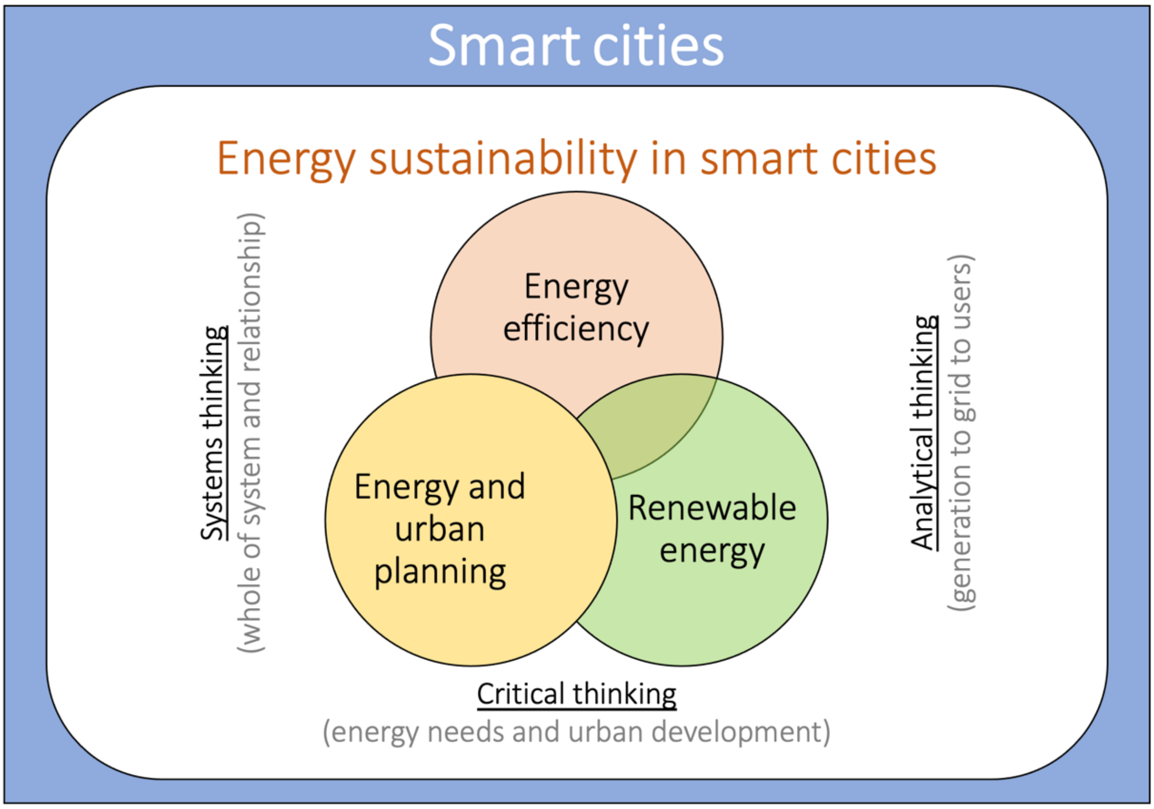

Figure 9. Conceptual model for energy sustainability in smart cities.

Implications for renewable energy in smart cities: There are various renewable energy forms that can be utilized in the urban environment. One of the most common renewable energy technologies is solar photovoltaic system (PV). In smart and sustainable cities, PV can provide renewable energy in a distributed manner, such as on rooftops, carparks, and building façades [82,83]. Another common form of renewable energy is wind, which needs more focused study on how wind resources can be integrated in smart cities for energy generation and cooling the built environment [84,85].

Implication for energy and urban planning for smart cities: In smart cities, urban planning may lay the foundation to enable energy sustainability without consuming extra resources and avoid pitfalls that may happen if planning has not first been confirmed. A real-world example can be given as follows: No dark roof is allowed in the western region of Sydney [86], which is a low to no risk option to mitigate the impact of urban heat islands and reduce electric energy use by natural ways of lowering solar heat gain for buildings.

A wide area study of 34 cities in Poland confirmed that sustainable development is at the core of urban management [87]. This study did not focus on the energy or electricity sector; however, it highlighted urban planning is a crucial factor to enable sustainable development.

Urban planning can offer more opportunities in enabling energy sustainability in cities, such as population density planning for net zero goals, building height limits for utilizing solar energy, and urban forms for wind utilization [88,89]. On the other hand, energy sustainability supports sustainable urban development in the context of smart cities.

4. Conclusions

The trend of rapidly increasing human population creates a high demand on energy, particularly in large metropolitan cities, which poses a major threat to our future energy security [90–93]. Given that this trend is already coupled with anthropogenic climate change externalities, the magnitude of this problem is colossal, which makes it a serious challenge for the authorities to tackle [94]. This sustainable energy challenge is of the utmost importance in meeting basic human needs, improving quality of lives, and avoiding contributing to further climate catastrophes [95].

Smart cities, during the last decade and a half, have offered some invaluable directions (at least at the theoretical level) for addressing this problem [96]. The smart city energy solutions focus on establishing: (a) energy efficiency; (b) energy sustainability, including utilization of renewable energy resources; and (c) energy and urban planning, including the utilization of smart grids, smart homes/buildings, smart urban and energy planning, electric vehicles, and so on [97–101].

While there is substantial literature with solutions in each of these areas, there are only limited comprehensively conducted review studies that shed light on the big picture for understanding sustainable energy in the context of smart cities [75,102,103]. To address this gap in the literature, this paper contributed to mapping out the academic studies that investigate the ways smart cities promote sustainability in the electricity sector. For this purpose, the study adopted a PRISMA protocol for the systematic literature review for the transparency and replicability of the review.

Energy, sustainability, and smart cities are associated concepts and require an integrated approach in promoting urban sustainability and quality of life of the world's population that today lives concentratedly in cities. The sustainable energy issue is a critical and integral part of the smart and sustainable cities agenda. Promoting energy sustainability is possible by applying appropriate technological solutions to obtain energy efficiency, but this should be implemented along with investing on renewable energy resources.

The major findings of this review include: (a) the academic publication landscape for smart city and energy sustainability research; (b) unbalanced publications when critically evaluating geographical continents' energy use intensity vs. smart cities' energy sustainability research outcomes; and (c) heavy concentration on the technology dimension of energy sustainability and efficiency, and renewables topics in the literature, but much less attention is paid to the energy and urban planning issues.

These insights inform urban and energy authorities in understanding sustainable energy in the context of smart cities and provide urban and energy scholars with directions for prospective research to tackle the wicked sustainable energy problems of our cities and societies. The focus of this paper is limited to smart city and energy research. Potential future research may include energy in practical smart city cases, smart communities, smart homes, or specific areas, such as connectivity and digital features.

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Appendix A

Table A1. Publications selected for systematic literature review.

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[104]	Pol, O., Palensky, P., Kuh, C., Leutgöb, K., Page, J., Zucker, G.	Integration of centralized energy monitoring specifications into the planning process of a new urban development area: a step towards smart cities	2012	Energy and urban planning	Other	Theoretical	Oceania
[105]	Pirisi, A., Grimaccia, F., Mussetta, M., Zich, R.E.	Novel speed bumps design and optimization for vehicles' energy recovery in smart cities	2012	Renewable energy	Energy harvesting devices	Empirical	Europe
[106]	Rodríguez-Molina, J., Martínez, J.-F., Castillejo, P., De Diego, R.	Smarc: a proposal for a smart, semantic middleware architecture focused on smart city energy management	2013	Energy efficiency	Smart grid	Empirical	Europe
[107]	Yamagata, Y., Seya, H.	Simulating a future smart city: an integrated land use-energy model	2013	Renewable energy	Hybrid energy system	Theoretical	Asia
[108]	Sanchez-Miralles, A., Calvillo, C., Martín, F., Villar, J.	Use of renewable energy systems in smart cities	2014	Renewable energy	Hybrid energy system	Theoretical	Europe
[109]	Battista, G., Evangelisti, L., Guattari, C., Basilicata, C., de Lieto, Vollaro, R.	Building's energy efficiency: interventions analysis under a smart cities approach	2014	Energy efficiency	Smart buildings	Empirical	Europe
[110]	Moreno, M.V., Zamora, M.A., Skarmeta, A.F.	User-centric smart buildings for energy sustainable smart cities	2014	Energy efficiency	Smart buildings	Empirical	Europe
[111]	Caponio, G., Massaro, V., Mossa, G., Mummolo, G.	Strategic energy planning of residential buildings in a smart city: a system dynamics approach	2015	Energy efficiency	Energy saving	Empirical	Europe
[112]	Sanseverino, E.R., Scaccianoce, G., Vaccaro, V., Carta, M., Sanseverino, R.R.	Smart cities and municipal building regulation for energy efficiency	2015	Energy efficiency	Smart buildings	Theoretical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[113]	Lützenberger, M., Masuch, N., Küster, T., Freund, D., Voß, M., Hrabia, C.-E., Pozo, D., Fähndrich, J., Trollmann, F., Keiser, J., Albayrak, S.	A common approach to intelligent energy and mobility services in a smart city environment	2015	Energy efficiency	Electric vehicle	Empirical	Europe
[114]	Jablonski, I.	Smart transducer interface-from networked on-site optimization of energy balance in research-demonstrative office building to smart city conception	2015	Energy efficiency	Smart buildings	Empirical	Europe
[115]	Aslam, S., Hasan, N.U., Jang, J.W., Lee, K.-G.	Optimized energy harvesting, cluster-head selection and channel allocation for IoTs in smart cities	2016	Energy efficiency	Smart grid	Empirical	Asia
[116]	Maier, S.	Smart energy systems for smart city districts: case study Reininghaus district	2016	Renewable energy	Hybrid energy system	Empirical	Oceania
[117]	Palomar, E., Chen, X., Liu, Z., Maharjan, S., Bowen, J.	Component-based modelling for scalable smart city systems interoperability: a case study on integrating energy demand response systems	2016	Energy efficiency	Smart buildings	Empirical	Europe
[118]	Wang, S., Wang, X., Wang, Z.L., Yang, Y.	Efficient scavenging of solar and wind energies in a smart city	2016	Renewable energy	Hybrid energy system	Empirical	Asia
[40]	Maltese, I., Mariotti, I., Boscacci, F.	Smart city, urban performance and energy	2016	Energy and urban planning	Other	Theoretical	Europe
[119]	Zambon, I., Monarca, D., Cecchini, M., Bedini, R., Longo, L., Romagnoli, M., Marucci, A.	Alternative energy and the development of local rural contexts: an approach to improve the degree of smart cities in the central-southern Italy	2016	Renewable energy	Hybrid energy system	Empirical	Europe
[120]	Mahapatra, C., Moharana, A.K., Leung, V.C.M.	Energy management in smart cities based on internet of things: peak demand reduction and energy savings	2017	Energy efficiency	Smart grid	Empirical	North America
[121]	Krozer, Y.	Innovative offices for smarter cities, including energy use and energy-related carbon dioxide emissions	2017	Energy efficiency	Smart buildings	Theoretical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[122]	Chen, Y., Ardila-Gomez, A., Frame, G.	Achieving energy savings by intelligent transportation systems investments in the context of smart cities	2017	Energy efficiency	Smart mobility	Theoretical	North America
[123]	Carli, R., Dotoli, M., Pellegrino, R.	A hierarchical decision-making strategy for the energy management of smart cities	2017	Energy and urban planning	Other	Theoretical	Europe
[124]	Brundu, F.G., Patti, E., Osello, A., Giudice, M.D., Rapetti, N., Krylovskiy, A., Jahn, M., Verda, V., Guelpa, E., Rietto, L., Acquaviva, A.	IoT software infrastructure for energy management and simulation in smart cities	2017	Energy efficiency	Smart grid	Empirical	Europe
[125]	Oldenbroek, V., Verhoef, L.A., van Wijk, A.J.M.	Fuel cell electric vehicle as a power plant: fully renewable integrated transport and energy system design and analysis for smart city areas	2017	Renewable energy	Hybrid energy system	Empirical	Europe
[126]	Nanni, S., Benetti, E., Mazzini, G.	Indoor monitoring in public buildings: workplace wellbeing and energy consumptions. An example of IoT for smart cities application	2017	Energy efficiency	Smart grid	Empirical	Europe
[127]	Kalli, M.	Energy solutions for future smart cities	2017	Energy and urban planning	Other	Theoretical	North America
[128]	Hung, P., Peng, K.	Green-energy, water-autonomous greenhouse system: an alternative-technology approach towards sustainable smart-green vertical greening in smart cities	2017	Energy and urban planning	Sustainable environment/vertical greening	Empirical	Asia
[129]	Bhati, A., Hansen, M., Chan, C.M.	Energy conservation through smart homes in a smart city: a lesson for Singapore households	2017	Energy efficiency	Energy saving	Empirical	Asia
[130]	Ejaz, W., Naeem, M., Shahid, A., Anpalagan, A., Jo, M.	Efficient energy management for the internet of things in smart cities	2017	Energy efficiency	Smart grid	Empirical	Asia
[33]	Pezzutto, S., Mosannenzadeh, F., Grilli, G., Sparber, W.	European union research and development funding on smart cities and their importance on climate and energy goals	2017	Energy and urban planning	Other	Theoretical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[53]	Manshahia, M.S.	Swarm intelligence-based energy-efficient data delivery in WSAN to virtualise IoT in smart cities	2018	Energy efficiency	Smart grid	Empirical	Asia
[45]	Chui, K.T., Lytras, M.D., Visvizi, A.	Energy sustainability in smart cities: artificial intelligence, smart monitoring, and optimization of energy consumption	2018	Energy efficiency	Smart grid	Empirical	Asia
[131]	Barresi, A.	Urban densification and energy efficiency in smart cities: the verge project (Switzerland)	2018	Renewable energy	Solar energy	Empirical	Europe
[132]	Colmenar-Santos, A., Molina-Ibáñez, E.-L., Rosales-Asensio, E., López-Rey, Á.	Technical approach for the inclusion of superconducting magnetic energy storage in a smart city	2018	Energy efficiency	Smart grid	Empirical	Europe
[133]	Cui, J., Yoon, H., Youn, B.D.	An omnidirectional biomechanical energy harvesting (OBEH) sidewalk block for a self-generative power grid in a smart city	2018	Renewable energy	Omnidirectional biomechanical energy harvesting	Empirical	Asia
[134]	Calvillo, C.F., Sanchez-Miralles, A., Villar, J.	Synergies of electric urban transport systems and distributed energy resources in smart cities	2018	Energy efficiency	Smart grid	Empirical	Europe
[135]	Hayashi, Y., Fujimoto, Y., Ishii, H., Takenobu, Y., Kikusato, H., Yoshizawa, S., Amano, Y., Tanabe, S.-I., Yamaguchi, Y., Shimoda, Y., Yoshinaga, J., Watanabe, M., Sasaki, S., Koike T., Jacobsen H.-A., Tomsovic K.	Versatile modeling platform for cooperative energy management systems in smart cities	2018	Energy efficiency	Smart grid	Empirical	Asia
[136]	Kai, C., Li, H., Xu, L., Li, Y., Jiang, T.	Energy-efficient device-to-device communications for green smart cities	2018	Energy efficiency	Smart grid	Empirical	Asia
[137]	Zhou, L., Wu, D., Chen, J., Dong, Z.	Greening the smart cities: energy-efficient massive content delivery via D2D communications	2018	Energy efficiency	Smart grid	Empirical	Asia
[138]	Lu, W., Gong, Y., Liu, X., Wu, J., Peng, H.	Collaborative energy and information transfer in green wireless sensor networks for smart cities	2018	Energy efficiency	Smart grid	Empirical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[62]	Deakin, M., Reid, A.	Smart cities: under-gridding the sustainability of city-districts as energy efficient-low carbon zones	2018	Energy and urban planning	Other	Theoretical	Europe
[139]	Rostirolla, G., Righi, R.D.R., Barbosa, J.L.V., Da Costa, C.A.	Elcity: an elastic multilevel energy saving model for smart cities	2018	Energy efficiency	Smart grid	Empirical	Latin America
[140]	Andreucci, M.B.	Linking future energy systems with heritage requalification in smart cities. On-going research and experimentation in the city of Trento (IT)	2018	Energy efficiency	Smart grid	Empirical	Europe
[43]	Abdullah, M.A., Al-Hadhrami, T., Tan, C.W., Yatim, A.H.	Towards green energy for smart cities: particle swarm optimization based MPPT approach	2018	Renewable energy	Wind energy	Empirical	Asia
[141]	Pieroni, A., Scarpato, N., Di Nunzio, L., Fallucchi, F., Raso, M.	Smarter city: smart energy grid based on blockchain technology	2018	Energy efficiency	Smart grid	Theoretical	Europe
[142]	Causone, F., Sangalli, A., Pagliano, L., Carlucci, S.	Assessing energy performance of smart cities	2018	Energy and urban planning	Other	Theoretical	Europe
[143]	Mutule, A.; Teremranova, J.; Antoskovs, N.	Smart city through a flexible approach to smart energy	2018	Energy and urban planning	Other	Theoretical	Europe
[144]	Condotta, M.; Borga, G.	Urban energy performance monitoring for smart city decision support environments	2018	Energy efficiency	Smart grid	Empirical	Europe
[145]	Barresi, A.	Urban densification and energy efficiency in smart cities—the verge project (Switzerland)	2018	Renewable energy	Solar energy	Empirical	Europe
[146]	Lanini, L.; Barsanti, E.A.	Hybrid building as social and energy hub for smart cities: Unite 2.0, a prototype	2018	Energy efficiency	Smart buildings	Empirical	Europe
[147]	Luo, H., Cai, H., Yu, H., Sun, Y., Bi, Z., Jiang, L.	A short-term energy prediction system based on edge computing for smart city	2019	Energy efficiency	Monitoring and energy efficiency	Empirical	Asia
[148]	Naseer, S., Liu, W., Sarkar, N.I.	Energy-efficient massive data dissemination through vehicle mobility in smart cities	2019	Energy efficiency	Network transmission	Empirical	Europe
[149]	Sato, M., Fukuyama, Y., Iizaka, T., Matsui, T.	Total optimization of energy networks in a smart city by multi-swarm differential evolutionary particle swarm optimization	2019	Energy efficiency	Smart grid	Empirical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[46]	Yu, Y., Zhang, N.	Does smart city policy improve energy efficiency? Evidence from a quasi-natural experiment in China	2019	Energy efficiency	Conceptualization of energy efficiency	Empirical	Asia
[150]	Le, L.T., Nguyen, H., Dou, J., Zhou, J.	A comparative study of PSO-ANN, GA-ANN, ICA-ANN, and ABC-ANN in estimating the heating load of buildings' energy efficiency for smart city planning	2019	Energy efficiency	Energy planning	Empirical	Asia
[151]	Abdullah, A., Yusoff, S.H., Zaini, S.A., Midi, N.S., Mohamad, S.Y.	Energy efficient smart street light for smart city using sensors and controller	2019	Energy efficiency	LED lighting	Empirical	Asia
[41]	Haarstad, H., Wathne, M.W.	Are smart city projects catalyzing urban energy sustainability?	2019	Renewable energy	Hybrid energy system	Theoretical	Europe
[152]	Corsini, F., Certomà, C., Dyer, M., Frey, M.	Participatory energy: research, imaginaries and practices on people' contribute to energy systems in the smart city	2019	Energy and urban planning	Network transmission	Theoretical	Europe
[153]	Aujla, G.S., Kumar, N., Singh, M., Zomaya, A.Y.	Energy trading with dynamic pricing for electric vehicles in a smart city environment	2019	Energy efficiency	Electric vehicles	Empirical	Asia
[154]	Hati, S., Dey, P., De, D.	WLAN based energy efficient smart city design	2019	Energy efficiency	Energy saving	Empirical	Asia
[155]	Liu, Y., Yang, C., Jiang, L., Xie, S., Zhang, Y.	Intelligent edge computing for IoT-based energy management in smart cities	2019	Energy efficiency	Smart grid	Empirical	Asia
[156]	Petritoli, E., Leccese, F., Pizzuti, S., Pieroni, F.	Smart lighting as basic building block of smart city: an energy performance comparative case study	2019	Energy efficiency	LED lighting	Empirical	Europe
[157]	Muhammad, K., Lloret, J., Baik, S.W.	Intelligent and energy-efficient data prioritization in green smart cities: current challenges and future directions	2019	Energy efficiency	Smart grid	Theoretical	Asia
[158]	Ahuja, K., Khosla, A.	Network selection criterion for ubiquitous communication provisioning in smart cities for smart energy system	2019	Energy efficiency	Smart grid	Empirical	Asia
[159]	Vázquez-Canteli, J.R., Ulyanin, S., Kämpf, J., Nagy, Z.	Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities	2019	Energy efficiency	Smart grid	Empirical	North America

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[160]	Cioara, T., Anghel, I., Salomie, I., Antal, M., Pop, C., Bertoncini, M., Arnone, D., Pop, F.	Exploiting data centres energy flexibility in smart cities: business scenarios	2019	Energy efficiency	Smart grid	Empirical	Europe
[161]	Parks, D.	Energy efficiency left behind? Policy assemblages in Sweden's most climate-smart city	2019	Energy efficiency	Smart grid	Theoretical	Europe
[162]	Gitelman, L.D., Kozhevnikov, M.V., Adam, L.A.	Sustainable energy for smart city	2019	Energy and urban planning	Other	Theoretical	Europe
[163]	Al-Nory, M.T.	Optimal decision guidance for the electricity supply chain integration with renewable energy: aligning smart cities research with sustainable development goals	2019	Renewable energy	Electricity supply chain	Theoretical	Asia
[164]	Nagy, Z., Sebestyén Szép, T., Szendi, D.	Regional disparities in Hungarian urban energy consumption—a link between smart cities and successful cities	2019	Energy and urban planning	Other	Theoretical	Europe
[165]	Aymen, F., Mahmoudi, C.	A novel energy optimization approach for electrical vehicles in a smart city	2019	Energy efficiency	Smart grid	Empirical	Africa
[166]	Wei, L., Hu, Y.	Research on new and old kinetic energy transformation supported by smart city construction in big data era	2019	Energy and urban planning	Urban experimentation	Empirical	Asia
[167]	Sato, M., Fukuyama, Y., Iizaka, T., Matsui, T.	Total optimization of energy networks in a smart city by multi-population global-best modified brain storm optimization with migration	2019	Energy efficiency	Smart grid	Empirical	Asia
[168]	O'Dwyer, E.; Pan, I.; Acha, S.; Shah, N.	Smart energy systems for sustainable smart cities: current developments, trends and future directions	2019	Energy and urban planning	Other	Theoretical	Europe
[169]	Huang, X., Huang, P., Huang, T.	Multi-objective optimization of digital management for renewable energies in smart cities	2020	Renewable energy	Hybrid energy system	Empirical	Asia
[170]	Khattak, H.A., Tehreem, K., Almogren, A., Ameer, Z., Din, I.U., Adnan, M.	Dynamic pricing in industrial internet of things: blockchain application for energy management in smart cities	2020	Energy efficiency	Energy saving	Theoretical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[42]	Pilipczuk, O.	Sustainable smart cities and energy management: the labor market perspective	2020	Energy and urban planning	Energy manager profession	Theoretical	Europe
[75]	Lewandowska, A., Chodkowska-Miszczuk, J., Rogatka, K., Starczewski, T.	Smart energy in a smart city: utopia or reality? Evidence from Poland	2020	Renewable energy	Hybrid energy system	Theoretical	Europe
[171]	Anthony Jnr, B.	Smart city data architecture for energy presumption in municipalities: concepts, requirements, and future directions	2020	Energy efficiency	Energy distribution	Theoretical	Asia
[172]	Chithaluru, P., Al-Turjman, F., Kumar, M., Stephan, T.	I-AREOR: an energy-balanced clustering protocol for implementing green IoT in smart cities	2020	Energy efficiency	Energy planning	Empirical	Asia
[173]	Gonçalves, D., Sheikhnejad, Y., Oliveira, M., Martins, N.	One step forward toward smart city utopia: smart building energy management based on adaptive surrogate modelling	2020	Energy efficiency	Smart building	Empirical	Europe
[174]	Giourka, P., Apostolopoulos, V., Angelakoglou, K., Kourtzanidis, K., Nikolopoulos, N., Sougkakis, V., Fuligni, F., Barberis, S., Verbeek, K., Costa, J.M., Formiga, J.	The nexus between market needs and value attributes of smart city solutions towards energy transition. An empirical evidence of two European Union (EU) smart cities, Evora and Alkmaar	2020	Energy and urban planning	Urban energy planning	Empirical	Europe
[175]	Angelakoglou, K., Kourtzanidis, K., Giourka, P., Apostolopoulos, V., Nikolopoulos, N., Kantorovitch, J.	From a comprehensive pool to a project-specific list of key performance indicators for monitoring the positive energy transition of smart cities—an experience-based approach	2020	Energy and urban planning	Other	Theoretical	Europe
[176]	Kumar, D.	Urban energy system management for enhanced energy potential for upcoming smart cities	2020	Renewable energy	Hybrid energy system	Theoretical	Asia
[177]	Parks, D.	Promises and techno-politics: renewable energy and Malmö's vision of a climate-smart city	2020	Energy efficiency	Energy planning	Theoretical	Europe
[178]	Gaska, K., Generowicz, A.	Smart computational solutions for the optimization of selected technology processes as an innovation and progress in improving energy efficiency of smart cities—a case study	2020	Energy efficiency	Smart grid	Empirical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[179]	Palanca, J., Jordán, J., Bajo, J., Botti, V.	An energy-aware algorithm for electric vehicle infrastructures in smart cities	2020	Energy efficiency	Electric vehicle	Empirical	Europe
[180]	Li, L., Zheng, Y., Zheng, S., Ke, H.	The new smart city programme: evaluating the effect of the internet of energy on air quality in China	2020	Energy and urban planning	Internet of energy	Empirical	Asia
[181]	Pei, P., Huo, Z., Martínez, O.S., Crespo, R.G.	Minimal green energy consumption and workload management for data centers on smart city platforms	2020	Renewable energy	Hybrid energy system	Empirical	Asia
[182]	Jettanasen, C., Songsukthawan, P., Ngaopitakkul, A.	Energy harvesting for smart city applications	2020	Renewable energy	Hybrid energy system	Empirical	Asia
[183]	Ye, H., Li, F.M., Liu, Z.X., Deng, X.D.	A green energy consumption policy of Bluetooth mobile devices for smart cities	2020	Energy and urban planning	Green computing mode	Empirical	Asia
[184]	Anthony Jnr, B., Abbas Petersen, S., Ahlers, D., Krogstie, J.	API deployment for big data management towards sustainable energy presumption in smart cities-a layered architecture perspective	2020	Energy efficiency	Smart grid	Empirical	Europe
[185]	Gitelman, L.D., Kozhevnikov, M.V., Starikov, E.M., Gamburg, A.V.	Sustainable energy in smart cities	2020	Energy efficiency	Smart grid	Theoretical	Asia
[186]	Deakin, M., Reid, A., Mora, L.	Smart cities: the metrics of future Internet-based developments and renewable energies of urban and regional innovation	2020	Renewable energy	Hybrid energy system	Theoretical	Europe
[187]	Serban, A.C., Lytras, M.D.	Artificial intelligence for smart renewable energy sector in Europe—smart energy infrastructures for next generation smart cities	2020	Renewable energy	Hybrid energy system	Empirical	Europe
[188]	Mekhum, W.	Smart cities: impact of renewable energy consumption, information and communication technologies and e-governance on CO_2 emission	2020	Renewable energy	Hybrid energy system	Theoretical	Asia
[34]	Sayah, Z., Kazar, O., Lejdel, B., Laouid, A., Ghenabzia, A.	An intelligent system for energy management in smart cities based on big data and ontology	2020	Energy efficiency	Energy saving	Theoretical	Africa
[189]	Petrović, N., Kocić, D.	Data-driven framework for energy-efficient smart cities	2020	Energy efficiency	Electric vehicle	Theoretical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[190]	Fadeyi, O., Krejcar, O., Maresova, P., Kuca, K., Brida, K., Selamat, A.	Opinions on sustainability of smart cities in the context of energy challenges posed by cryptocurrency mining	2020	Energy efficiency	Energy saving	Theoretical	Europe
[191]	Strielkowski, W., Veinbender, T., Tvaronavičienė, M., Lace, N.	Economic efficiency and energy security of smart cities	2020	Energy efficiency	LED lighting	Theoretical	Europe
[192]	Abbas, S., Khan, M.A., Falcon-Morales, L.E., Rehman, A., Saeed, Y., Zareei, M., Zeb, A., Mohamed, E.M.	Modeling, simulation and optimization of power plant energy sustainability for IoT enabled smart cities empowered with deep extreme learning machine	2020	Energy efficiency	Energy planning	Empirical	Central America
[193]	Oldenbroek, V., Smink, G., Salet, T., van Wijk, A.J.M.	Fuel cell electric vehicle as a power plant: techno-economic scenario analysis of a renewable integrated transportation and energy system for smart cities in two climates	2020	Renewable energy	Hydrogen	Empirical	Europe
[194]	Shu, M.; Wu, S.Z.; Wu, T.; Qiao, Z.L.; Wang, N.; Xu, F.; Shanthini, A.; Muthu, B.A.	Efficient energy consumption system using heuristic renewable demand energy optimization in smart city	2020	Renewable energy	Hybrid energy system	Empirical	Asia
[195]	Tanwar, S.; Popat, A.; Bhattacharya, P.; Gupta, R.; Kumar, N.	A taxonomy of energy optimization techniques for smart cities: architecture and future directions	2020	Energy efficiency	Decentralized systems	Theoretical	Asia
[196]	Arif, A.; Barrigon, F.A.; Gregoretti, F.; Iqbal, J.; Lavagno, L.; Lazarescu, M.T.; Ma, L.; Palomino, M.; Segura, J.L.L.	Performance and energy-efficient implementation of a smart city application on FPGAs	2020	Energy efficiency	Smart grid	Empirical	Europe
[72]	Biancardi, M., Di Bari, A., Villani, G.	R&D investment decision on smart cities: energy sustainability and opportunity	2021	Energy and urban planning	Renewable energy and urban planning	Empirical	Europe
[197]	Cho, K., Yang, J., Kim, T., Jang, W.	Influence of building characteristics and renovation techniques on the energy-saving performances of EU smart city projects	2021	Energy and urban planning	Smart buildings	Theoretical	Asia
[58]	Duan, P., Askari, M., Hemat, K., Ali, Z.M.	Optimal operation and simultaneous analysis of the electric transport systems and distributed energy resources in the smart city	2021	Energy efficiency	Energy distribution	Empirical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[67]	Kuznetsov, P., Rimar, M., Yakimovich, B., Kulikova, O., Lopusniak, M., Voronin, D., Evstigneev, V.	Parametric optimization of combined wind-solar energy power plants for sustainable smart city development	2021	Renewable energy	Combined wind-solar energy power plants	Theoretical	Europe
[6]	Hussain, M.M., Akram, R., Memon, Z.A., Nazir, M.H., Javed, W., Siddique, M.	Demand side management techniques for home energy management systems for smart cities	2021	Energy efficiency	Combined energy sources	Theoretical	Europe
[198]	Sabory, N.R., Senjyu, T., Danish, M.S.S., Hosham, A., Noorzada, A., Amiri, A.S., Muhammdi, Z.	Applicable smart city strategies to ensure energy efficiency and renewable energy integration in poor cities: Kabul case study	2021	Energy and urban planning	Urban energy planning	Theoretical	Asia
[199]	Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M.G., Naghedi, R., Eftekhari, M., Fathollahi-Fard, A.M., Dulebenets, M.A., Tian, G.	Implementation of solar energy in smart cities using an integration of artificial neural network, photovoltaic system and classical Delphi methods	2021	Renewable energy	Solar energy	Empirical	Asia
[200]	Boeri, A., Boulanger, S.O.M., Turci, G., Pagliula, S.	Enabling strategies for mixed-used PEDs: energy efficiency between smart cities and Industry 4.0 (strategie e tecnologie abilitanti per ped misti: efficienza tra smart cities e industria 4.0)	2021	Energy and urban planning	Urban energy planning	Empirical	Europe
[201]	Xia, X., Wu, X., BalaMurugan, S., Marimuthu, K.	Effect of environmental and social responsibility in energy-efficient management models for smart cities infrastructure	2021	Energy efficiency	LED lighting	Theoretical	Asia
[202]	Shen, X., Yu, H., Liu, X., Bin, Q., Luhach, A.K., Saravanan, V.	The optimized energy-efficient sensible edge processing model for the internet of vehicles in smart cities	2021	Energy efficiency	Electric vehicle	Empirical	Asia
[203]	Lu, C.-W., Huang, J.-C., Chen, C., Shu, M.-H., Hsu, C.-W., Tapas Bapu, B.R.	An energy-efficient smart city for sustainable green tourism industry	2021	Energy and urban planning	Tourism	Theoretical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[204]	Wang, C., Gu, J., Sanjuán Martínez, O., González Crespo, R.	Economic and environmental impacts of energy efficiency over smart cities and regulatory measures using a smart technological solution	2021	Energy efficiency	Conceptualization of energy efficiency	Theoretical	Asia
[205]	Sami, M.S., Abrar, M., Akram, R., Hussain, M.M., Nazir, M.H., Khan, M.S., Raza, S.	Energy management of microgrids for smart cities: a review	2021	Energy efficiency	Micro-grids	Theoretical	Europe
[63]	Govindarajan, H.K., Ganesh, L.S.	Renewable energy for electricity use in India: evidence from India's smart cities mission	2021	Renewable energy	Hybrid energy system	Theoretical	Asia
[49]	Carrera, B., Peyrard, S., Kim, K.	Meta-regression framework for energy consumption prediction in a smart city: a case study of Songdo in South Korea	2021	Energy efficiency	Energy planning	Theoretical	Asia
[56]	Zhang, X., Manogaran, G., Muthu, B.	IoT enabled integrated system for green energy into smart cities	2021	Energy efficiency	Energy saving	Empirical	Asia
[206]	Ashwin, M., Alqahtani, A.S., Mubarakali, A.	IoT based intelligent route selection of wastage segregation for smart cities using solar energy	2021	Energy efficiency	Solar energy	Empirical	Asia
[207]	Abu-Rayash, A., Dincer, I.	Development and analysis of an integrated solar energy system for smart cities	2021	Renewable energy	Solar energy	Empirical	North America
[208]	Gorla, P., Chamola, V.	Battery lifetime estimation for energy efficient telecommunication networks in smart cities	2021	Energy efficiency	Solar energy	Empirical	Asia
[209]	Khalil, M.I., Jhanjhi, N.Z., Humayun, M., Sivanesan, S., Masud, M., Hossain, M.S.	Hybrid smart grid with sustainable energy efficient resources for smart cities	2021	Renewable energy	Hybrid energy system	Empirical	Asia
[210]	Abdel-Basset, M., Hawash, H., Chakrabortty, R.K., Ryan, M.	Energy-net: a deep learning approach for smart energy management in IoT-based smart cities	2021	Energy and urban planning	Internet-of-things	Empirical	Africa
[57]	Zhang, W., Yue, M.	The application of building energy management system based on IoT technology in smart city	2021	Energy efficiency	Hybrid energy system	Empirical	Asia
[44]	Hoang, A.T., Pham, V.V., Nguyen, X.P.	Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process	2021	Renewable energy	Hybrid energy system	Theoretical	Asia

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[211]	Mutule, A., Domingues, M., Ulloa-Vásquez, F., Carrizo, D., García-Santander, L., Dumitrescu, A.-M., Issicaba, D., Melo, L.	Implementing smart city technologies to inspire change in consumer energy behaviour	2021	Energy efficiency	Energy consumer	Empirical	Europe
[212]	Miyasawa, A., Akira, S., Fujimoto, Y., Hayashi, Y.	Spatial demand forecasting based on smart meter data for improving local energy self-sufficiency in smart cities	2021	Energy and urban planning	Urban energy planning	Theoretical	Asia
[213]	Bachanek, K.H., Tundys, B., Wiśniewski, T., Puzio, E., Maroušková, A.	Intelligent street lighting in a smart city concepts: a direction to energy saving in cities: an overview and case study	2021	Renewable energy	Hybrid energy system	Empirical	Europe
[68]	Mahmood, D., Javaid, N., Ahmed, G., Khan, S., Monteiro, V.	A review on optimization strategies integrating renewable energy sources focusing uncertainty factor—paving path to eco-friendly smart cities	2021	Renewable energy	Hybrid energy system	Theoretical	Asia
[214]	Zekić-Sušac, M., Mitrović, S., Has, A.	Machine learning based system for managing energy efficiency of public sector as an approach towards smart cities	2021	Energy efficiency	Energy planning	Empirical	Europe
[215]	Hajduk, S., Jelonek, D.	A decision-making approach based on TOPSIS method for ranking smart cities in the context of urban energy	2021	Energy and urban planning	Energy planning	Theoretical	Europe
[216]	Vrabie, C.	Converting municipal waste to energy through the biomass chain, a key technology for environmental issues in (smart) cities	2021	Renewable energy	Biomass	Theoretical	Europe
[217]	Xiaoyi, Z., Dongling, W., Yuming, Z., Manokaran, K.B., Benny Antony, A.	IoT driven framework based efficient green energy management in smart cities using multi-objective distributed dispatching algorithm	2021	Renewable energy	Hybrid energy system	Empirical	Asia
[218]	Babar, M., Khattak, A.S., Jan, M.A., Tariq, M.U.	Energy aware smart city management system using data analytics and internet of things	2021	Energy efficiency	Energy planning	Empirical	Asia
[219]	Tantau, A., Şanta, A.-M.I.	New energy policy directions in the European Union developing the concept of smart cities	2021	Energy and urban planning	Other	Theoretical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[220]	Swain, A., Salkuti, S.R., Swain, K.	An optimized and decentralized energy provision system for smart cities	2021	Energy efficiency	Hybrid energy system	Empirical	Asia
[221]	Kim, D., Kwon, D., Park, L., Kim, J., Cho, S.	Multiscale LSTM-based deep learning for very-short-term photovoltaic power generation forecasting in smart city energy management	2021	Renewable energy	Solar energy	Empirical	Asia
[222]	Uspenskaia, D., Specht, K., Kondziella, H., Bruckner, T.	Challenges and barriers for net-zero/positive energy buildings and districts—empirical evidence from the smart city project Sparcs	2021	Energy efficiency	Hybrid energy system	Empirical	Europe
[223]	Elkamel, M., Ahmadian, A., Diabat, A., Zheng, Q.P.	Stochastic optimization for price-based unit commitment in renewable energy-based personal rapid transit systems in sustainable smart cities	2021	Energy efficiency	Hybrid energy system	Empirical	North America
[224]	Avotins, A., Adrian, L.R., Porins, R., Apse-Apsitis, P., Ribickis, L.	Smart city street lighting system quality and control issues to increase energy efficiency and safety	2021	Energy and urban planning	Street lighting	Empirical	Europe
[225]	Vukovic, N., Koriugina, U., Illarionova, D., Pankratova, D., Kiseleva, P., Gontareva, A.	Towards smart green cities: analysis of integrated renewable energy use in smart cities	2021	Energy and urban planning	Energy planning	Theoretical	Europe
[226]	Nesmachnow, S., Colacurcio, G., Rossit, D.G., Toutouh, J., Luna, F.	Optimizing household energy planning in smart cities: a multiobjective approach (optimización de la planificación energética en hogares inteligentes: un enfoque multi-objetivo)	2021	Energy efficiency	Energy planning	Empirical	Latin America
[73]	Martín, C., Castillo-Calzadilla, T., Zabala, K., Arrizabalaga, E., Hernández, P., Mabe, L., López, J.R., Casado, J.M., Santos, M.N., Guardo, J., Molinete, B.	The opportunity for smart city projects at municipal scale: implementing a positive energy district in Zorrozaurre	2021	Energy and urban planning	Urban energy planning	Empirical	Europe

Table A1. *Cont.*

Ref.	Authors	Title	Year	Categories	Aim	Approach	Continent
[227]	Chen, L., Han, P.	The construction of a smart city energy efficiency management system oriented to the mobile data aggregation of the internet of things	2021	Energy efficiency	Energy saving	Theoretical	Asia
[69]	Meenakshi, Mothi Kumar, K.E., Kumari, N.	A geo-spatial approach for quantifying rooftop photovoltaic energy potential in Karnal smart city, Haryana-a case study	2021	Renewable energy	Solar energy	Empirical	Asia
[228]	Wang, X., Chen, Q., Wang, J.	Fuzzy rough set based sustainable methods for energy efficient smart city development	2021	Energy and urban planning	Solar energy	Empirical	Asia
[229]	Farid, A.M., Alshareef, M., Badhesha, P.S., Boccaletti, C., Cacho, N.A.A., Carlier, C.-I., Corriveau, A., Khayal, I., Liner, B., Martins, J.S.B., Rahimi, F., Rossetti, R., Schoonen-berg, W.C.H., Stillwell, A., Wang, Y.	Smart city drivers and challenges in energy and water systems	2021	Energy efficiency	Electric vehicle	Theoretical	North America
[230]	V E S., Shin, C., Cho, Y.	Efficient energy consumption prediction model for a data analytic-enabled industry building in a smart city	2021	Energy efficiency	Energy consumer	Empirical	Asia
[231]	Martins, F.; Patrao, C.; Moura, P.; de Almeida, A.T.	A review of energy modeling tools for energy efficiency in smart cities	2021	Energy efficiency	Energy efficiency planning	Theoretical	Europe
[232]	Verma, S.	Energy-efficient routing paradigm for resource-constrained internet of things-based cognitive smart city	2021	Energy efficiency	Clusters	Empirical	Asia
[233]	Hadidi, L.A.; Rahman, S.M.; Maghrabi, A.T.	Smart city: a sustainable solution for enhancing energy efficiency and climate change mitigation in Saudi Arabia	2021	Energy efficiency	Savings in power	Empirical	Asia
[234]	Nuvvula, R.; Devaraj, E.; Srinivasa, K.T.	A comprehensive assessment of large-scale battery integrated hybrid renewable energy system to improve sustainability of a smart city	2021	Renewable energy	Solar energy	Empirical	Asia

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