

Article

# IoT Technology Applications-Based Smart Cities: Research Analysis

Mariana-Daniela González-Zamar <sup>1,2,\*</sup> , Emilio Abad-Segura <sup>3,\*</sup> , Esteban Vázquez-Cano <sup>4</sup>   
and Eloy López-Meneses <sup>5,6</sup> 

<sup>1</sup> Department of Education, University of Almeria, 04120 Almeria, Spain

<sup>2</sup> Higher Technical School of Architecture of Seville, Avenida de la Reina Mercedes, 2, 41012 Seville, Spain

<sup>3</sup> Department of Economics and Business, University of Almeria, 04120 Almeria, Spain

<sup>4</sup> Department of Didactics and School Organization, National University of Distance Education, 28040 Madrid, Spain; evazquez@edu.uned.es

<sup>5</sup> Department of Education and Social Psychology, Pablo de Olavide University, 41013 Seville, Spain; elopmen@upo.es

<sup>6</sup> Research Institute in Social Sciences and Education, Vice-Rectorate for Research and Postgraduate, University of Atacama, Copiapó 1530000, Chile

\* Correspondence: mgz857@ual.es (M.-D.G.-Z.); eas297@ual.es (E.A.-S.)

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**Abstract:** The development of technologies enables the application of the Internet of Things (IoT) in urban environments, creating smart cities. Hence, the optimal management of data generated in the interconnection of electronic sensors in real time improves the quality of life. The objective of this study is to analyze global research on smart cities based on IoT technology applications. For this, bibliometric techniques were applied to 1232 documents on this topic, corresponding to the period 2011–2019, to obtain findings on scientific activity and the main thematic areas. Scientific production has increased annually, so that the last triennium has accumulated 83.23% of the publications. The most outstanding thematic areas were Computer Science and Engineering. Seven lines have been identified in the development of research on smart cities based on IoT applications. In addition, the study has detected seven new future research directions. The growing trend at the global level of scientific production shows the interest in developing aspects of smart cities based on IoT applications. This study contributes to the academic, scientific, and institutional discussion to improve decision making based on the available information.

**Keywords:** smart city; internet of the things; application; technology; scientific production

## 1. Introduction

In recent years, digitization of society and transformation of business sector have allowed the development of cities based on Internet of Things (IoT) technology, the hyperconnection of electronic devices, and the interpretation of data that these generate [1,2]. Therefore, the purpose of smart cities is to achieve a more sustainable and livable environment that improves the quality of life of citizens based on IoT technological innovation [3].

In a broad sense, IoT consists of digital interconnection of everyday objects, through sensors that capture real-world data that are sent to platforms for processing, and these through service platforms become information and actions [4,5]. The analysis of data allows generating a better understanding of data and making optimal decisions. In this sense, the application of IoT in urban environments allows the development of smart cities, so that one concept is inextricably linked to the other. The application of this technology will drive production models such as Industry 4.0 [6], the development of new

consumption and production models from the innovation of the Circular Economy [7], the intelligent management of public and private resources [8,9], the appearance of smart citizens by evaluating their opinions in real time [10], and intelligent mobility from public transport and traffic control. In this order, mobile connectivity is fundamental, and it is fundamentally based on 5G [11,12] technology.

Consequently, the smart city is defined as an urban space that performs more efficient management of its community services through digital technology. Such is the case of intelligent traffic management with the aim of reducing air, light, and noise pollution; improving the safety and health of citizens through Big Data; or developing a smart economy through sensors that help optimize available resources [13–15]. Hence, the development of smart and connected cities will depend on effective measures to guarantee the security of communications and data that will be transferred from IoT devices [16,17].

This approach justifies the research interest. Therefore, the motivation of this study is to document the evolution of the global knowledge base on smart cities based on IoT technology applications. Furthermore, the reviewed literature has allowed to focus on this topic, so that the research questions seek to find answers to the following. (1) What is the global structure of knowledge on smart cities based on IoT technology applications? (2) Who are the authors, research institutions, and the most productive countries? (3) What are the thematic axes that this research topic develops? (4) What are the future directions of research?

The main objective of this study is to analyze global research of the smart cities based on IoT technology applications, during the period 2011–2019. To obtain answers to the research questions, a sample of 1232 articles from scientific journals selected from Scopus database was analyzed. This work uses the bibliometric method to synthesize the global knowledge base on smart cities based on IoT technology applications. The results showed the contributions in this research field, so that it has allowed identifying the main driving agents (authors, research institutions, and countries), and current and future research directions.

This study presents a set of limitations, some defined by the research itself. For example, others unrelated to this refer to the difficulty of distinguishing whether the growth in the volume of articles published in the examination period can be related, among other causes, to the exponential development of digital technologies, with regulatory regulation, or with the demands of stakeholders.

Among the research lines developed at the international level, they mainly refer to the analysis of a smart city' holistic vision; to studying IoT applications; to analyzing network security solutions; to identifying all macroscopic approaches to wireless telecommunication systems; to the implications of Internet in smart cities development; to cloud computing and the availability of data centers; and, finally, to the automation of processes.

Globally, research on smart cities based on IoT technology applications continues to progress, so this study has identified new directions in the research, which should contribute to the development of different aspects.

To achieve the stated objective, this study is organized as follows. Section 2 justifies the relevance of the research topic, delimiting the unit of analysis and conducting a review of the background, theoretical principles, and a conceptual framework of smart cities based on IoT technology applications. Section 3 details the methodology applied in this study. Section 4 shows and discusses the main results obtained. To close, the last section is dedicated to presenting the main conclusions of this research.

## 2. Scope of Research

Section 2 provides the theoretical principles and provides the definition of the key concepts that will be used in the analysis of the study on smart cities based on IoT technology applications, to avoid different interpretations of these. The purpose of this section is to serve as a guide for research and to offer theoretical and conceptual frameworks for interpreting the results and discussions of the next section.

## 2.1. Backgrounds

The evolution of smart cities based on IoT technology applications has been shaped by a series of chronological events. In this way, the Internet emerged connecting people through machines or devices. This was the origin of the IoT, with the purpose of moving the network to the objects, connecting them, and exchanging information [18].

In 1999, N. Gershenfeld, from the Massachusetts Institute of Technology (MIT), established the rights of things, in the sense of having identity, accessing other objects, and detecting their surroundings [19,20]. Thereby, in 2005, the International Telecommunication Union (ITU), from the United Nations, presented its report on the IoT, indicating that the next step would be to integrate things into a ubiquitous communication network—that is, anywhere, anytime, by anyone, and with anything. The technologies that made this network possible were radio frequency identification tags, wireless sensors, embedded intelligence, and nanotechnology. Likewise, the IoT user contemplates three levels of experiences: (1) tangible, which involves the introduction into the body of a device that allows data transmission; (2) the connection and sharing of information, and (3) visualization and reflection, which enables the acquisition of a broader knowledge of the environment and the objects we use [21–23].

With the development of this technology, IoT has been applied in cities. Thereby, Smart City is the most ambitious representation, whose purpose is to bring together intelligent systems that manage information around the factors that influence the positive evolution of the city, such as the economic, political, social, environmental, public and private mobility, and quality of life [12,15,24].

## 2.2. Framework

This research study is sustained by a set of theoretical principles, which together with the basic concepts define the framework for global research of the smart cities based on IoT technology applications. Moreover, a set of concepts related to the subject of study have been defined, which introduce part of the concepts that will stand out in the results and discussions due to their importance and connection.

In a first bibliographic search with the purpose of delimiting the research problem and avoiding approaches that are not connected with the study, a set of articles is identified that includes the essential concepts, provides evidence and an initial synthesis on the subject, and allows defining the objective of the research. Table 1 shows the main articles selected after reviewing the literature on the research topic, establishing a framework between the theoretical basis and the terminology of smart cities based on IoT technology applications at an international level. For this reason, the documents in Table 1 focus on the theoretical and conceptual structure of the research topic. This analysis has allowed determining the problem, the purpose, and the objective of the research, as well as obtaining the key terms to apply the methodology specified in Section 3.

**Table 1.** Key documents to define the research.

Year	Article Title [Reference]	Author(s)	Journal
2019	A Digital Model for Smart City using Internet of Things (IoT) [25]	Alam, K.	Global Sci-Tech
2019	Structuring Reference Architectures for the Industrial Internet of Things [26]	Bader, S.R.; Maleshkova, M.; Lohmann, S.	Future Internet
2019	Blockchain Powered Smart Cities [27]	Dhondse, A.; Singh, S.	Communications on Applied Electronics
2019	Communication Protocols of an Industrial Internet of Things Environment: A Comparative Study [28]	Jaloudi, S.	Future Internet

Table 1. Cont.

Year	Article Title [Reference]	Author(s)	Journal
2019	IoT Based Smart City with Vehicular Safety Monitoring [29]	Mohapatra, H.; Behura, A.	Internet of Things and Cloud Computing
2019	Blockchain-Supported Smart City Platform for Social Value Co-Creation and Exchange [30]	Scekic, O.; Nastic, S.; Dustdar, S.	IEEE Internet Computing
2018	Redefining the Smart City: Culture, Metabolism, and Governance [31]	Allam, Z.; Newman, P.	Smart Cities
2018	Smart cities and urban data platforms: Designing interfaces for smart governance [32]	Barns, S.	City, Culture and Society
2018	IoT-based reconfigurable smart city architecture [33]	Geetha Pratyusha, M.; Misra, Y.; Anil Kumar, M.	International Journal of Engineering & Technology
2018	Artificial Intelligence-Based Semantic Internet of Things in a User-Centric Smart City [34]	Guo, K.; Lu, Y.; Gao, H.; Cao, R.	Sensors
2018	Development of Information Evaluation System for Smart City Planning Using Geoinformatics Techniques [35]	Persai, P.; Katiyar, S.K.	Journal of the Indian Society of Remote Sensing
2018	A Comprehensive Study on Smart City using Blockchain Technology [36]	Raja, A.	International Journal of Computer Sciences and Engineering
2018	Smart City Development with Urban Transfer Learning [37]	Wang, L.; Guo, B.; Yang, Q.	Computer
2016	Cloud computing security: protecting cloud-based smart city applications [38]	Giannakoulis, A.	Journal of Smart Cities
2015	An Information Framework for Creating a Smart City Through Internet of Things [39]	Poslad, S.; Ma, A.; Wang, Z.; Mei, H.	Sensors
2014	Using a Smart City IoT to Incentivise and Target Shifts in Mobility Behaviour—Is It a Piece of Pie? [40]	Jin, J.; Gubbi, J.; Marusic, S.; Palaniswami, M.	IEEE Internet of Things Journal

The literature review has established the framework of this research field related to, among other aspects, Information and Communication Technologies (ICT), efficient urban planning, educational technologies, transparency between local governments and citizens, technologies applied to the health sector, open data, sustainable urban mobility, efficient waste management, automation and control in smart buildings, air pollution management, crime prevention and criminal activity through smart video surveillance, or sustainable public lighting.

The basis of research on smart cities based on IoT technology applications is confirmed by a set of theoretical principles. Hence, digital transformation consists of the reinvention or evolution of an entity using digital technology to improve performance [41,42]. The Internet and digital technologies, influenced by the speed of growth, transform business models and business sectors, establishing a new digital economy with a social, cultural, and economic impact. Thus, to conduct digital transformation optimally, whether in a company or in a city, the digitization of its strategic processes is key. This contributes to a better understanding of the business, optimizing decision-making, improving efficiency in each area, and increasing competitiveness [43,44].

Likewise, it is necessary to establish the key concepts or variables in the context of this research. First, the Internet refers to the decentralized set of interconnected communication networks, which ensures that the heterogeneous physical networks that comprise it constitute a single logical network with global reach. Its origin comes from ARPANet (Advanced Research Projects Agency Network), in 1969, when the first connection between Stanford and UCLA computers arose [45–47].

Along these lines, the concept of Internet of Things (IoT), a term first coined in 1999 as a key element of digital transformation and the digital economy, refers to digital interconnection of everyday objects with the Internet, thus becoming smart objects. In other words, it consists of connecting the Internet with objects, mainly through sensors that send and receive data continuously, and then after their interpretation, proceed to carry out actions [48,49]. This term signals a radical change in the quality of life of people in society, since it allows new opportunities for access to data, educational services, security, healthcare, communications, and transportation. The unquestionable relevance of IoT is in the substantial changes that they suppose in society, notably in sectors such as Industry 4.0, smart cities, e-health, finance, tourism, education, business, entrepreneurship, or cybersecurity [50–52].

In relation to the subject of study, the concept of the city refers to the settlement of population with attributions and political, administrative, economic, and religious functions. This concept is reflected in the specific location of buildings and in its urban configuration. In other words, a city is an urban space with a high population density, with commerce, industry, and services predominating [53,54].

In this sense, a smart city is considered an evolution of city, since it uses technology, innovation, and other resources to promote sustainable development and improve the quality of life of its citizens [55,56]. It includes the concepts of energy efficiency and sustainability, contributing to the balance between the environment and the consumption of natural resources. Likewise, it refers to the city with investments in human and social capital, and in communication infrastructures, which promote sustainable development and quality of life [57,58]. It is also considered as a prototype for urban planning and development, an answer to environmental problems, as well as a solution to energy problems. Among its advantages, the following stand out: (1) a decrease in spending dedicated to the provision and management of public services; (2) offers a platform for innovation; (3) increases the efficiency and quality of services, appropriately managing resources; (4) facilitates the identification of the needs of city; (5) offers real-time information; (6) increases the transparency of the Local Administrations; and (7) promotes social development [59–61].

### 2.3. Related Concepts

To build an underlying conceptual structure on this theme, other concepts have been identified that form the knowledge base on smart cities based on IoT technology applications. Hence, terms such as Sensor, Application, Big Data, Blockchain, and Machine Learning are defined below in the context of this research.

A key concept to understand the implications of smart cities based on IoT technology applications is the sensor. This is a device to detect external actions or stimuli and respond accordingly [62,63]. In other words, they allow the information from the physical environment to be captured, and then the physical or chemical quantities to be measured and transformed into electrical signals so that they can be understood by a microcontroller [64].

In this order, an application consists of a computer program used as a tool that enables a user to perform tasks, and they belong to the application software. In general, a computer application is geared toward automating complicated tasks [65,66]. As a result of technological evolution, consolidated global start-ups and suppliers constantly innovate in new applications to respond to the needs that arise. Thus, the implementation of solutions for more devices with IoT will have an impact on development and security of smart cities [67,68].

Likewise, the concept of Big Data refers to the management and analysis of enormous volumes of data that cannot be processed in a conventional way, by overcoming the limits and capabilities of the software tools commonly used for data capture, management, and processing [69,70]. The purpose of Big Data, in the same way as conventional analytical systems, is to convert the data into suitable information for decision-making. This term encompasses technological infrastructures and services created to provide solutions to the processing of huge structured, unstructured, or semi-structured datasets [71,72].

In this technology, the term Blockchain refers to a shared database for the registration of transactions. Each block has a specific place in the chain, since each contains information from the hash of the previous block. The complete chain is saved in each node of the network that makes up the Blockchain [73,74]. As new records are created, they are first verified and validated by network nodes; then, they are added to a new block that binds to the chain. Blockchain technology allows storing information that can never be lost, modified, or deleted. Each node of the network uses certificates and digital signatures to verify the information and validate the transactions and data stored on Blockchain, which allows ensuring the authenticity of said information [75,76]. Therefore, any type of information that needs to be preserved intact and that must remain available can be stored on the Blockchain in a secure, decentralized, and cheaper way than through intermediaries. Moreover, if this information is kept encrypted, its confidentiality can be guaranteed. Therefore, its use can be applied, among others, to the economy, health, and IoT [77–79].

In this context, the Machine Learning concept refers to the scientific discipline in the field of Artificial Intelligence that creates systems that automatically learn [80,81]. The machine that really learns is an algorithm that reviews data and can predict future behavior. It automatically implies that these systems improve autonomously over time, without human intervention. In practice, it is used, for example, to predict urban traffic, make medical pre-diagnoses based on patient symptoms, or detect intrusions in a data communications network [82,83].

### 3. Materials and Methods

Section 3 shows the methodology applied in this study, and the data collection procedure, based on research questions, that will make up the article sample. Subsequently, they will be processed, analyzed, and interpreted.

#### 3.1. Bibliometric Method

Bibliometrics applies mathematical and statistical methods to scientific literature, to analyze the activity of a certain scientific field. This methodology was started by E. Garfield in the middle of the 20th century, and since then, it has become generalized in the analysis of scientific research and has contributed to reviewing knowledge in multiple disciplines [84,85]. In this way, bibliometrics has evolved from reflection on scientific development and from the availability of numerous databases accessible to the researcher.

It has also become an indispensable tool for managers and specialists in management or in organizations that develop research or innovation programs. Quantitative studies, based on bibliometrics, enrich the understanding and description of the dynamics of activity and scientific production [86–88].

In recent years, bibliometric methodology has encouraged the revision of different schools of scientific knowledge. It has been used by numerous scientists, including management, finance, economics, and education [89–91]. Bibliometric indicators are the instruments used to measure the results of scientific activity in any of its manifestations [92].

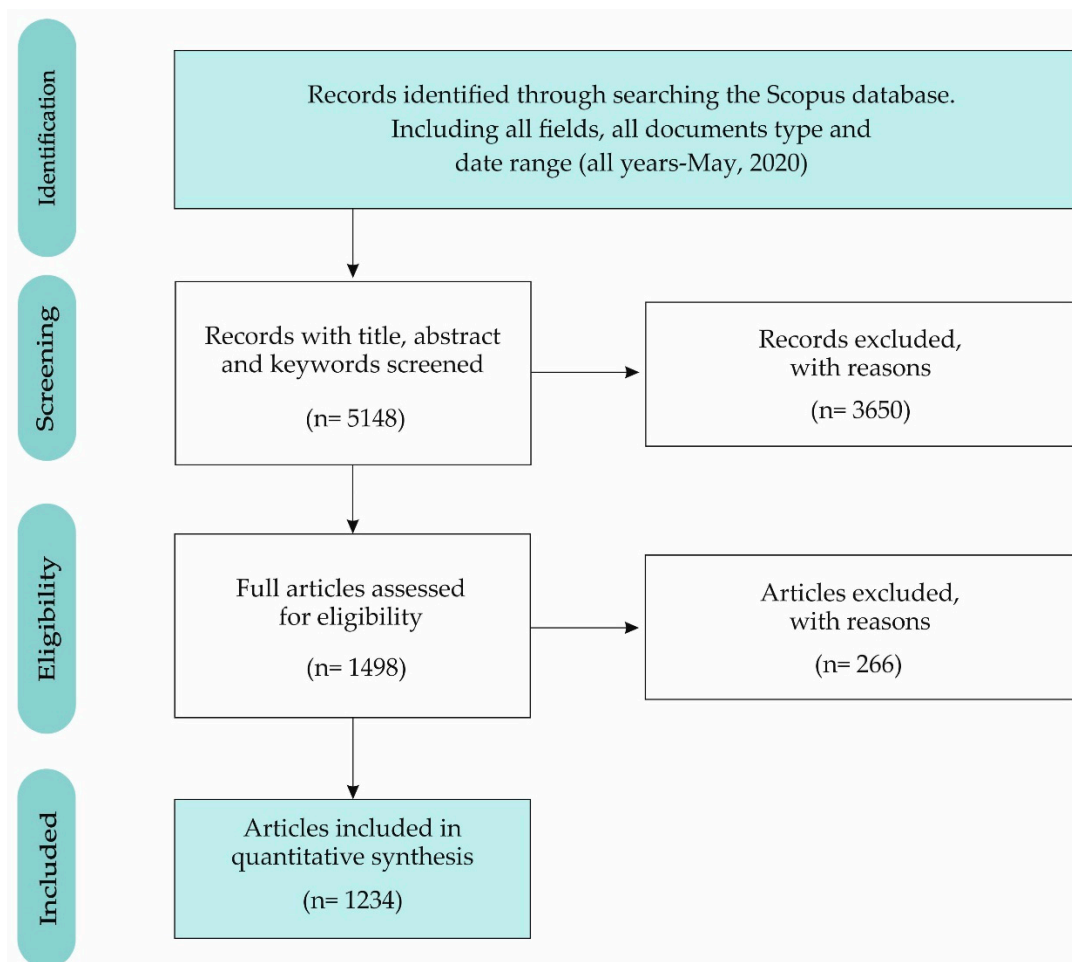
#### 3.2. Search Criteria and Data Collection

The aim of this study is to determinate the general dynamics of the smart cities based on IoT technology applications research at a global level. Hence, a quantitative analysis is performed using the bibliometric method. According to the main literature reviewed on this topic, which is presented in Table 1, the terms chosen in the search string have been “internet of things” and “smart city”.

Mainly, the preference of the Scopus database for the analysis of the document sample is due to the fact that when performing the initial search in the Web of Science (WoS) and Scopus databases, it showed a significant difference in the volume of articles during the period analyzed (2011–2019). That is, from WoS, 264 articles were extracted, while from Scopus, 1232 articles were extracted.

Scopus has a number of advantages over WoS, such as: (1) it is considered the largest deposit of peer-reviewed literature; (2) it minimizes the risk of losing documents during the search; (3) it is easily accessible; (4) it offers tools for data visualization and analysis; (5) it allows the sample to be downloaded in different formats; and (6) it presents a wide variety of data [93,94].

Hence, the procedure followed to select the sample on research in IoT and smart cities is adjusted to the flowchart of Figure 1, in relation to the Preferred Reporting Elements for Systematic Reviews and Meta-Analyses (PRISMA) [95].



**Figure 1.** PRISMA flowchart (Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)).

In phase 1 (identification), 22,621 records were identified from the Scopus database, considering all the fields for each of the key search terms (internet of things, smart city), all types of documents, and all years in the data range (All years to Present: May 2020).

Next, in phase 2 (screening) the option of “article title, abstract and keywords” was chosen in the field of each term; consequently 17,513 were excluded, so that 5148 records remained.

In phase 3 (eligibility), only the “articles” were selected as the type of document, to guarantee the quality derived from the peer review process. Therefore, 3650 documents were excluded, and 1498 records were obtained.

The time horizon analysis was between 2011 and 2019, and both years were included—that is, from the publication of the first article on this topic (2011) to the last full year (2019). For these reasons, in the last phase (included), 266 documents were excluded, so the final sample included 1232 articles.

The search selected records from the subfields of title, abstract, and keywords, in the period that contains the last 9 years (2011–2019). This procedure has been successfully applied in numerous studies that have used the bibliometric method [96,97].

### 3.3. Data Processing

In this research study, the indicators of scientific production analyzed have been the distribution by years of the published articles and the productivity of the authors, research institutions, and countries. The quality indicators used and referred to the impact of the different agents of this research topic have been (1) the count of the number of citations; (2) the h-index, which allows to detect which are the most outstanding authors in the discipline, based on the number of citations that have received their scientific articles [98]; and (3) the 2018 CiteScore indicator, which is obtained from the calculation of the number of citations in a year received by academic articles published in a journal in the 3 immediately preceding years, divided by the total number of articles published during those same 3 years [99]; (4) the 2018 SCImago Journal Rank (SJR), which measures the quality of the scientific journals included in Scopus database [100]; and (5) the 2018 Source Normalized Impact per Paper (SNIP), which counts the number of citations received by a journal for three years divided by the potential citation from the journal's scientific field [101].

Likewise, the indicators of the collaboration structure, which measure the links between the authors, research institutions, and countries, have been analyzed using the processing tools and network maps due to their reliability and suitability in bibliometric analysis, using the co-authorship method. Co-authorship of an article is an official declaration of the participation of two or more authors, organizations, or countries. Thereby, co-authorship analysis is widely used to understand and evaluate patterns of scientific collaboration. For this, in co-authoring networks, nodes represent authors, organizations, or countries that are connected when they share the authorship of an article [102,103].

The analysis of the keywords has allowed the detection of the main current or future research topics, based on the analysis of co-occurrences, since scientific texts can be reduced to the set of joint appearances between the words it comprises [104,105]. The co-occurrence of two concepts is very high if they frequently appear together in one set of documents and rarely do so separately in the rest. With the analysis of co-occurrences, the proximity relationship of two or more terms in a text unit is established. Furthermore, the graphic representation of the co-occurrence networks allows them to be viewed [106–108]. For the analysis of these relationship indicators, the software VOSviewer (version 1.6.10, Leiden University, Leiden, The Netherlands) has been applied, which provides data on collaborations and the evaluation of the contents, in order to measure the activities of the research networks [109,110].

The findings gained are valuable for a group of actors involved in scientific research on the evolution and innovation of smart cities based on IoT technology applications and who demand an examination of past and future information, such as engineers, analysts investment, academics, researchers, research institutes, universities, government agencies, materials, and services providers, among others.

## 4. Results and Discussion

Section 4, first, presents and discusses the main results of the evolution of scientific production in a global context on smart cities based on IoT technology applications. Then, the distribution of articles by subject area and journal is analyzed. Later, the results obtained from the analysis of the main keywords associated with this topic are discussed, which allowed identifying the main current lines. Next, the main keywords and subject areas associated with the most prolific authors, research institutions, and countries are presented. Lastly, future research directions are presented.

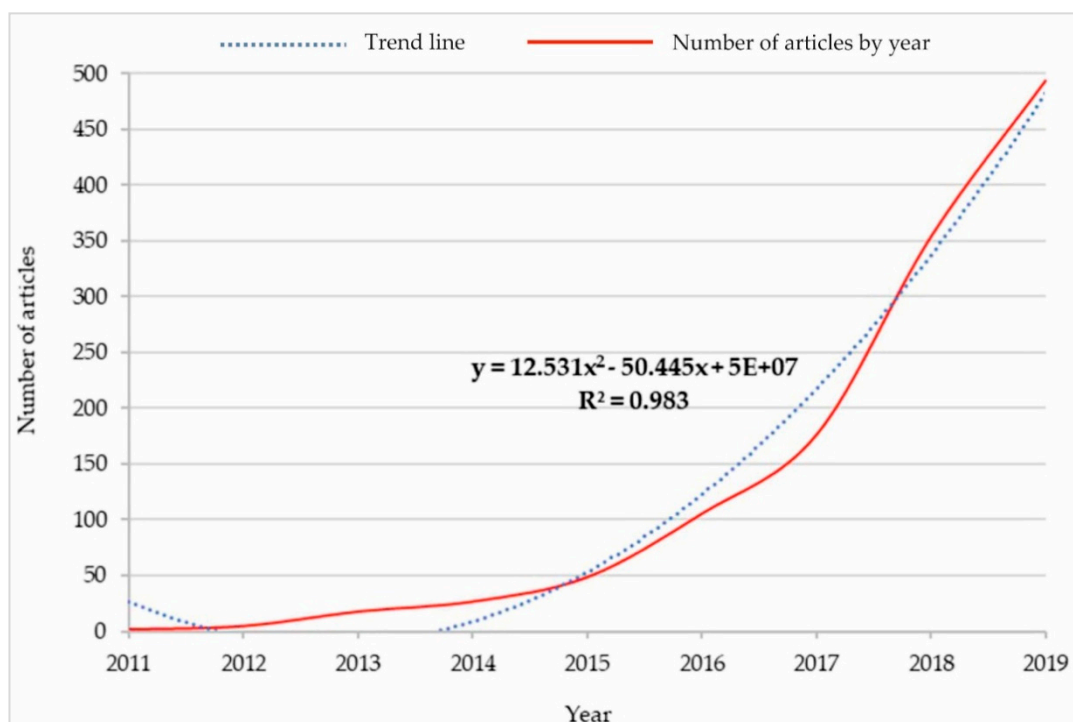


#### 4.1. Scientific Production

Section 4.1 displays the evolution of scientific production on smart cities based on IoT technology applications. The interest of the scientific and academic community has increased significantly since 2011, when the first 2 articles on this topic were published, up to 95 in the last year analyzed (2019).

The repercussion of this theme is better understood when it is observed that 95.78% of the total has been published in the last five years (1180 articles), in the last triennium, 83.20% (1025), and in the last year, 40.02% (493).

Figure 2 shows the evolution of the total of the 1232 articles identified in the search carried out in the Scopus database. The polynomial trend line of order 2 indicates that the number of articles in this research topic increases more rapidly over time, in the last 9 years. This trend line, shaped like a parabola, displays a practically perfect goodness of fit to the data, with a coefficient of determination close to 1 ( $R^2 = 0.983$ ). The second-order polynomial model turned out to be the most appropriate for obtaining the growth curve.



**Figure 2.** Evolution of scientific production (2011–2019).

The evolution of scientific production in this area of knowledge is part of the result of the fourth Industrial Revolution on a global scale, which is related to computing, transmission, and analysis of data, sensors and low-cost communication devices, and hyperconnectivity enabled by the digital ecosystem [111,112].

Furthermore, IoT transformation by connecting society and the business world has led to the dynamism of industries and their processes, as well as the appearance of new business models, effective health systems, new products and services, and, in particular, smarter cities that are also sustainable [113,114]. This transformation has also influenced research, where a growth in scientific activity is observed at the international level in recent years. In other words, scientific production reflects innovation and the changes that disruptive technologies and connectivity entail. Likewise, cooperation between the main actors that make up the core of scientific activity on smart cities based on IoT technology applications is a key factor in this growth [115,116].

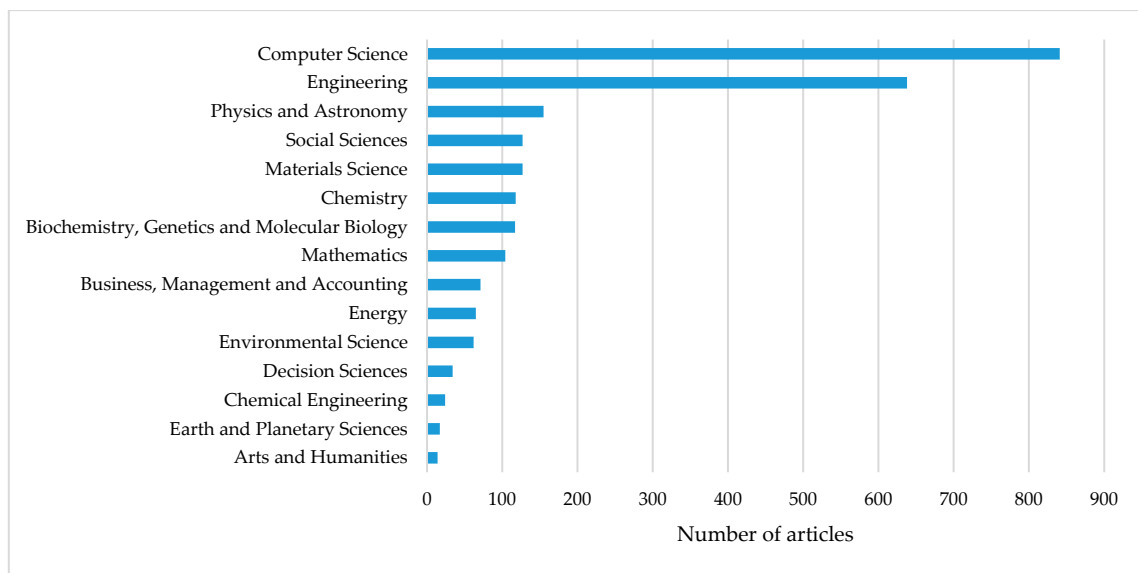
In this research topic, 98.30% of the articles are written in English (1211). This circumstance is related to the fact that the publication in this language broadens its audience, as it happens widely in

the searches made in the Scopus database [117]. In addition, the articles have been published in other languages with less representation: Chinese (12, 0.97%), Persian (3, 0.24%), German (2, 0.16%), Polish, Portuguese, and Russian (1, 0.08% each one of them).

#### 4.2. Subject Areas and Journals

This section shows and discusses the main subject areas into which scientific production is classified and the analysis of the main journals on smart cities based on IoT technology applications, during the 2011–2019 period.

Hence, the 1232 articles are classified into 23 subject areas, according to the Scopus database. In this sense, an article could be classified in more than one subject area, or in a single area. There is a correlation between the subject areas and the journals, with the publisher being the journal who ends up cataloguing each article in a thematic area. Figure 3 presents the classification of these 23 main subject areas where articles are classified in worldwide research on smart cities based on IoT technology applications.



**Figure 3.** Top 15 subject areas (2011–2019).

Computer Science is the category that collects the most articles (68.10%, 839 articles published), followed by Engineering (51.79%, 638). Next, they are followed by Physics and Astronomy (12.58%, 155), Materials Science (10.31%, 127), Social Sciences (10.31%, 127), Chemistry (9.58%, 118), Biochemistry, Genetics, and Molecular Biology (9.50%, 117), Mathematics (8.44%, 104), Business, Management, and Accounting (5.76%, 71), Energy (5.28%, 65), and Environmental Science (5.03%, 62). The rest of subject areas do not reach 2% each of the published documents.

The phenomenon of the transformation of urban environments into smart cities is the subject of multidisciplinary research. Its analysis is complex, since its evolution is the reflection of numerous disciplines [118]. Although in a subject related from its origin to computer science and engineering, it is also linked by its repercussions with the social sciences, the economy, health, or urban planning [119].

Table 2 displays the main characteristics of the 10 most productive scientific journals on the research topic in the 2011–2019 period: number of articles, number of citations for all articles, number of citations by article, country, subject area, h-index in this research topic, Scopus main quality metrics (CiteScore, SJR and SNIP), and year of the first and last published article.

**Table 2.** Top 10 journals (2011–2019).

Journal	A	C	C/A	Country	Subject Area	h *	Citescore *	SJR *	SNIP *	1A *	LA *
Sensors	101	1112	0.901	Switzerland	BGM-CH-EN-PA	23	3.72	0.592	1.576	2013	2019
IEEE Access	92	1408	1.141	USA	CS-EN-PA	20	4.96	0.609	1.718	2015	2019
IEEE Internet of Things Journal	80	4774	3.869	USA	CS	25	11.33	1.396	3.874	2014	2019
Future Generation Computer Systems	66	2362	1.914	Netherlands	CS	25	6.30	0.835	2.464	2016	2019
IEEE Communications Magazine	24	843	0.683	USA	CS-EN	15	11.27	2.373	4.681	2013	2019
International Journal of Innovative Technology and Exploring Engineering	23	0	0.000	India	CS-EN	1	NA	NA	NA	2019	2019
Sustainable Cities and Society	17	283	0.229	Netherlands	EY-EN-SS	9	5.22	1.100	1.745	2017	2019
International Journal of Recent Technology and Engineering	16	3	0.002	India	BMA-EN	1	NA	NA	NA	2018	2019
Sustainability	16	86	0.070	Switzerland	EY-ES-SS	7	3.01	0.549	1.169	2016	2019
International Journal of Advanced Computer Science and Applications	13	9	0.007	UK	CS	2	NA	NA	NA	2018	2019

A: number of articles; C: total citations; C/A: average number of citations per article; BGM: Biochemistry, Genetics, and Molecular Biology; CH: Chemistry; EN: Engineering; PA: Physics and Astronomy; CS: Computer Science; EY: Energy; SS: Social Sciences; BMA: Business, Management and Accounting; ES: Environmental Science; h: h-index or Hirsch index; CiteScore: CiteScore metric (2018); SJR: Scimago Journal Rank (2018); SNIP: Source Normalized Impact per Paper (2018); 1A: first article; LA: last article; NA: not available; (\*) in this research topic.

According to the number of articles published and the percentage they represent of the total sample, this ranking is led by *Sensors* (101, 8.18%), followed by *IEEE Access* (92, 7.46%). Both are followed by, in order, *The IEEE Internet of Things Journal* (6.48%) and *Future Generation Computer Systems* (5.35%). The rest of the journals in this ranking do not exceed 2% of the total. It highlights that 50% of these journals are of European origin (2 Swiss, 2 Dutch and 1 British), while 30% are North American and 20% are Indian.

The variety of the countries of the most outstanding journals is related to a set of socioeconomic factors existing in the context where the scientific activity is carried out, such as: investment for research and development (R&D), gross domestic product (GDP), economically active population (PEA), number of researchers, etc. Other factors such as cultural factors, the influence of educational systems, historical tradition, the scientific policies of governments, and the development of private companies also influence. All this allows certain regions and countries to excel in investments and R&D budgets with their consequent results in scientific advances. In this globalized and increasingly technological world, scientific production, publishers, journals, and readers are distributed heterogeneously throughout the world [10,31,38].

Moreover, *The IEEE Internet of Things Journal* (80 articles) is the journal with the most citations (4774), and the highest average number of citations per article (3.869), despite the fact that it has been publishing articles on this topic for only 6 years. It is followed by the Dutch *Future Generation Computer Systems* (2362, 1.914), which published its first article on IoT in smart city research in 2016. These two journals present the highest h-index in the ranking with 25.

The Computer Science and Engineering subject areas are the most outstanding, just as it happens in the total computation (see Figure 4), since 6 journals classify their articles in these. They are followed by Physics and Astronomy and Energy and Social Sciences with 2 journals each. This aspect reveals that the articles on smart cities based on IoT technology applications are classified in a wide range of subject areas, in addition to Computer Science and Engineering.



Thereby, Table 3 lists, according to the Scopus database, the 20 most frequently used keywords in the 1232 articles of the analyzed sample. The most prominent terms are “Internet of Things” (in 901 articles, 73.01%) and “Smart City” (654, 53%). These two keywords were considered in the search query for the Scopus database. Similar terms to the main ones appear in the following positions: Smart Cities (280, 22.69%), Internet of Things (IoT) (269, 21.80%), and IoT (171, 13.86%).

**Table 3.** Top 20 keywords (2011–2019).

Rank	Keyword	Articles	%	Links	Total Link Strength	Cluster (See Figure 4)
1	Internet of Things	901	73.13%	493	6811	2
2	Smart City	654	53.08%	489	5068	1
3	Big Data	147	11.93%	335	1355	1
4	Internet	126	10.23%	273	989	5
5	Wireless Sensor Networks	111	9.01%	304	1059	2
6	Automation	105	8.52%	306	1071	7
7	Network Security	97	7.87%	287	962	3
8	Intelligent Buildings	95	7.71%	280	979	7
9	Cloud Computing	88	7.14%	249	799	6
10	Energy Efficiency	80	6.49%	262	841	2
11	Network Architecture	78	6.33%	259	831	6
12	Information Management	74	6.01%	266	780	1
13	Distributed Computer Systems	72	5.84%	243	729	1
14	Energy Utilization	72	5.84%	246	696	2
15	Data Handling	57	4.63%	214	590	1
16	Sensors	55	4.46%	194	456	1
17	Fog Computing	53	4.30%	176	501	6
18	Digital Storage	51	4.14%	191	485	6
19	Decision Making	50	4.06%	199	476	1
20	Security	49	3.98%	162	391	2

%; percentage of total articles published.

The other keywords in these top 20 are grouped around thematic disciplines such as data intelligence—Big Data (147, 11.91%), Information Management (74, 6.00%) and Data Handling (57, 4.62%); Networks and sensors: Wireless Sensor Networks (111, 9%), Network Security (97, 7.86%), Network Architecture (78, 6.32%), Sensors (55, 4.46%) and Sensor Nodes (54, 4.38%); computing—Internet (126, 10.21%), Automation (105, 8.51%), Cloud Computing (88, 7.13%), Distributed Computer Systems (72, 5.83%); and architecture and urbanism—Intelligent Buildings (95, 7.70%), Energy Efficiency (80, 6.48%), and Energy Utilization (72, 5.83%).

The research theme of this study requires an interdisciplinary and transversal effort. The relatively recent emergence of this research field means that it is studied from different perspectives, both technical and social, that promote the emergence of new terms at an international level associated with this scientific approach [122,123].

The VOSviewer tool provides the data for the link and the total link strength attributes. The first denotes a co-occurrence connection between two keywords, while the second indicates the number of posts in which two keywords appear together. Thus, the “Internet of Things” is the one with more links (732) and more total link strength (6811), followed by “Smart City” (489, 5068). Among the similar terms, the criterion that follows has been to quantify only the one that is present in a greater number of articles, in order to avoid the software grouping them into different clusters.

Figure 4 represents the network map for the keywords of the articles on this research topic, which is based on the co-occurrence method. The color of the nodes is used to distinguish the different clusters based on the number of co-occurrences, while the size varies according to the number of repetitions.

VOSviewer software has identified in seven main lines of research from the different keyword communities on smart cities based on IoT technology applications. The keyword with the largest

number of articles within each cluster has allowed us to name and define the research axis and on which the rest of the terms are associated. These are “Smart City”, “Internet of Things”, “Network Security”, “Wireless Telecommunication Systems”, “Internet”, “Cloud Computing”, and “Automation”. For each of the terms, the occurrences attribute is indicated, which denotes the number of documents in which a term appears, and the total strength of the link, which, as previously commented, refers to the number of publications in which two terms appear together.

Cluster 1 (pink color) is led by “Smart City” (occurrences: 655, links: 489, total link strength: 5068) and groups 21.86% of the keywords. Table 4 contains the 20 main keywords associated with this cluster. This first thematic axis studies the holistic vision of the city that applies new technologies to increase the quality of life and accessibility of its citizens, while considering sustainable development. This interconnected system manages transport systems, the efficient use of energy or water resources, socio-economic aspects, security in public spaces, and the commercial fabric, or effective communication [124,125].

**Table 4.** Cluster 1: Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Big Data	147	335	1355	11	Semantics	32	122	260
2	Information Management	74	266	780	12	Data Acquisition	30	150	315
3	Distributed Computer Systems	72	243	729	13	Data Analytics	28	138	292
4	Data Handling	57	214	590	14	Middleware	28	124	227
5	Sensors	55	194	456	15	Environmental Monitoring	27	120	221
6	Decision Making	50	199	476	16	Ubiquitous Computing	26	126	235
7	Monitoring	45	186	431	17	Privacy	23	113	220
8	Data Privacy	37	177	418	18	Proposed Architectures	23	134	288
9	Cryptography	35	148	345	19	Application Programs	21	125	204
10	Information and Communication Technologies	32	170	335	20	Smartphones	20	119	192

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Cluster 2 (green color) groups 21.26% of the main terms and is headed by “Internet of Things” (occurrences: 902, link: 493, total link strength: 6811). Table 5 contains the 20 main keywords associated with this cluster. This second thematic axis studies the network of physical objects that uses sensors and application programming interfaces to connect and exchange data over the Internet, together with Big Data management tools, predictive analytics, radio frequency identification, AI and machine learning, or the cloud [126,127].

**Table 5.** Cluster 2: Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Wireless Sensor Networks	111	304	1059	11	Intelligent Transportation Systems	29	136	310
2	Energy Efficiency	81	262	841	12	Energy Conservation	26	124	250
3	Energy Utilization	72	246	696	13	Complex Networks	25	141	239
4	Security	49	162	391	14	Mobile Telecommunication Systems	23	121	210
5	Intelligent Systems	43	178	437	15	Scheduling	22	118	212
6	Authentication	35	113	317	16	Wireless Sensor Network	21	120	205
7	Optimization	33	147	268	17	Gateways (Computer Networks)	20	99	205
8	Vehicles	32	154	343	18	Wireless Sensor Network (WSNS)	18	75	161
9	5G Mobile Communication Systems	30	141	265	19	Energy Harvesting	17	79	140
10	Intelligent Transportation Systems	29	136	310	20	Traffic Congestion	17	108	178

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Cluster 3 (red color) is led by “Network Security” (occurrences: 97, link: 287, total link strength: 962), and it groups 18.83% of the keywords. Table 6 contains the 20 main keywords associated with this cluster. This third research line looks at network security that ensures the integrity, availability, and performance of an organization through the protection of IT assets against cyber threats. Thereby, it is a key component of network optimization, to prevent attacks and increase the productivity of companies [128,129].

**Table 6.** Cluster 3: Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Machine Learning	40	176	385	11	Transportation	20	117	216
2	Data Mining	39	143	331	12	Waste Management	20	84	168
3	Artificial Intelligence	33	164	317	13	Air Quality	18	83	157
4	Learning Systems	33	177	356	14	Architecture	17	84	144
5	Sensor Networks	30	132	241	15	Neural Networks	16	82	153
6	Deep Learning	28	131	266	16	Sensors and Actuators	16	89	144
7	Real Time Systems	26	154	293	17	Security of Data	15	75	128
8	Forecasting	21	90	179	18	Urban Transportation	14	68	123
9	Learning Algorithms	20	112	213	19	Economic and Social Effects	13	89	122
10	Security Systems	20	100	189	20	Interactive Computer Systems	13	90	151

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Cluster 4 (yellow color) associates 17% of the main keywords and is headed by “Wireless Telecommunication Systems” (occurrences: 40, link: 185, total link strength: 450). Table 7 contains the 20 main keywords associated with this cluster. The fourth thematic axis develops a macroscopic approach to wireless telecommunications systems through specific analyses related to power, data rates, multiple access, cellular engineering, and access network architectures [130,131].

**Table 7.** Cluster 4. Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Internet Protocols	34	160	357	12	Long Range Technology (LORA)	17	62	130
2	Embedded Systems	29	153	306	13	Network Layers	17	110	185
3	Radio Frequency Identification (RFID)	27	125	228	14	Cost Effectiveness	16	100	166
4	Low Power Electronics	25	132	279	15	IoT Architectures	15	81	132
5	Smart Power Grids	23	129	261	16	Zigbee	15	78	120
6	Communication Technologies	22	123	211	17	Wide Area Networks	14	90	181
7	Electric Power Transmission Networks	22	138	263	18	LoRaWAN	13	65	120
8	Smart Grid	22	126	233	19	Standards	13	77	114
9	Wireless Communications	19	120	209	20	Wi-Fi	13	93	146
10	Radio Frequency Identification (RFID)	18	103	209	20	Message Queue Telemetry Transport (MQTT)	12	31	49

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Cluster 5 (purple color) is led by “Internet” (occurrences: 126, link: 273, total link strength: 989), and it groups 8.91% of the keywords. Table 8 contains the 20 main keywords associated with this cluster. The fifth research line has developed contributions on the concept of “Internet” in relation to smart cities based on IoT technology applications, as a decentralized set of interconnected communication networks that use the Transmission Control Protocol/Internet Protocol (TCP/IP), guaranteeing that the heterogeneous physical networks that comprise it constitute a unique logical global network [132,133].

**Table 8.** Cluster 5: Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Interoperability	38	145	301	11	Smart Environment	13	68	104
2	IoT Applications	31	107	215	12	Information and Communication Technology	12	35	70
3	Sustainable Development	29	131	264	13	Ecology	11	68	113
4	Urban Growth	27	131	272	14	Mobility	11	38	63
5	Semantic Web	23	99	195	15	Quality of Life	11	57	85
6	Urban Planning	22	93	184	16	Energy	10	62	101
7	Electronic Commerce	21	76	152	17	Technological Development	9	33	54
8	Ecosystems	18	113	189	18	5G	8	46	58
9	Population Statistics	18	99	173	19	Building Blocks	8	33	47
10	Sustainability	16	79	146	20	Innovation	8	25	43

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Cluster 6 (cyan color) is led by “Cloud Computing” (occurrences: 88, link: 249, total link strength: 799), and it groups 8.70% of the keywords. Table 9 contains the 20 main keywords associated with this cluster. The sixth thematic axis develops studies on cloud computing, in relation to the availability upon request of the resources of the computer system, such as data storage and computing capacity, without direct active management by the user. This keyword represents the data centers available from anywhere over the Internet from any mobile or fixed device [134,135].



**Table 9.** Cluster 6. Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Network Architecture	78	259	831	11	Resource Management	15	88	159
2	Fog Computing	53	176	501	12	Telecommunication Services	14	90	138
3	Digital Storage	51	191	485	13	Cloud	13	53	87
4	Quality of Service	47	218	464	14	Software Defined Networking	13	100	162
5	Edge Computing	44	179	445	15	Web Services	12	56	95
6	Fog	40	153	419	16	Augmented Reality	11	63	90
7	Computer Architecture	37	177	445	17	Heterogeneous Devices	11	72	107
8	Blockchain	26	101	194	18	Energy Consumption	10	73	104
9	Green Computing	25	157	306	19	Industry 4.0	10	38	49
10	Information Services	23	140	263	20	Mobile Devices	10	59	83

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

Finally, cluster 7 (orange color) associates 3.44% of the main terms and is headed by “Automation” (link: 306, total link strength: 1071, occurrences: 105). Table 10 contains the 20 main keywords associated with this cluster. The seventh line of research contributes to developing automation, with reference to the system that allows a machine to carry out certain processes or perform tasks without human intervention, guaranteeing time and cost savings [136,137].

**Table 10.** Cluster 7: Top 20 keywords (2011–2019).

R	Keyword	O	L	TLS	R	Keyword	O	L	TLS
1	Intelligent Buildings	95	280	979	11	Lighting	6	43	55
2	Smart Homes	26	106	250	12	Wireless Sensor Networks (WSN)	6	30	44
3	Energy Management	17	90	178	13	Building Management System	5	37	56
4	Energy Management Systems	11	54	96	14	Energy Optimization	5	40	54
5	Buildings	10	64	119	15	Light-Emitting Diodes	5	32	41
6	Future Internet	10	48	73	16	Security Requirements	6	29	49
7	Smart Building	8	47	86	17	Service-Oriented Architecture (SOA)	6	42	65
8	Commerce	7	48	63	18	Control Systems	5	28	38
9	Architectural Design	6	29	36	19	Realtime Processing	5	50	60
10	Cameras	6	33	43	20	Electronic Data Interchange	5	50	59

R: Rank position; O: Occurrences; L: Links; TLS: Total Link Strength.

These research lines identified bring together all the concepts related to smart cities based on IoT technology applications global research, during the 2011–2019 period. In other words, these thematic axes include the different approaches analyzed by the different actors (authors, research institutions and countries) that make up this research field.

#### 4.4. Analysis of Authors, Research Institutions, and Countries

Section 4.4 shows the thematic areas in which the articles and the main keywords of the authors, research institutions, and most productive countries are classified. Likewise, their collaboration networks are shown, based on co-authorship analysis.

##### 4.4.1. Authors

Table 11 shows the main characteristics of the 10 most prolific authors in this research topic. The sample of articles has been written by 3744 authors.

**Table 11.** Top 10 authors and main keywords (2011–2019).

Author	Institution	A	Country	SA	C	C/A	h*	1A*	LA*	Keyword 1	Keyword 2	Keyword 3
Muñoz, L.	Universidad de Cantabria	10	Spain	CS-E	618	62	8	2011	2019	Internet	Electronic Commerce	Experimentation
Choo, K.K.R.	University of Texas at San Antonio	9	USA	CS	169	19	6	2016	2019	Cloud computing	Digital Storage	Blockchain
Kantarci, B.	University of Ottawa	9	Canada	CS-MA	155	17	7	2016	2019	Mobile Crowdsensing	Data Acquisition	Crowdsensing
Al-Turjman, F.	Antalya Bilim University	8	Turkey	CS-E	111	14	6	2018	2019	Energy Utilization	Extensive Simulations	Power Management (telecommunication)
Park, J.H.	Seoul National University of Science and Technology	8	South Korea	CS-EY	163	20	5	2017	2019	Network Architecture	Blockchain	Network Security
Santana, J.R.	Universidad de Cantabria	8	Spain	E-CS	383	48	6	2012	2019	Internet	Testbed	Electronic Commerce
Barnaghi, P.	UK Dementia Research Institute	7	UK	CS-E	148	21	6	2015	2019	Data Mining	Semantics	Data Analytics
Guizani, M.	Qatar University	7	Qatar	CS-E	99	14	6	2017	2019	5G Mobile Communication Systems	Blockchain	Device-to-Device Communications
Sotres, P.	Universidad de Cantabria	7	Spain	CS-E	378	54	5	2012	2019	Network Architecture	Electronic Commerce	Information and Communication Technologies
Zaslavsky, A.	Deakin University	7	Australia	CS-E	583	83	5	2014	2019	Waste Management	Internet	Waste Disposal

A: number of articles; SA: subject areas; CS: Computer Science; EN: Engineering; MA: Mathematics; EY: Energy; C: total citations; C/A: average number of citations per article; h: h-index or Hirsch index; 1A: first article; LA: last article; (\*) in this research topic.

Hence, the 10 most productive authors and the research institutions to which they are affiliated were Muñoz, L. (Network Planning and Mobile Communications Laboratory, Universidad de Cantabria, Santander, Spain); Choo, K.K.R. (Department of Information Systems and Cyber Security, University of Texas at San Antonio, San Antonio, TX, USA); Kantarci, B. (School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, ON, Canada); Al-Turjman, F. (Antalya Bilim University, Antalya, Turkey); Park, J.H. (Seoul National University of Science and Technology—SNUST, Seoul, South Korea); Santana, J.R. (Network Planning and Mobile Communications Laboratory, Universidad de Cantabria, Santander, Spain); Barnaghi, P. (UK Dementia Research Institute, Care Research and Technology Centre, London, UK; Centre for Vision, Speech and Signal Processing, University of Surrey, Guildford, UK); Guizani, M. (Department of Computer Science and Engineering, Qatar University, Doha, Qatar); Sotres, P. (Network Planning and Mobile Communications Laboratory, Universidad de Cantabria, Santander, Spain); and Zaslavsky, A. (School of Information Technology, Deakin University, Geelong, Australia).

By territory, 4 authors are of European origin (3 Spanish: Muñoz, Santana, and Stores; and 1 British: Barnaghi); 3 are of Asian origin (Al-Turjman, Park, and Guizani), 2 are of American origin (Choo and Kantarci) and 1 is of Australian origin (Zaslavsky). In this line, by subject area, all the authors of this ranking classify their articles in Computer Science; followed by Engineering with 5 authors; and Mathematics and Energy with 1 author each.

In other words, the main thematic areas (Computer Science and Engineering) associated with the most prolific authors' articles have been identified. These areas reflect the interests of this scientific field, which has implications both in technology and processes, as well as in innovation and ubiquity, all related to an infrastructure complex with the aim of improving the lives of city dwellers [138,139].

Moreover, among the 10 most productive authors on this topic in the 2011–2019 period, the keywords most used by them, not counting “Internet of Things” or “Smart City”, are mainly linked, in order, to cluster 6 (Blockchain, Network Architecture, Cloud Computing, and Digital Storage); cluster 5 (Internet, Electronic Commerce, and Experimentation); cluster 3 (Waste Management, Data Mining, Network Security, and Waste Disposal); cluster 2 (Energy Utilization, 5G Mobile Communication

Systems, Extensive Simulations, and Power Management (telecommunication)); cluster 1 (Data Acquisition, Data Analytics, Semantics, Crowdsensing, and Information and Communication Technologies); and cluster 4 (Testbed).

On the other hand, the top 10 authors of this topic associate their articles, mainly, with research lines that analyze cloud computing, that is, the paradigm that offers computer services through the Internet [39]; and automation, which refers to the application of machines or automatic procedures in carrying out a process or in an industry [44,136].

Figure 5 displays the cooperation map between the authors, based on co-authorship analysis, who have published globally on smart cities based on IoT technology applications. The color of each cluster is related with the group of authors in the publication of articles, while the diameter of the circle indicates the number of articles by the author. The authors in this research topic are associated into 7 groups. In this sense, it is noteworthy that cluster 1, the most numerous, is mostly made up of authors of Chinese origin, and it is in a central position, confirming its potential for research and cooperation among its members. Likewise, component 2 describes the cooperation of the American authors who also confirm their potential researcher at a global level. This cluster is positioned laterally with a certain distance from component 1, which mainly includes authorship of Chinese origin. On the other hand, it is observed that cluster 5, predominantly of Spanish collaboration, is located laterally and is somewhat detached from the rest of the clusters.

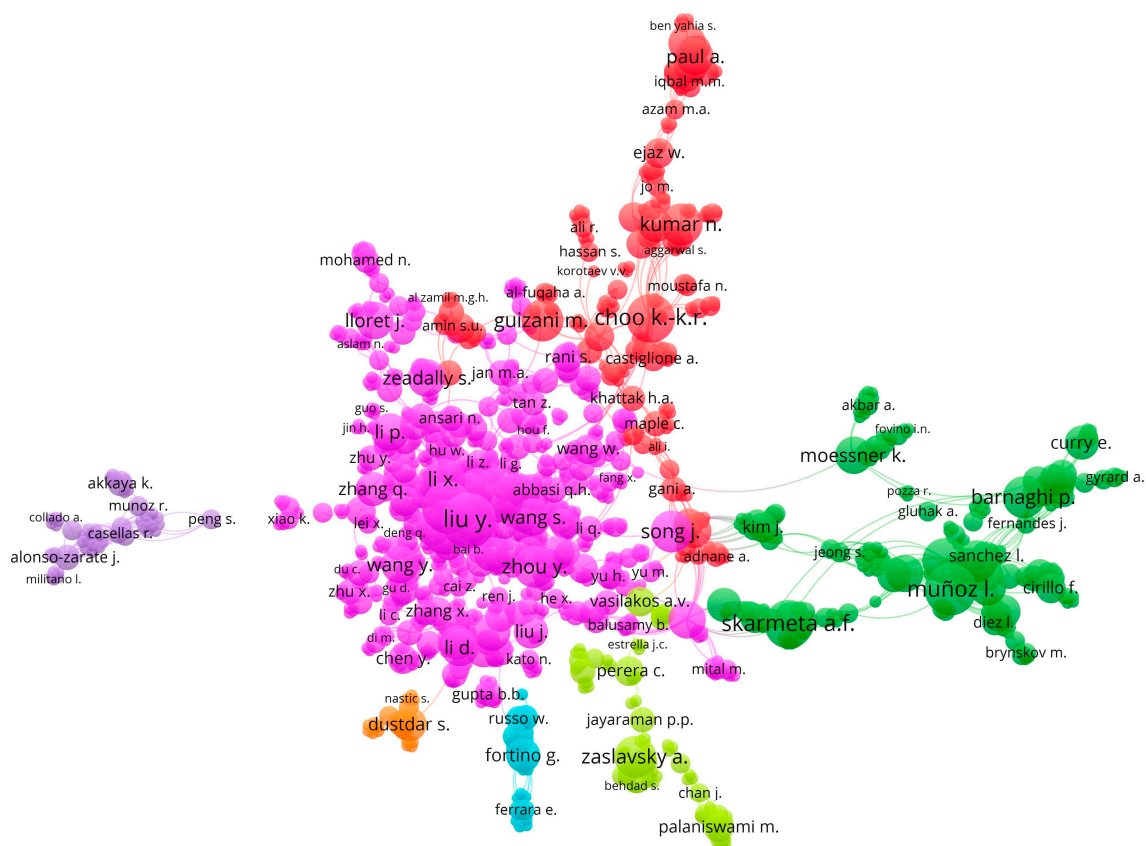


Figure 5. Authors network based on co-authorship method (2011–2019).

Table 12 presents the leading authors by number of articles and the main collaborating authors of each of the 7 clusters formed.

**Table 12.** Clusters of authors (2011–2019).

Cluster	Cluster Color (See in Figure 5)	%	Authors	Articles	Links	TLS	Citations
1	Pink	54.92%	Liu Y. (*)	11	49	53	189
			Zhang Y.	11	41	46	139
			Liu X.	10	36	40	147
			Wang X.	8	29	29	88
			Zhou Y.	7	27	30	119
2	Green	15.89%	Muñoz L. (*)	10	31	57	681
			Skarmeta A.F.	9	25	34	235
			Santana J.R.	8	42	68	420
			Sotres P.	7	25	49	412
			Barnaghi P.	7	23	36	164
3	Red	15.66%	Choo K.-K.R. (*)	9	33	36	242
			Kumar N.	7	21	29	165
			Guizani M.	7	25	26	164
			Paul A.	6	11	22	485
			Rathore M.M.	6	15	24	485
4	Yellow	5.90%	Zaslavsky A. (*)	7	25	31	627
			Perera C.	4	15	15	861
			Palaniswami M.	4	14	18	636
			Vasilakos A.V.	4	19	19	296
			Anagnostopoulos T.	4	16	21	116
5	Violet	4.09%	Alonso-Záate J. (*)	3	25	25	100
			Akkaya K.	3	8	8	23
			Casellas R.	2	30	32	76
			Verikoukis C.	2	30	32	76
			Vilalta R.	2	30	32	76
6	Cyan	1.97%	Fortino G. (*)	5	16	23	405
			Russo W.	3	7	14	100
			Savaglio C.	3	7	14	100
			Pianini D.	3	8	14	78
			Viroli M.	3	8	14	78
7	Orange	1.5%	Dustdar S. (*)	5	13	19	95
			Vögler M.	4	11	15	88
			Inzinger C.	3	4	9	76
			Schleicher J.M.	3	4	9	76
			Truong H.-L.	2	13	13	22

#: percentage of total authors; (\*) leading author; TLS: Total Link Strength.

The network of authors denotes the potential, fundamentally, of authors of Chinese, North American, and Spanish origin. This result is confirmed by the development of scientific activity in these countries. In this sense, the participation of public and private entities promote production for the purposes of these programs [140,141].

#### 4.4.2. Research Institutions

The 1232 articles selected in smart cities based on IoT technology applications research have been written in 2680 international affiliations. Table 13 displays the 10 most prolific research institutions in this topic. This ranking highlights that 50% are of European origin (University of Surrey, Universidad de Cantabria, Universidad de Murcia, Alma Mater Studiorum Università di Bologna, and Universitat Politècnica de Catalunya) and 50% are of Asian origin (King Saud University, University of Electronic Science and Technology of China, COMSATS University Islamabad, K L Deemed to be University,

and Kyungpook National University). Moreover, all these research institutions classify their published articles into the Computer Science and Engineering categories.

**Table 13.** Top 10 research institutions and main keywords (2011–2019).

Research Institution	A	Country	Subject Area	h *	1A *	LA *	Keyword 1	Keyword 2	Keyword 3
King Saud University	20	Saudi Arabia	CS-EN	11	2013	2019	Big Data	Deep Learning	Health Care
University of Surrey	18	UK	CS-EN	9	2012	2019	Data Mining	Information Management	Internet
University of Electronic Science and Technology of China	17	China	CS-EN	8	2016	2019	5G Mobile Communication System	Cryptography	Data Communication System
Universidad de Cantabria	17	Spain	CS-EN	10	2011	2019	Internet	Electronic Commerce	Co-creation
Universidad de Murcia	16	Spain	CS-EN	10	2013	2019	Internet	Internet Protocol	Energy Efficiency
Alma Mater Studiorum Università di Bologna	15	Italy	CS-EN	9	2013	2019	Aggregate Computing	Distributed Computer System	Simulation
COMSATS University Islamabad	15	Pakistan	CS-EN	8	2017	2019	Automation	Intelligent Building	Energy Efficiency
Universitat Politècnica de Catalunya	13	Spain	EN-CS	8	2015	2019	Automation	Distributed Computer System	Energy
K L Deemed to be University	13	India	EN-CS	2	2016	2019	Security	Wireless Sensor Network	Air Pollution
Kyungpook National University	12	South Korea	CS-EN	8	2016	2019	Big Data	Automation	Intelligent Building

A: number of articles; EN: Engineering; CS: Computer Science; h: h-index or Hirsch index; 1A: first article; LA: last article; (\*) in this research topic.

Regarding the subject areas, all the research institutions classify the articles produced in Computer Science and Engineering, just as it happens with all scientific production.

On the other hand, Table 13 also shows the main keywords associated with the articles published by the top 10 institutions in this research field. Among the most outstanding research institutions, the presence of the Vellore Institute of Technology (India) and the Chinese Academy of Sciences (China), which are made up of several organizations, are observed. Even though their contributions do not make a significant difference and occupy positions 7 and 8, respectively, the decision has been made not to include them in this ranking. In this ranking, the search keywords (Internet of Things, Smart City) have been omitted, since they occupied the first two positions in all research institutions. As for the main keywords linked to the top 10 research institutions and that define the thematic axes that they develop, they stand out: cluster 1 (Big Data, Distributed Computer System, Health Care, Information Management, Air Pollution); cluster 2 (5G Mobile Communication System, Data Communication Systems, Energy Efficiency, Simulation, Security, Wireless Sensor Network); cluster 3 (Data Mining, Deep Learning, Internet Protocol); cluster 5 (Electronic Commerce, Energy, Internet); and cluster 7 (Automation, Intelligent Building). In other words, it is observed from the research lines of these authors that the topics developed in their articles reach a wide range of aspects; although it also highlights that the thematic axis related to clusters 4 and 6 are not as well developed among these authors.

The process of digital transformation in the IoT in smart cities has a more collective than individual impact on research. Institutions play a key role in the implementation of projects that promote initiatives around different multidisciplinary objectives. This assumes that scientific activity is not concentrated in a few institutions, but rather that there is a wide variety that affects the research focus, as evidenced by the different key terms of the top 10 institutions [142].

Figure 6 shows the network of research institutions based on the co-authorship analysis. The VOSviewer software tool associates them into 5 groups. The co-authorship analysis of the research institutions infer that a greater number of actors involved in this topic will have an impact on accelerating the adoption of technology and generating a greater scientific impact. Thus, the multidisciplinary approach of this research field is linked to that of the variety of research institutions involved [143].

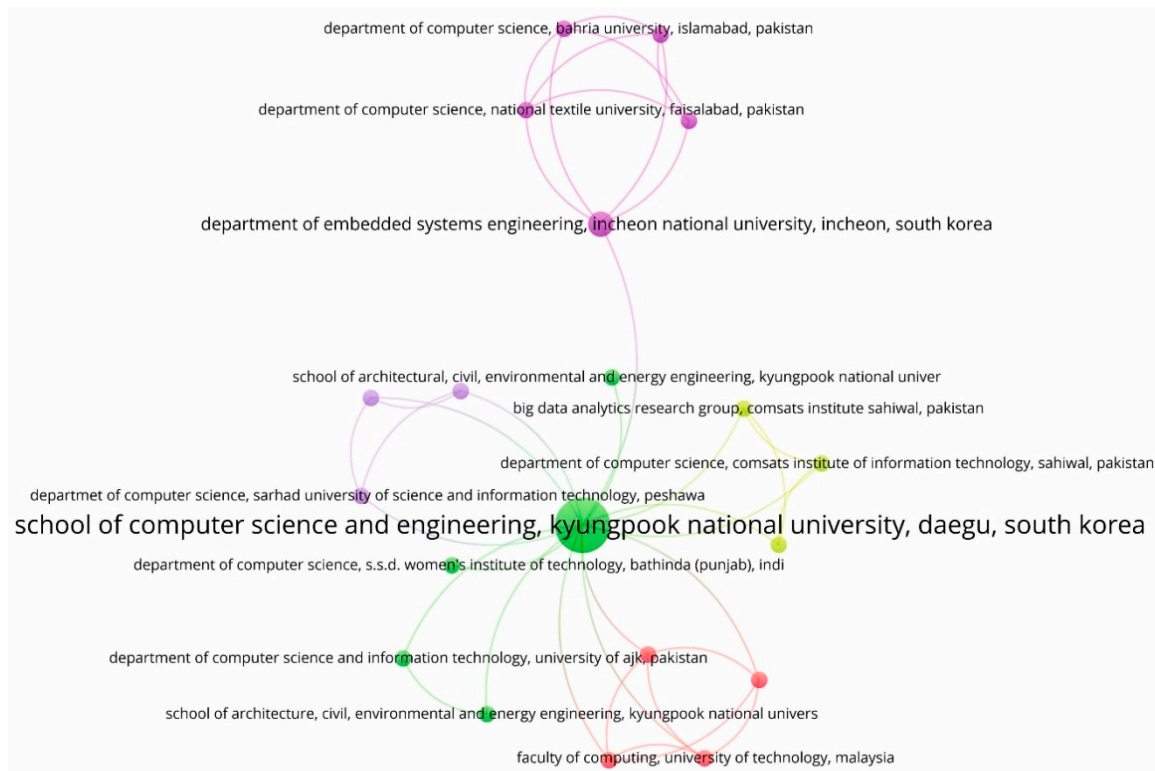


Figure 6. Research Institutions network based on the co-authorship method (2011–2019).

Table 14 presents the leading research institutions by number of articles and the main collaborating authors of each of the 5 clusters formed.

Table 14. Clusters of authors (2011–2019).

Cluster Number	Cluster Color (See in Figure 6)	%	Research Institution	Region, Country	A	L	C
1	Pink	25%	Department of Embedded Systems Engineering (Incheon National University)	Incheon, South Korea	2	5	41
			Department of Computer Science (Bahria University)	Islamabad, Pakistan	1	4	2
			Department of Computer Science (National Textile University)	Faisalabad, Pakistan	1	4	2
			Department of Computer Science, University of Engineering and Technology	Taxila, Pakistan	1	4	2
			School of Electronic Engineering (Xidian University)	Shaanxi, China	1	4	2

Table 14. Cont.

Cluster Number	Cluster Color (See in Figure 6)	%	Research Institution	Region, Country	A	L	C
2	Green	25%	School of Computer Science and Engineering, Kyungpook National University	Daegu, South Korea	7	15	120
			Department of Computer Science and Information Technology, University of Ajk	Cachemira Azad, Pakistan	1	2	38
			Department of Computer Science, S.S.D. Women's Institute of Technology	Bathinda (Punjab), India	1	1	14
			School of Architecture, Civil, Environmental and Energy Engineering, Kyungpook National University	Daegu, South Korea	1	2	42
3	Red	20%	Department of Computer Science, University of Peshawar	Peshawar, Pakistan	1	4	2
			Department of Control and Computer Engineering (Dauin)	Torino, Italy	1	4	2
			Faculty of Computing, University of Technology	Skudai, Malaysia	1	4	2
			School of Computing, Universiti Utara Malaysia (UUM)	Kedah, Malaysia	1	4	2
4	Yellow	15%	Big Data Analytics Research Group, Comsats Institute Sahiwal	Sahiwal, Pakistan	1	3	8
			Department of Computer Science, Comsats Institute of Information Technology (Ciit)	Vehari, Pakistan	1	3	8
			Department of Computer Science, Comsats Institute of Information Technology	Sahiwal, Pakistan	1	3	8
5	Violet	15%	Department of Computer Software Engineering, National University of Sciences and Technology	Islamabad, Pakistan	1	3	13
			Department of Information Communications Engineering, Hankuk University of Foreign Studies	Seoul, South Korea	1	3	13
			Department of Computer Science, Sarhad University of Science and Information Technology	Peshawar, Pakistan	1	3	13

%; percentage of total research institutions; (\*) leading institution; A: articles; L: Links; C: citations.

#### 4.4.3. Countries

In this research topic, the 1232 articles were written in 93 different countries. Table 15 shows the top 10 countries in this research field. The country with the most articles is China (articles: 216, percentage of total: 17.53%), followed by the United States (201, 16.31%), India (195, 15.83%), Spain (137, 11.12%), Italy (108, 8.77%), the United Kingdom (104, 8.44%), South Korea (81, 6.57%), Australia (62, 5.03%), Canada (55, 4.46%), and Pakistan (53, 4.30%).

**Table 15.** Top 10 Countries and main keywords (2011–2019).

Country	A	%	Subject Area	h *	1A *	LA *	Keyword 1	Keyword 2	Keyword 3
China	216	17.53	CS-EN	35	2011	2019	Big Data	Network Security	Automation
USA	201	16.31	CS-EN	37	2013	2019	Big Data	Automation	Wireless Sensor Network
India	195	15.83	EN-CS	20	2015	2019	Wireless Sensor Network	Cloud Computing	Big Data
Spain	137	11.12	CS-EN	26	2011	2019	Internet	Energy Utilization	Wireless Sensor Network
Italy	108	8.77	CS-EN	27	2012	2019	Internet	Big Data	Wireless Sensor Network
UK	104	8.44	CS-EN	29	2012	2019	Internet	Big Data	Information Management
South Korea	81	6.57	CS-EN	18	2013	2019	Network Security	Automation	Big Data
Australia	62	5.03	CS-EN	19	2014	2019	Internet	Big Data	Cloud Computing
Canada	55	4.46	CS-EN	16	2013	2019	Automation	Big Data	Energy Efficiency
Pakistan	53	4.30	CS-EN	14	2016	2019	Big Data	Automation	Intelligent Building

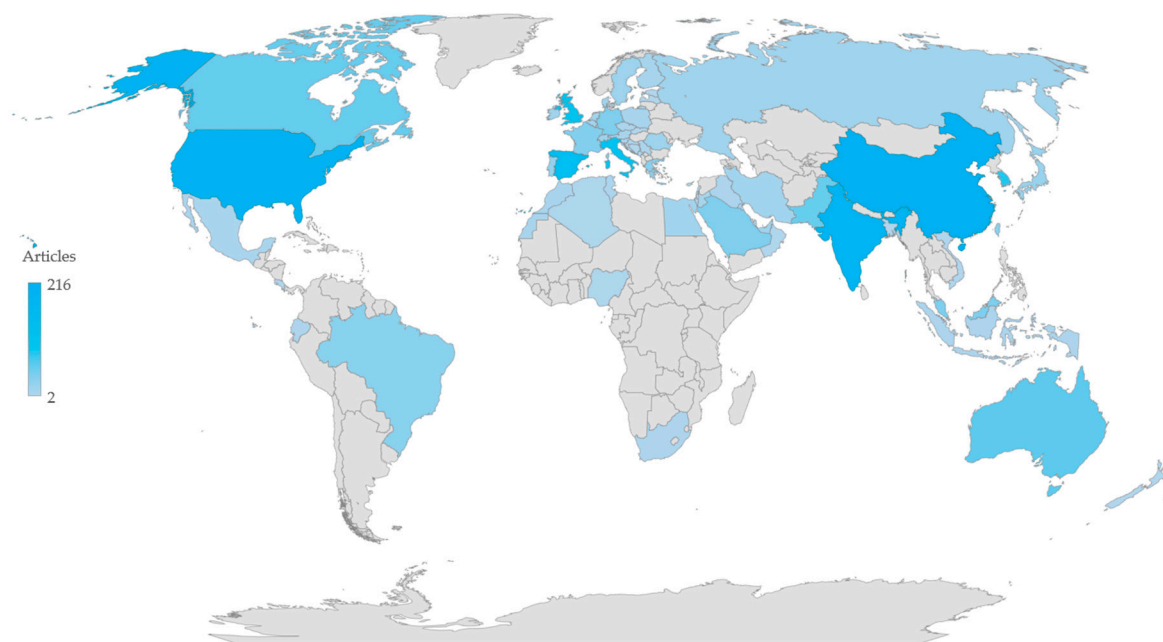
A: number of articles; %: percentage of total articles published; CS: Computer Science; EN: Engineering; h: h-index or Hirsch index; 1A: first article; LA: last article; (\*) in this research topic.

The articles published by the top 10 countries in the research on IoT technology applications-based smart cities are classified mainly in the same subject areas that make up the majority of the scientific production examined (see Figure 3), that is, Sciences of the Computing and Engineering.

Furthermore, Table 15 also presents the 3 main keywords for the most productive countries in this research topic. The main terms used by the top 10 countries in this thematic area in their articles are associated with six of the identified thematic axes, except for the one that develops the line on “wireless telecommunication systems”. Therefore, each cluster is represented by a set of terms that identify the topics mainly dealt with by these countries during the period 2011–2019. Hence, cluster 1 (Big Data, Information Management); cluster 2 (Energy Utilization, Wireless Sensor Network); cluster 3 (Energy Efficiency, Network Security); cluster 5 (Internet); cluster 6 (Cloud Computing); and cluster 7 (Automation, Intelligent Building).

The multidisciplinary approach of this research topic is related to the variety of countries and continents involved. Thereby, in the same way that it happens with the authors and research institutions, in the countries, as observed in the reviewed literature and in the keywords of the top 10 countries, there is also a multidisciplinary research [144,145].

Figure 7 shows the choropleth map of the countries that contribute to the development of smart cities based on IoT technology applications research. The color range of the blue color has been used to represent the number of articles published on this topic. This map allows visualizing the level of variability of the research at a global level.



**Figure 7.** Scientific production by countries (2011–2019).



Despite the fact that the United States, China, and India, as benchmarks for North America and Asia, bear the weight of research on smart cities based on IoT technology applications globally, the map also shows that Europe, with Spain, Italy, and the United Kingdom, also join this leadership. Australia, on the other hand, is also giving Oceania a voice in this research, and to a lesser extent, both Latin America and Africa are contributing to the more social approach to this topic [146].

Figure 8 shows a collaboration network between the main countries based on the co-authorship analysis. Different colors represent the different clusters formed by the groups of countries, while the diameter of the circle varies depending on the number of articles published by each country. The VOSviewer software has grouped them into 6 components.

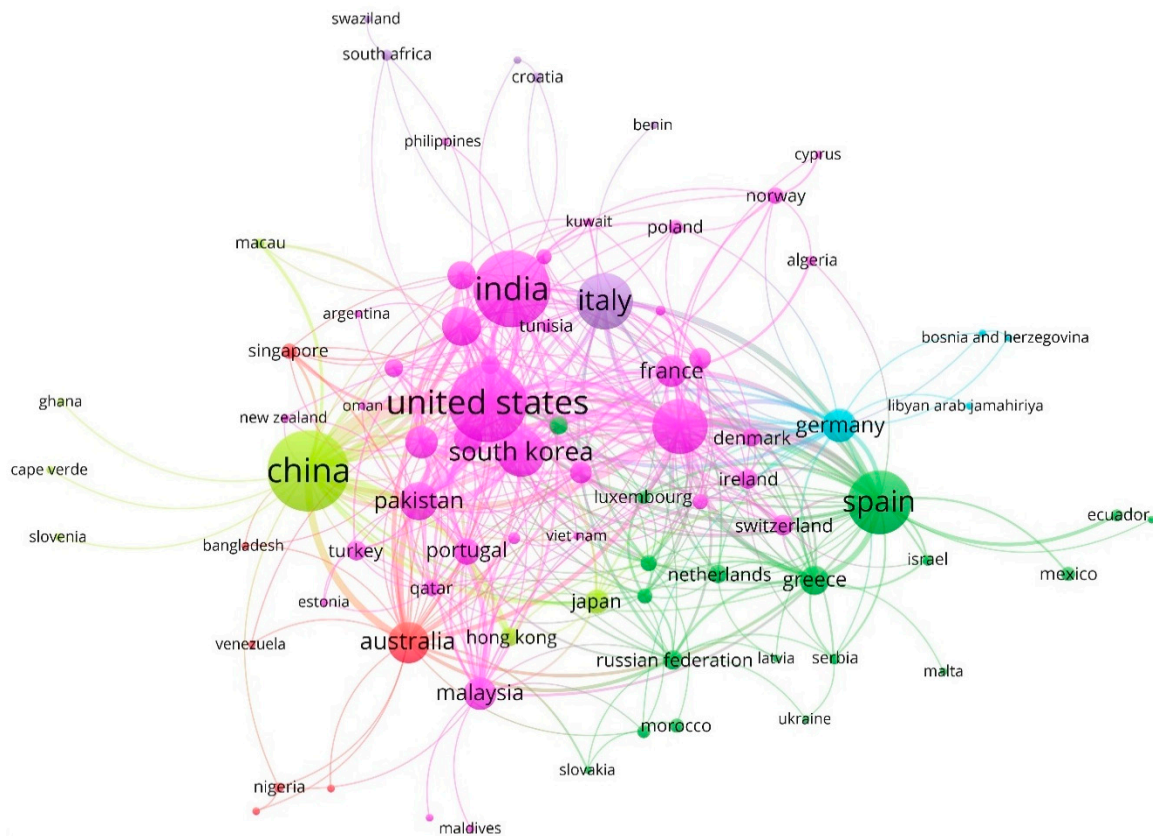


Figure 8. Countries network based on the co-authorship method (2011–2019).

Table 16 presents the leading countries by number of articles and the main collaborating countries of each of the 6 clusters formed.

Globally, the co-authorship analysis of the countries indicates that a greater number of participants will have an impact on accelerating research on the adoption of new technologies in smart cities. The centrality of the United States indicates the strength of its research activity and cooperation in its contributions at the international level. Likewise, China stands out in the development of this research field. The association in different clusters adds value to the international sound of this topic and promotes the participation and contributions of any country [147].

Table 16. Clusters of countries (2011–2019).

Cluster	Cluster Color (See in Figure 8)	%	Country	Articles	Links	TLS	Citations
1	Pink	47.56%	United States (*)	201	40	213	5441
			India	195	33	77	1350
			United Kingdom	104	38	165	3312
			South Korea	81	26	89	1671
			Canada	55	29	75	935
2	Green	23.17%	Spain (*)	137	33	127	5073
			Greece	32	24	66	1213
			Russian	15	16	30	500
			Netherlands	13	12	15	108
			Belgium	11	17	23	365
3	Red	8.54%	Australia (*)	62	29	85	2287
			Singapore	10	8	15	166
			Nigeria	4	4	4	287
			Bangladesh	2	3	3	13
			Botswana	1	2	2	10
4	Yellow	8.54%	China (*)	218	39	202	5002
			Japan	22	9	18	310
			Hong Kong	14	5	17	178
			Macau	4	3	8	728
			Slovenia	2	1	1	25
5	Violet	7.32%	Italy (*)	108	27	87	5856
			South Africa	5	4	4	73
			Croatia	4	3	3	21
			Benin	1	1	1	4
			Chile	1	2	2	9
6	Cyan	4.88%	Germany (*)	41	26	55	1136
			Bosnia and Herzegovina	2	2	2	38
			Montenegro	2	3	3	39
			Libyan	1	1	1	0

#: percentage of total countries; (\*) leading country; TLS: Total Link Strength.

#### 4.5. Future Research Directions

Section 4.5 presents the evolution that keywords have followed in the research in smart cities based on IoT technology applications during the period examined. Hence, the pioneering terms associated with this research are identified, which have been incorporated from the increase in published articles. For this reason, Figure 9 shows the evolution and maturity of each keyword community, since it differentiates the period in which they have been analyzed and associated with the articles examined. In this way, it is verified that there has been a progress in terminology in smart cities based on IoT technology applications research.

In this evolution of keywords associated with the research topic, Figure 9 shows that the group of pioneering keywords was incorporated and has allowed the study of smart cities based on IoT technology applications to be formed; this group includes smartphones, web services, augmented reality, network, and cloud computing technologies. In this first stage, the research has been devoted in a transversal way to the analysis and study of technologies that respond to the development and use of artificial intelligence and data analytics, connectivity, security, and well-being [148]. Next, the research focuses on studying the economic, environmental, and social challenges. The analysis of innovations worldwide allows collective participation and analyzes the key issues of Internet regulation and identifies solutions based on experiences in the previous stage [149]. Later, the research focuses on



research identified by the number of links and the total link strength. In addition, a description of each of the future research directions detected is added.

**Table 17.** Future research lines.

Research Line	Links	Total Link Strength	Description
Energy Storage	67	71	Efficient energy storage as an essential support for the energy transition and key to a decarbonized future. This allows flexibility in the production of renewable energy and guarantees its integration into the system.
Environmental Temperature	48	48	Development of measurement, instruments, and applications of sensors for environmental and urban temperature. Establish an intelligence guide to ambient temperature in the IoT environment.
Geographic Distribution	48	48	Use of remote sensors in the analysis of landscape fragmentation to monitor the patterns involved in fragmentation processes and thus avoid the loss of ecosystems and biodiversity.
Intentional Contaminations	40	40	Increased research on pollution sensors that measure environmental variables, such as the concentration of CO <sub>2</sub> and particles in suspension, in addition to generating urban pollution maps by region.
Remote Health Monitoring	32	32	Remote patient monitoring technology that allows patient observation outside of conventional clinical settings. This will mean access to care and lower costs of medical care.
End Users	29	30	Training tools for end users of information systems. Study of the user experience in the positive evolution of the smart city based on IoT, from the comfort, security, and control associated with connectivity. Analysis of the perception of the benefits of the IoT by the end user, for example, in energy savings in the home or car or in a more efficient use of daily activities.
Electronic Crime Countermeasures	28	28	Protection against Computer Crime and Information Security, in addition to regulatory development.
Industrial Internet of Things (IIoT)	26	27	Development and extension of the use of the Internet of Things (IoT) in industrial sectors and applications, such as robotics, medical devices, and software-defined production processes.
Flood Control	27	27	Design and specifications of flood control systems with IoT sensors. Real-time control of flood control structures, using rainfall forecasts, sensor data, and water level and flow forecasts.
Social Internet of Things (SIoT)	24	24	Study of how the integration of the principles of social networks in the IoT generates social and economic impact among the information consuming society.

Although the research trends are global, the responses—that is, the materialization of these contributions—are local and varied. This is mainly due to differences in different factors when identifying applications in IoT, such as economic, social, or climatic factors. The progress of the research allows us to recognize various models of smart cities, which are mainly focused on technological aspects, the factor of sustainable development, or digital literacy for a better understanding of digital transformation.

Regarding the initiatives that arise around the development of smart cities based on IoT technology applications, the following stand out. The European Innovation Partnership on Smart Cities and Communities (EIP-SCC), within the European Commission, Regarding the initiatives that arise around the development of smart cities based on applications of IoT technology, the following stand out:

The European Association of Innovation on Smart Cities and Communities (EIP-SCC), within the European Commission, was developed in the European Union's Research and Innovation Funding Program, Horizon 2020 (H2020). This association combines ICT together with energy and transport management, with the aim of providing innovative responses to environmental challenges, Social and Health Sciences of European Cities [153,154]. Additionally, Alliance for Internet of Things Innovation (AIOTI) is another leading initiative of the European Commission, as a space for the interaction of different IoT actors in Europe, such as research centers, universities, and associations [155,156].

Likewise, there are other means that foster interest in these topics, such as: "Smart Cities World" [157], which provides updated information on the infrastructure necessary to create a smart city; "SmartCity.Press" [158], which transmits updated knowledge, progress, and transformation on smart cities; or "IoT World Today" [159], which provides news and case studies on technologies used in the IoT, in different industries, such as smart cities.

## 5. Conclusions

The aim of this study was to analyze the evolution of scientific production and research trends at a global level, over the last 9 years (2011–2019), on smart cities based on IoT technology applications. To this, a bibliometric analysis of a sample of 1232 articles obtained from the Scopus database has been developed. Fundamentally, the evolution of the number of articles, the subject areas where they are classified, the journals where they are published, the authors, the research institutions, and the most productive countries have been identified. Furthermore, current and future main research lines have been detected.

Scientific production has increased especially in the last triennium (2017–2019), where 1025 articles have been published. These represent 83.20% of the total on the subject in smart cities based on IoT technology applications, which confirms the relevance at the global level and the impact of this research topic. In the same way, the authors, the research institutions, and the most productive countries also link their articles to these two areas of knowledge. In addition, the most prolific countries in this research topic are China, the United States, India, and Spain.

On the other hand, this study has also identified the most influential areas of knowledge where the publications are classified: Computer Science and Engineering. Although it is a multidisciplinary research field, its link with technology and computing is observed.

In relation to the journals in which IoT articles are published in smart cities, Sensors stands out because since 2013, it has contributed to the field of research with the largest number of articles, and in addition, it classifies them in the thematic areas of Engineering, Physics and Astronomy, Biochemistry, Genetics and Molecular Biology, and Chemistry.

The research lines identified that develop the field of study in smart cities based on IoT technology applications generate contributions on the following: (1) the holistic vision of a smart city; (2) IoT applications; (3) network security solutions; (4) the macroscopic approach to wireless telecommunications systems; (5) the implications of Internet in the development of smart cities; (6) cloud computing and the availability of data centers; and (7) the automation of processes.

Globally, the research in smart cities based on IoT technology applications continues to evolve, so this study has identified new directions in research: (1) Energy Storage; (2) Environmental Temperature; (3) Geographic Distribution; (4) Intentional Contaminations; (5) Remote Health Monitoring; (6) End Users, (7) Electronic Crime Countermeasures; (8) Industrial Internet of Things (IIoT); (9) Flood Control; and (10) Social Internet of Things (SIoT).

This study supposes an analysis of the scientific production and the actors that stimulate the smart cities based on IoT technology applications research, in the period 2011–2019, as well as the identification of the research lines and future research directions. Innovation in this research field has been identified based on the groups of authors, research institutions, countries, and keywords, and also the intensity of the relationships that develop in them. The findings obtained are a complement to knowledge in smart cities based on IoT technology applications and allow establishing the relationship

between science and technology and favoring the decision-making process. In this way, the individual quality of life of citizens would be benefited, in addition to a collective increase in productivity, since it would be easier for governments to have a better infrastructure at a lower cost to achieve an optimized management of resources.

However, the study has a set of limitations, which have conditioned the results obtained, and these could be considered as the basis for future research articles. Among these limitations, the Scopus database chosen to apply the methodology can be highlighted, as well as the keywords selected to extract the article sample, the study period, the bibliometric methodology used, and even the variables examined. It is also necessary to recognize that using data mining, one could explore large databases and find repetitive patterns that explain the behavior of this data.

Finally, it has been observed that global research in smart cities based on IoT technology applications shows an upward trend, which is derived both from the number of articles and from current and future lines of research. This indicates the interest increasingly accentuated by the academic and scientific community, which is mainly due to the multidisciplinary nature of the subject.

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