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Assessing Worldwide Research Activity on ICT in Climate Change Using Scopus Database: A Bibliometric Analysis

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Internet and Communication Technology (ICT) tools have been already introduced in every aspect of environmental science. Regarding climate change, research trends and developments on ICT help realize how ICT evolved and its potential future role in climate change. This study aimed to assess ICT solutions in climate change research trends using the Scopus database, bibliometric indicators, and network visualization. After a preliminary application of various combinations, the phrase "ICT and climate change" was used with language selection "English" from 01/01/1999 to 01/12/2021. A collection of 453 articles published in scientific journals and conference proceedings was revealed, which allowed the visualization mapping of the research agenda in the field of ICT and climate change. The most relevant topics are related to Computer Science, Engineering, Environmental and Social sciences. It has been found that a significant amount of documents were published after 2008. The Royal Institute of Technology-KTH was the most productive institution, followed by the Consiglio Nazionale Delle Ricerche and the Universitetet I Oslo. In addition, the dominant countries in the respective research area were the United Kingdom, Italy, United States, India and Sweden. According to citations, most of the published research activity emerged in various journals, like Environment and Planning, Cities and Energies. It was possible to spot past trends and ongoing development, intending to introduce ICT tools in climate change impacts and examine the issues expected to be pertinent in the future.

Keywords: bibliometric, ICT, climate change, environment, policy, public health, health

INTRODUCTION

Environmental issues dictate the global research agenda of this century. Climate change mitigation and adaptation policies influence every aspect of the social and environmental debate at the national and international levels. ICT, analytical tools and frameworks for the communication of respecting challenges are vital players in combatting and describing research trends and preparedness to tackle climate change.

Climate change is not just about global warming. The global climate changes the occurrence and the severity of weather phenomena and concurrently increases the existing pressure on ecosystems and societies (Field et al., 2014). Climate change caused by anthropogenic activities (CO_2, CH_4, HFCs, N_2O emissions) also exacerbates natural-weather phenomena such as storms, fires, floods, and heatwaves (Sahil and Sood, 2021). The Intergovernmental Panel on Climate Change (IPCC) stated that natural disasters are expected to increase with a 1.5°C increase in global warming (Djalante, 2019). In the same context, Street et al. (2019) emphasize the importance of using data from climate change to strengthen prevention and reconstruction measures for a natural disaster. Preventive measures and action plan to reduce the risk and occurrence of catastrophic events should also involve all actors and levels so that all decisions are based on valid information and data such as time series, seasonal forecasts, minimum and maximum temperature trends, short-term forecasts of temperatures and rainfall, models of fire forecasts, models of gas and water currents, the use of communication and information technologies. The aim is to develop decision-making systems to promote policies that will strengthen the full range of state preparedness and response in a natural disaster (Street et al., 2019; Khan et al., 2020; Zuccaro et al., 2020)

The devastating effects of climate change are putting enormous pressure on societies. Cities need to develop strategies and actions to reduce and mitigate these effects. Urbanization creates additional challenges, and as the population of cities increases, so does the need for energy. Thus a new concept has been added to sustainability and the proper management of natural resources. This concept is the digitalization and management of data generated from the individual to the city level ((Balogun et al., 2020).

This data through ICT can offer enormous potential for societies to adapt to climate change. There is a space for digital innovation, from creating databases to the real-time monitoring of natural phenomena to the utilization of clean technologies, interoperability of systems, and transparent diffusion of all this information and data (Munang et al., 2013). Moreover, ICT tools and applications deployment fortify global monitoring of environmental pollution, GHG emissions and ecosystem resilience, food resources, deforestation, the balance of energy demand and supply, energy efficiency, waste management and educational activities for climate change mitigation (Keith Dickerson et al., 2010; Lee and Mwebaza, 2022).

Today, talking about climate change, innovation and digitalization, the benchmark is sustainability and the goals that have been set. The 11th and 13th sustainable development goals, referred to smart cities and climate action, are two goals related to both climate change and energy systems management. On the one hand, ICT can provide solutions; on the other, its use raises questions (Mondejar et al., 2021). Questions are raised about the environmental impact of ICT, the energy requirements for their production and management, the resilience of energy systems, their life cycle, their construction materials and the intensification of their industrial production. Therefore, it is essential to focus on examining the scientific content of ICT concerning climate change (Jasiūnas et al., 2021; Kunkel and Tyfield, 2021).

Internet and Communication Technology applications conceptualize problems and solutions, risks and effects of climate change and global warming on agriculture, energy efficiency, renewable energy, water supply, hazard risk management, weather phenomena, food systems, and sustainable development. Moreover, this century is also the century of big data and data analytics. The digitalization of environmental sciences throughout ICT products provides a contemporary framework for addressing climate change challenges and perspectives (Tongia et al., 2005; Ballantyne et al., 2016; Gangopadhyay et al., 2019; Koliouska and Andreopoulou, 2020).

The core of ICT is the transmission, processing and interpretation of electronically generated information and data through devices. The interconnection of devices and sensors and the development of WiFi technologies emerged in the Internet of Things (IoT). Therefore, IoT provides vast data without analytic platforms and frameworks that are not interpretable and useful for decision-making and planning. IoT applications such as smart grids, smart healthcare, smart transportation, smart cities, smart agriculture, and the respective produced data can now be utilized since IoT technologies enhance interoperability of big data, cloud computing, fog computing, edge computing, and semantic web, and data storage (Ahmed et al., 2017; Atitallah et al., 2020).

Along with the increase and processing of these data, a need arose for transparency and protection. Blockchain technology is also used for this purpose. Blockchain, Artificial Intelligence (A.I.), and cloud computing expand into research areas such as security and privacy, software engineering, resource management and energy management (Gill et al., 2019; Majeed et al., 2021). These ICT technologies and their potential for sustainability have already been recognized and integrated into sustainability goals. Moreover, the transition to more proper resource and data management across the spectrum of food production, processing and distribution, as a result of digitalization, has led, among other things, to more energy-efficient management, reduction of greenhouse gases from the agricultural sector, carbon emissions trade, clean trade energy reduction, reduction of waste, reduction of commercial and processing costs, food tracking, food supply chain transparency (El Bilali and Allahyari, 2018; Talari et al., 2021).

As the population grows, so does the energy demand locally and nationally. At the same time, the environmental pressure from greenhouse gases is increasing. Therefore, adopting and applying innovative technologies such as IoT provides opportunities for proper management across the energy sector, such as production, transmission, management, design and transition to renewable forms (Ahmad and Zhang, 2021; Cheng et al., 2022).

Bibliographic trends and studies on various factors and research topics with a central focus on climate change have been carried out; however, it does not appear if there is any similar bibliometric research on this topic. Hou and Wang (2021) discuss the connection and the association between environment, energy and climate change. ICT usage and its contribution as a development factor of global greenhouse gas emission (GHGE) was the aim of another bibliometric analysis performed by Zaung Nau and Marinova (2020). Besides, Wang et al. (2014) submitted a bibliometric analysis regarding climate change vulnerability through various bibliometric indicators. Another study dealing with climate change was completed by Haunschild et al. (2016). The target was only climate change for an extended period in this research. Despite the increasing usage of bibliometric techniques in various research domains, there have been few attempts to collect and analyze publications data on the ICT in climate change.

One of the most common tools for analyzing and evaluating research production is bibliometric indicators. The research evaluation also reflects the development at the theoretical and technological level as new tools and methods are used to deepen a research field.

Bibliometric research of a domain relies on various indicators like publications patterns, citation, references similarities, research productivity of authors and institutes, and keyword analyses of multiple entities like authors, nations, organizations, and literature patterns. It unveils diverse scientific insights and clarifies various issues researchers tackle in quantifying a domain's frontiers, evolution, progress, and future perspective.

The following research questions (R.Q.) will help the study offer academics and decision-makers a perspective on ICT and climate change research content and topics addressed in the literature. RQ1: What changes have occurred in the literature on ICT and Climate change from 1999 to 2021? RQ2: What have been the most influential research articles, such as those published in Scopus? RQ3: What are the most important topics discussed in the ICT and climate change literature?

This specific study contributes to the imprint of the scientific literature, while the bibliometric indexes of this research outline the research production on ICT and climate change. Scientific articles covered the period from 1999 to 2021, when the usage of digital tools and the digitalization of many research areas were magnified. Thus, this research aims to assess the trends and frontiers in ICT in climate change using the Scopus database, various bibliometric indicators, and visualizing respective scientific literature. Moreover, this research delivers a bibliometric approach describing the research direction of this field and helps future decision-making processes for policymakers, including the public and private sectors. (Wang et al., 2014; Haunschild et al., 2016; Einecker and Kirby 2020; Zaung Nau and Marinova 2020; Bertoglio et al., 2021; Hou and Wang 2021).

MATERIAL AND METHODS

For the above research, a search was performed in the Scopus database, as it includes 1,7 billion cited references and covered nearly 2,600 serial titles from approximately 7,000 publishers in top-level subject fields: life, social sciences, physical sciences and health sciences. Additionally, the Scopus database offers many advantages like diversification, the flexibility of research fields and an advanced document analyzer mechanism[1] (Yataganbaba and Kurtbaş, 2016; Martín-Martín et al., 2018; Zyoud and Fuchs-Hanusch, 2019). This mechanism is based on Boolean Syntax for retrieving documents by combining keywords using various Boolean operators (Yataganbaba and Kurtbas 2016; Martín-Martín et al., 2018; Zyoud and Fuchs-Hanusch 2019; Sahil and Sood, 2021). Overall, the Scopus database provides many scientific journals with an advanced indexing operation (Zhao et al., 2019; Darko et al., 2020).

After a preliminary application of various combinations, the phrase 'ICT and climate change" was used with a time range from 01/01/1999 to 01/12/2021 and with language selection in English, and search details: TITLE-ABS-KEY (ICT AND climate AND change) AND [LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cr")]. Only research documents, manuscripts from conference proceedings and reviews were included. Moreover, the obtained manuscripts were recorded in the Microsoft Excel program by the year, subject area, document type, and institutional affiliation. VOS Viewer program was applied to visualize the results and create a bibliographic map[2]. We performed a co-authorship analysis using the full counting method, assigning the same weight to each co-authorship link. The full counting method was further used in the co-occurrence analysis of the keywords in the title, abstract, and the text of the manuscripts. The bibliometric analysis was developed by executing the following steps: research criteria, study questions, and analysis approach selection (the year, subject area, document type, and institutional affiliation, keyword analysis, network of authors, research evolution), bibliometric data selection, and analysis by using the bibliometric software, and generate networks, visualization figures, and interpretation of the results. The research productivity of different countries was further normalized, applying the national Gross Domestic Product (GDP) extracted from the World Bank online databases[3].

RESULTS

Research articles and conference papers were the most common document types published for "ICT and climate change" of 453 manuscripts (**Table 1**). Further, the top five institutions that published ICT and climate change documents were identified (**Table 1**). The Royal Institute of Technology-KTH was the most productive institution in academic publications, followed by the Consiglio Nazionale Delle Ricerche and the Universitetet I Oslo

[1]https://www.elsevier.com/solutions/scopus (Last accessed 10/09/2021).

[2]https://docs.google.com/viewer?url=https%3A%2F%2Fwww.vosviewer.com%2Fdocumentation%2FManual_VOSviewer_1.6.8.pdf&pdf=true.

[3]https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?view=map.

TABLE 1 | Descriptive characteristics of manuscripts indexed in the Scopus database.

Document by type N (%)	Top 5 institutions (N documents)	Top 5 productive countries (N documents)	Documents/trillion GDP (Rank)
Article 218 (48.1%)	The Royal Institute of Technology-KTH (11)	United Kingdom (52)	19.2 (3)
Conference paper 196 (43.3%)	Consiglio Nazionale delle Ricerche (10)	Italy (41)	21.73 (2)
Review 24 (5.3%)	Universitetet i Oslo (7)	United States (35)	1.5 (20)
Conference review 15 (3.3%)	The University of Manchester (6)	India (28)	1.67 (5)
	European Commission Joint Research Centre (6)	Sweden (26)	48.05 (1)

TABLE 2 | Top five cited articles indexed in the Scopus database.

Author	Title	Year	Source title	Cited by
1) Viitanen, J., Kingston, R. A	Smart cities and green growth: Outsourcing democratic and environmental resilience to the global technology sector	2014	Environment and Planning A 46 (4), pp. 803–819	211
2) Bousquet, J., Schunemann, H.J., Fonseca, J., (...), Zidarn, M., Mercier, J.	MACVIA-ARIA Sentinel NetworK for allergic rhinitis (MASK-rhinitis): The new generation guideline implementation	2015	Allergy: European Journal of Allergy and Clinical Immunology 70 (11), pp. 1372–1392	146
3) Malmodin, J., Moberg, A.S., Lundén, D., Finnveden, G., Lövehagen, N.	Greenhouse gas emissions and operational electricity use in the ICT and entertainment and Media sectors	2010	Journal of Industrial Ecology 14 (5), pp. 770–790	124
4) Avgerinou, M., Bertoldi, P., Castellazzi, L	Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency	2017	Energies 10 (10), 1470	123
5) Collier, M.J., Nedović-Budić, Z., Aerts, J., (...), Slaev, A., Verburg, P.	Transitioning to resilience and sustainability in urban communities	2013	Cities 32, pp. S21–S28	119

(**Table 1**). Moreover, three European countries, the United Kingdom, Italy and Sweden, were among the top five productive countries. The list also includes the United States and India.

Considering GDP, Sweden is the number one country among the top five productive countries, followed by Italy and United Kingdom. Greece has the best score (~100-data not shown) in this indicator, considering the number of records, 19 and the nominal GDP. It is worth mentioning the absence of countries that originated from Latin America and Africa in all respective categories of **Table 1**. The absence of African and Latin American countries is mainly documented by the general delay in adopting information technologies in many areas of the economic and social sectors. Obstacles exist from critical structural economic problems of African countries, lack of access, poor network infrastructures, lack of ICT skills, language barriers, high cost of software and hardware, lack of proper legal framework, lack of investments (Touray et al., 2013; Tuheirwe-Mukasa et al., 2019). Moreover, high level of illiteracy and low education level, low dissemination level of ICT due to the low educational and trained workforce in developing countries, non-use of the Internet by youth in African regions contribute to the low absorbance of such technologies to social and economic processes (Niyibizi and Komakech, 2013; Goel and Vishnoi, 2022; Jolex and Tufa, 2022; Zhang et al., 2022).

In the same context, barriers to adopting ICT in countries of Latin America usage are high costs, lack of skills, low broadband subscriptions, and various socioeconomic and infrastructural factors like income, gender, GDP per capita and educational level leading to low adoption and implementation of ICT tools and products ((Leroux et al., 2008; Galperin, 2017; Alderete, 2019; Arredondo-Trapero et al., 2021**).** In addition, a clear positive link between utilization of ICT and access to electricity, civil liberties, urban population, infrastructure and social stratification is also identified (Pick et al., 2021).

The highest citation number was 211 for the article entitled “Smart cities and green growth: Outsourcing democratic and environmental resilience to the global technology sector” (**Table 2**). This document received the most outstanding scientific attention and was published in 2014 in Environment and Planning A journal. It recorded 211 citations up to the data analysis time (01/12/2021). It is worth highlighting that the top five highly cited papers were published in five different journals from 2010 to 2017.

The number of published manuscripts determines a reasonable evaluation of the respective trend in a specific research domain. Publications were categorized annually, disclosing that the first manuscript appeared in 1999; however, the exponential growth of produced articles is signified after 2008 (**Figure 1**). In 2020, the highest number of manuscripts (52) was published. This year (2021), 44 records have already been published until now (01/12/2021). Furthermore, the annual publication graph illustrates that researchers have started paying attention to how ICT tools can reinforce climate change policies since 2009. This scientific interest is evident because there has been an exponential increase in published documents after 2009.

Figure 2 illustrates the number of documents that combine the subject area of ICT products and the climate change research theme. ICT regarding climate change has become a topic also for multiple disciplines beyond environmental sciences. More than 20 subject areas cover this scientific domain, and most of the

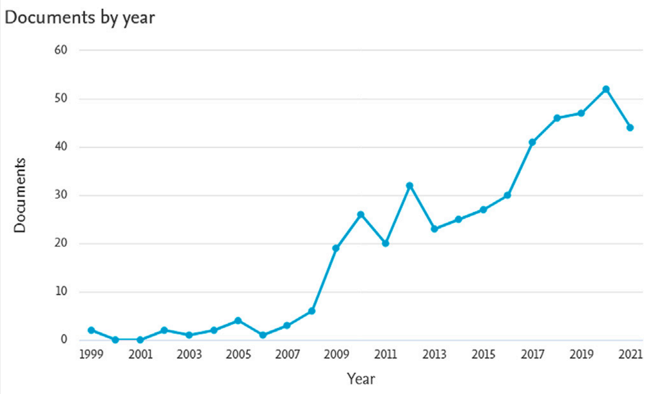

FIGURE 1 | Number of documents by year.

retrieved manuscripts belong to Computer science (23.88%), Engineering (15.88%), Social (14.59%) and Environmental Science (11.06%). Furthermore, as shown in **Figure 2**, Energy, Decision Management, Earth Sciences, and Agricultural and Biological Science are also linked to climate change research and ICT.

A network visualization map of the co-occurrence of keywords is depicted in **Figure 3**. This outcome was executed based on the 3,664 terms extracted from the title, keywords, and abstract fields of retrieved records. Setting the minimum number of keyword occurrences to 10, only 44 met the threshold. The map categorized terms into six significant clusters with respective colours. The colour of an item is dictated by the cluster to which the item belongs. In essence, the closer two keywords are spotted, the stronger their relatedness.

Figure 3 illustrates each cluster item with the best score of total link strength. Moreover, total link strength measures each keyword's importance through an assigned weight in VOS software. In this line, climate change is the item of the second cluster with the best score and ICT of the fourth cluster, justifying the essential search criteria.

Based on the map, six clusters were identified. The terms with the highest occurrences were greenhouse gases (red cluster-10 items), climate change (green cluster-10 items), energy efficiency (blue cluster-7 items), information and communication technology (yellow cluster-7 items), sustainable development (purple cluster-6 items) and information systems (light-blue cluster-4 items). An analytical description of the correspondence items is presented in **Table 3**.

The red cluster contains ten keywords and their co-occurrence relationships. This cluster is built around emissions and contains carbon dioxide, carbon emission and footprint, economic and social effects, emission control, gas emissions, global warming, greenhouse gases and investments. Moreover, the red cluster represents the research frontiers between gas emissions policy and respective economic objectives. The green cluster includes 11 keywords and refers to climate change. Agriculture, climate change, decision making and support systems, disasters, information and communication technologies, Internet of things, smart city and strategic approach are keywords that belong to this cluster. Decision support systems and ICT products are required in agriculture to tackle climate change impacts. The blue cluster with seven keywords (energy conservation, energy efficiency, energy policy, energy utilization, green computing, renewable energy, renewable energy resources) covers principal energy issues. The energy sector plays a crucial role in climate change agendas and mitigation decision-making processes.

The yellow cluster encompasses environmental impact, ICT, management, and life cycle items. This cluster accentuates the contribution and the driving force of ICT in environmental management and resources. In the same vein, the purple cluster involves e-learning, education, environment, information technology, sustainability, and sustainable development. This cluster provides research approaches to environmental sustainability and development using information technology and e-learning tools. Light-blue cluster amount to four keywords, developing countries, environmental sustainability, information systems and innovation. This cluster

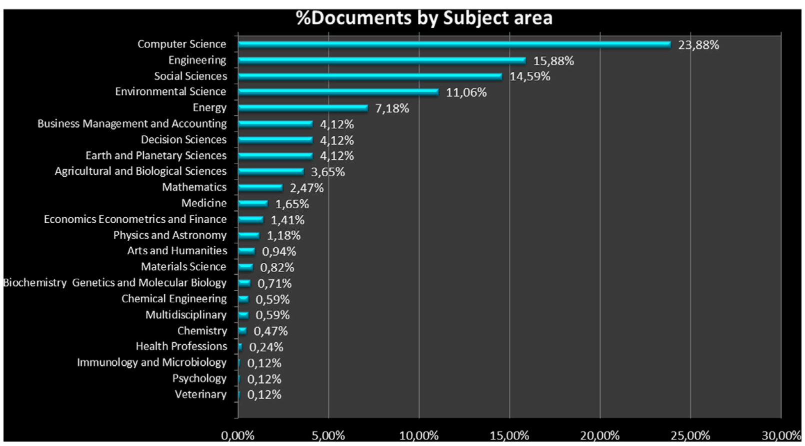

FIGURE 2 | Percentage of documents by subject area.

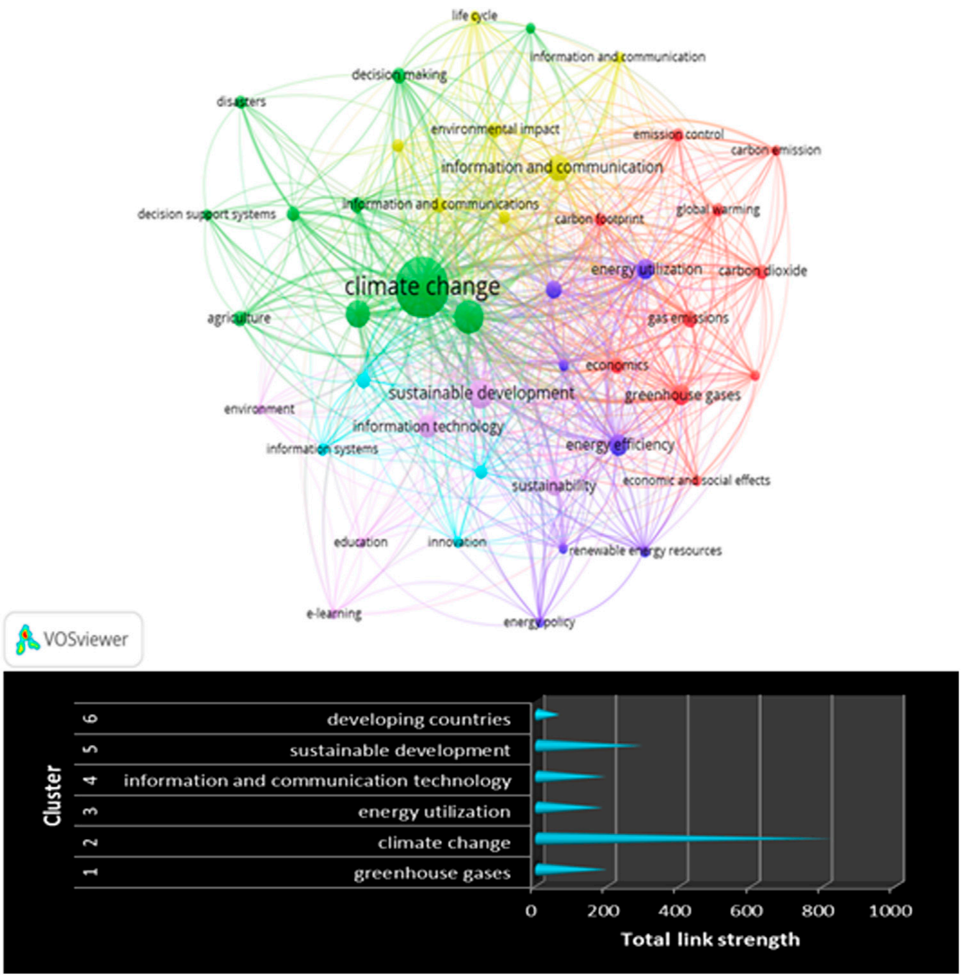

FIGURE 3 | Keyword analysis and total link strength of keywords in each cluster.

links the relationship of economic feasibility with environmental sustainability through the pivotal determinant of innovation.

In terms of authorship, three documents per author are considered to retrieve the author link strength in this bibliometric analysis. Out of 1,380 authors, 11 authors meet the threshold. Some of the authors are close together, while others are linked in a cluster. The closer the authors are to each other, the stronger their relationship is in the analysis[4] (McAllister et al., 2021). Researchers in ICT and climate change with the maximum number of published documents are Preist, C., Moberg, A., Hasan, H. and Bergmark, P. (**Figure 4**).

Furthermore, when considering the authors' total link strength, Acquaviva, A. with Patti E., Kasim, H. with Al-ghaili A.M. and Monzon A. with Valdes C. are connected, formulating three clusters. Although they are visible in the network, the other five authors are not connected with any authors. We can say that the above researchers' studies are influential and have great importance in this domain.

The visualization of the selected keywords using the total link strength of the VOSviewer is depicted in **Figure 5**. Research trends in the last decade are also identified. The initial research in this domain was primarily focused on information technology. In the following years, environmental impact, global warming and emission control enriched the research agenda. In the middle of the last decade, greenhouse gases and energy issues were emphasized, while sustainability concepts and educational topics have also entered the scientific domain of ICT in climate change. Eventually, the Internet of things and holistic approaches to climate change issues penetrated this research content at the end of the previous decade.

DISCUSSION

Climate change mitigation and sustainability go hand in hand. Most of the clusters revealed in this bibliometric analysis discuss

[4]https://docs.google.com/viewer?url=https%3A%2F%2Fwww.vosviewer.com%2Fdocumentation%2FManual_VOSviewer_1.6.8.pdf&pdf=true.

TABLE 3 | VOSviewer clusters "'ICT and climate change".

Cluster identification	Keywords	Cluster interpretation
Red cluster	Carbon dioxide, carbon emission, carbon footprint, economic and social effects economics, emission control, gas emissions, global warming, greenhouse gases, investments	Emissions
Green cluster	Agriculture, climate change, decision making, decision support systems, disasters, ICT, information and communication technologies, Internet of things, smart city, strategic approach	Climate change
Blue cluster	Energy conservation, energy efficiency energy policy, energy utilization, green computing, renewable energy, renewable energy resources	Energy
Yellow cluster	Environmental impact, environmental technology, information and communication technology, information and communication technology, information and communications technology, information management life cycle	ICT and environment
Purple cluster	e-learning, education, environment information technology, sustainability sustainable development	ICT and sustainability
Light blue cluster	Developing countries, environmental sustainability, information systems, innovation	Developing countries and sustainability

sustainability and refer to it in various forms and perspectives. One information and communication technology task is to unite and balance geographical and economic disparities among countries and conceptualize the know-how of sustainability and sustainability schemes (Malmodin et al., 2010).

Research attention has been dedicated to sustainability, e-learning and educational tools. The process of long-term education aimed at changing society's attitude towards climate change and reducing the resulting environmental burden is often underestimated. A typical example is waste management, which directly and indirectly affects the environment, producing pollutants, deteriorating public health and raising questions about the circular economy and the transition to more renewable energy technologies (Pappas et al., 2022). Knowledge management systems and processes, including knowledge capturing, knowledge creation, knowledge transferring, and knowledge reusing, are crucial in accomplishing ICT utilization tools, like sensors, decision support systems and semantic technologies toward green economic, social and environmental perceptions (Malmodin et al., 2010; Hamad, 2018).

Dissemination activities and actions plans against climate change include the engagement of people and societies in every aspect. Alexandru et al. (2013) describe the efforts of students to participate in activities against climate change consequences and combine a strategic approach toward this goal from various disciplines and scientific perspectives (McNeil 2011; Alexandru et al., 2013; Klimova 2018). Geospatial ICT, climate planning, policies, and green infrastructure, among others, are discussed as critical players in sustainable urban transition in the last most cited paper that revealed this bibliographic research (Collier et al., 2013).

Climate change and extreme weather phenomena affect the whole spectrum of agricultural production and agricultural practices. Climate change affects the productivity of agriculture with a wide range of factors such as meteorological conditions, the emergence of pests and diseases, and the adaptability of crop varieties. Minimizing the effects of climate change can be reversed by integrating digital technologies and data innovation. The advent of smart farming and loT can transform the agriculture domain.

Studies on the interactions and the links between climate change and the Internet and communication technology have broadly connected innovation in the agricultural sector to battle climate change impacts. Keywords like agriculture, ICT, global warming, and environmental impact are rotated around the digital transformation of the agricultural sector and the usage of ICT applications to minimize exploitation of natural resources and maximize usage of renewable energy resources (Wolfert et al., 2017; Moysiadis et al., 2021). Smart farming will maintain the sustainability of agriculture and will continue to support it. In addition, ICT services such as Big Data, Cloud Computing, Image Processing, Machine Learning, Artificial Intelligence, Unmanned Aerial Vehicles and Wireless Communication Networks will be integrated into the entire production's infrastructure and support agronomists' decision-making. In addition, complete solutions that combine crops, livestock and forestry, along with the weather forecasts, promise to reduce overall production costs and greenhouse gas (GHG) missions (Wolfert et al., 2017; Moysiadis et al., 2021).

The agricultural sector has a significant contribution to global warming through the production of greenhouse gases. ICT applications and technological innovations are applied to manage produced data from the digital transformation of agricultural practices. For instance, RFID and blockchain technology contribute to collecting and circulating critical information on the production, processing, and storage of products in the agri-food sector while elevating these products' quality and simultaneously enhancing traceability (Singh et al., 2015; Kamilaris et al., 2016; Tian, 2016; Wolfert et al., 2017; Braun et al., 2018).

Another sector that is very intensely involved in climate change through increased greenhouse gas emissions is the transport sector, which in Europe is the second-largest emitter of greenhouse gases. Aiming at the sector's decarbonization, Internet and communication technologies and digital innovation play an essential role in integrating clean technologies and the proper energy management (Madurai Elavarasan et al., 2022). For example, heating and cooling systems management, automation power consumption, circuit management automation, industrial energy optimization with

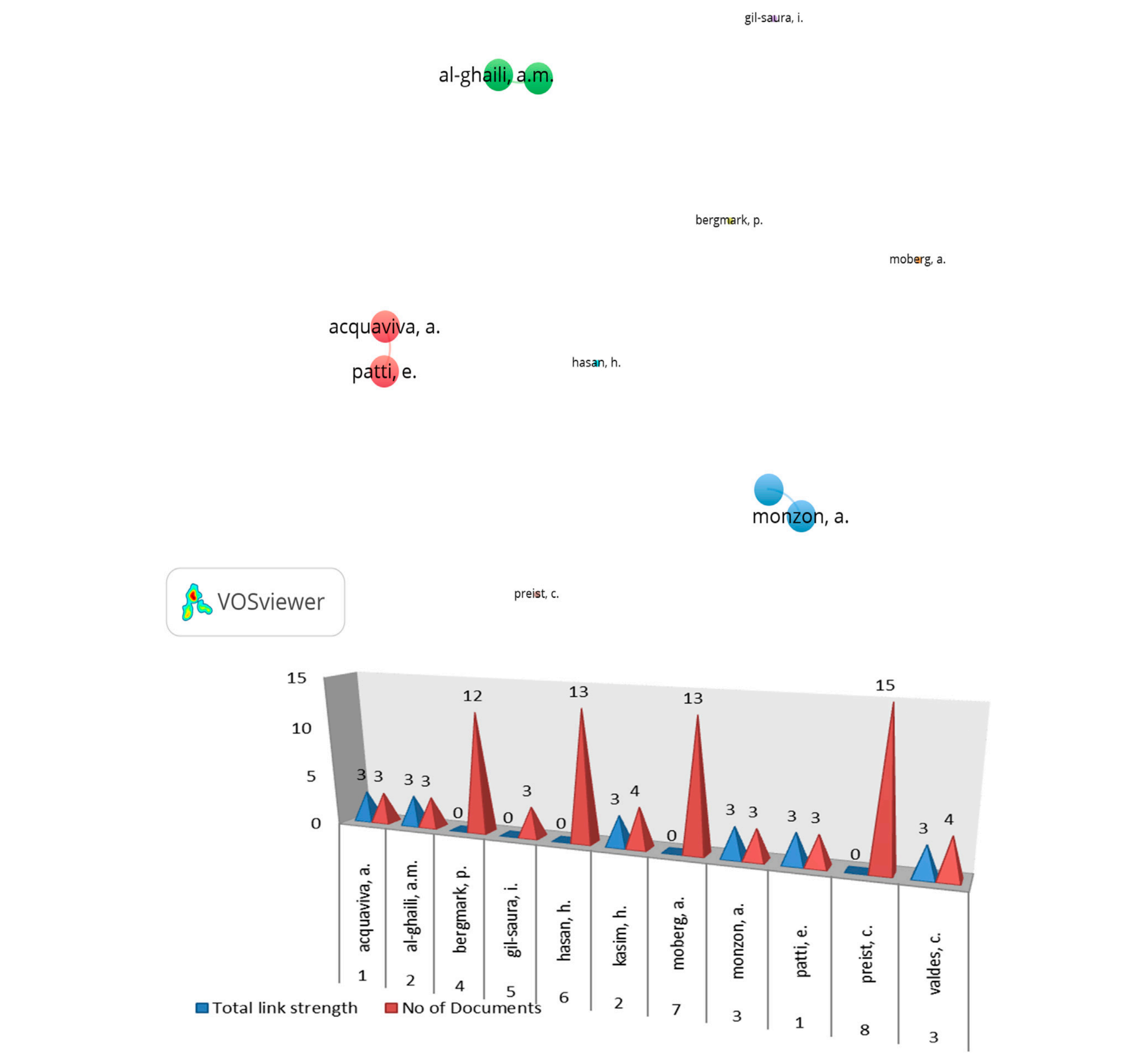

FIGURE 4 | Network of authors, number of documents and total link strength.

sensors, artificial intelligence in reducing energy consumption in aviation, shipping and vehicle industry and innovative home applications, energy calculation in the building construction industry, are some of the solutions offered by ICT and digitalization in energy consumption (Madurai Elavarasan et al., 2022). Needless to say that this is realized through the generation and analysis of produced data and taken into account in energy planning and monitoring, smart-city and smart building energy management and energy savings, industrial energy management and smart energy management strategies and energy demand forecasting. Circularity and connectivity coordinate with sustainability and climate-friendly actions (Kim, 2018; Andersson and Eidenskog, 2020; Ahmad and Zhang, 2021).

Against this background, ICT, energy and sustainable development dictated the research evolution in the last decade in this field, and researchers' respective interests have been increased. Experts and policymakers in the E.U. notably design actions-plans to confront challenges from the growing population, energy demand, and climate change (Koliouska and Andreopoulou 2020). Today, more than ever, digital innovations strive to unite sustainability and natural resource management through circular economy projects. Circular economy and respective ICT tools are

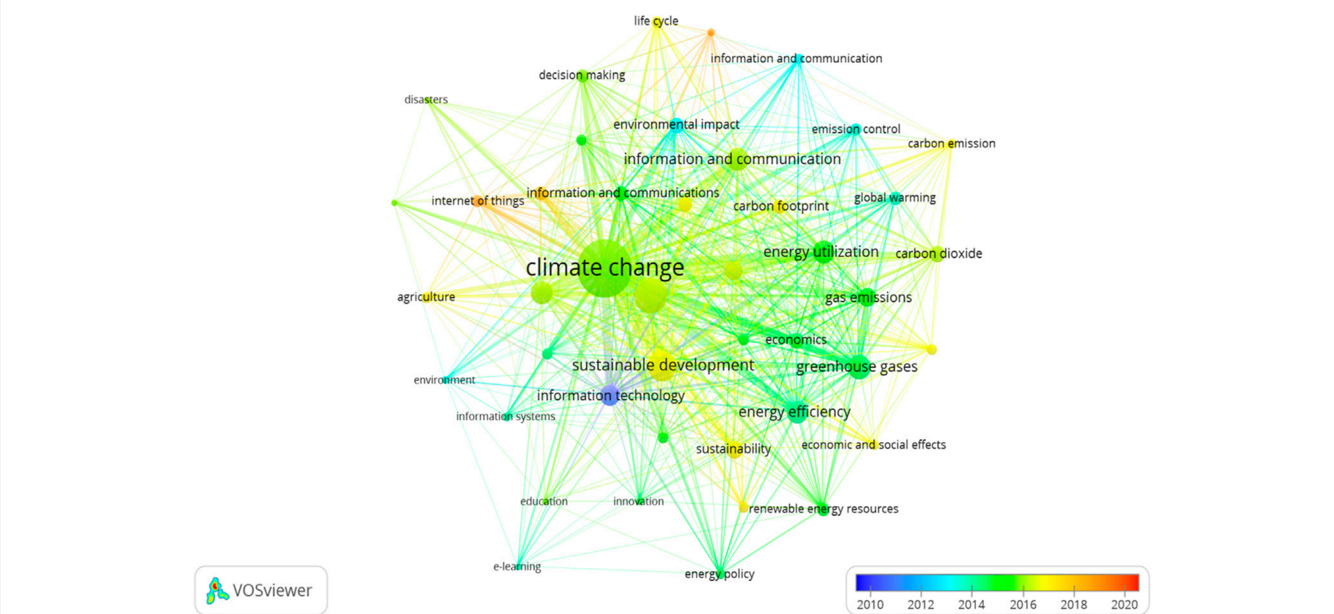

FIGURE 5 | Evolution of research on ICT in climate change over time.

related to life-cycle product costing, impact assessments and circularity measurements inside firms and organizations. In addition, new business models of circular economy favour big data management, artificial intelligence, machine learning, and blockchain technology. These models lead to the new value creation of products and services through digitalization with minimum environmental impact (Chauhan et al., 2022).

Moreover, adopting ICT products and tools can act as a unit of measurement between developing and developed countries in climate change mitigation. This research showed that India is the only developing country among the top five most productive countries in this research field. In this vein, developing countries need to support the establishment and deployment of ICT infrastructures and tools to tackle climate change impacts and promote the transformation of their economy (Hilty 2008; Mohamed et al., 2010; Andreopoulou et al., 2014).

In addition, seen from the viewpoint of research orientation among the top-cited articles, the manuscript from Viitanen and Kingston (2014) called for a critical evaluation of the smart city concept, the role of the private digital firms and whether this leads to a limited and vague perception of citizens regarding green growth (Viitanen and Kingston 2014).

The effects of climate change on public health are multidimensional and multifaceted. The intensity, frequency and magnitude of natural disasters resulting from climate change and environmental degradation also affect the health profile of people. By recording climatic factors such as extreme weather events, which affect the anthropogenic environment, affecting human risk and vulnerability, various ways of burdening public health are finally emerging. Some examples are diseases related to the deterioration of air quality, epidemics of contamination of aquatic ecosystems, cardiovascular diseases from extreme temperatures, mental disorders and many others (Crimmins et al., 2016).

Furthermore, the research topic of the second most cited study was focused on a clinical issue related to climate change, allergies. Weather phenomena, atmospheric disturbances, and environmental factors related to climate change are expected to influence the prevalence of allergic diseases and alter public health issues and policies (D'amato et al., 2007; Ayres et al., 2009; Haahtela 2009; Bousquet et al., 2015). It is recognized that urbanization contributes to air pollution and climate change, affecting air quality. Air pollution is severe in developed and developing countries and translates into premature deaths, 9 out of 10 recorded in low- and middle-income countries, cardiovascular and respiratory diseases. For instance, in 2016, 4 out of 10 Americans lived in environments with sub-standard air quality levels[5] (Balogun et al., 2021).

The paper of Malmodin et al. (2010) highlighted a distinct argument about the contribution of ICT products to the entertainment and media sector in greenhouse gas emissions. However, this study did not consider the capabilities of ICT solutions to mitigate climate change impacts (Malmodin et al., 2010). A more detailed analysis regarding the energy consumption of ICT products and the potential carbon footprint of data centres in Europe was conducted by Avgerinou et al. (2017). This study highlighted the positive correlation between the incremental production of ICT products for communication that generates data to be managed and the energy consumption of data centres. A

[5]https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (Last accessed 15/04/2022).

declined trend in energy consumption was also observed, and overall, the authors underlined the key policies to be adopted from the ICT sector to develop and advance energy efficiency in data centres (Avgerinou et al., 2017). Although the digitization and use of ICT contribute positively to economic, social and environmental sustainability, the energy requirements for the production and provision of these digital services need further study, especially when their contribution is considered concerning goals such as the transition to renewables and decarbonization (Freitag et al., 2021; Madurai Elavarasan et al., 2022). Digitalization impacts the energy sector and plays a vital role in energy storage and optimization.

Various ICT applications and solutions for renewable energy sources and their demand and supply management help distribute the generated energy from a small house to transnational energy exchange and trade (Mondejar et al., 2021). On top of that, the term "Green IoT" has appeared in the literature recently. Green IoT aims to minimize greenhouse gases from the Internet of Things, existing IoT devices and services, such as networks, cloud computing and data centres (Benhamaid et al., 2022).

ICT applications are at the forefront of tackling climate change through sophisticated products. Monitoring, predicting and managing the environmental, ecosystem, and anthropogenic inputs provide critical help to countries to adapt, prepare and plan respective policies about the energy sector, agricultural sector, sustainable development, and climate change impacts. Significantly, the energy consumption in cities renders ICT utilization necessary to tackle climate change consequences. Energy efficiency in an urban environment is at the heart of smart cities and the Internet of Things concept of exploiting data and connecting devices through ICT infrastructures (Silva et al., 2018).

CONCLUSION

The present study addresses the bibliometric analysis of ICT regarding the climate change research agenda available in the Scopus database. Four hundred fifteen three documents met the criteria. Most of the articles were classified in Computer Science, Engineering, Environmental and Social Science, Energy and multiple diversified subject areas, highlighting the interdisciplinarity of Internet and Communication Technology diffusion in climate change issues. Subsequently, this bibliometric study allowed visualization of the research trends for the topic mentioned above in the last 22 years. Greenhouse gases, climate change, ICT, agriculture, energy utilization and efficiency, sustainable development and innovation are, among others, topics highly related to climate change and ICT and are an essential focus of global research (Bandh et al., 2021).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CS and EG: Conceptualization, methodology, visualization, investigation, writing- reviewing and editing. KK and AT: Data curation, writing- original draft preparation. EN, CT, YK, ID, CK, CV, EC, and TK: Supervision. EB: Project administration.

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REFERENCES

Ahmad, T., and Zhang, D. (2021). Using the Internet of Things in Smart Energy Systems and Networks. *Sustain. Cities Soc.* 68, 102783. doi:10.1016/J.SCS.2021.102783

Ahmed, E., Yaqoob, I., Hashem, I. A. T., Khan, I., Ahmed, A. I. A., Imran, M., et al. (2017). The Role of Big Data Analytics in Internet of Things. *Comput. Netw.* 129, 459–471. doi:10.1016/J.COMNET.2017.06.013

Alderete, M. V. (2019). Broadband adoption in Latin American countries: does geographic proximity matter? *Problemas del Desarrollo. Rev. Latinoam. Econ.* 50, 67411. doi:10.22201/iiec.20078951e.2019.198.67411

Alexandru, A., Ianculescu, M., Tudora, E., and Bica, O. (2013). ICT Challenges and Issues in Climate Change Education. *Stud. Inf. Control* 22, 349–358. doi:10.24846/v22i4y201310

Andersson, R., and Eidenskog, M. (2020). How Can Digital Building Information Modelling (BIM) Facilitate Climate Transition in Cities? *IOP Conf. Ser. Earth Environ. Sci.* 588, 32002. doi:10.1088/1755-1315/588/3/032002

Andreopoulou, Z., Samathrakis, V., Louca, S., and Viachopoulou, M. (2014). *E-innovation for Sustainable Development of Rural Resources during Global Economic Crisis*. 1466645504th ed. Hershey, PA: IGI Global.

Arredondo-Trapero, F. G., Vázquez-Parra, J. C., and Guerra-Leal, E. M. (2021). Information and Communication Technologies and Their Impact on Competitiveness in Latin America. *J. Technol. Manag. & Innovation* 15, 43–53. doi:10.4067/S0718-27242020000400043

Atitallah, S. B., Driss, M., Boulila, W., and Ghezala, H. B. (2020). Leveraging Deep Learning and IoT Big Data Analytics to Support the Smart Cities Development: Review and Future Directions. *Comput. Sci. Rev.* 38, 100303. doi:10.1016/J.COSREV.2020.100303

Avgerinou, M., Bertoldi, P., and Castellazzi, L. (2017). Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency. *Energies* 10, 1970. doi:10.3390/en10101470

Ayres, J. G., Forsberg, B., Annesi-Maesano, I., Dey, R., Ebi, K. L., Helms, P. J., et al. (2009). Climate Change and Respiratory Disease: European Respiratory Society Position Statement. *Eur. Respir. J.* 34, 295–302. doi:10.1183/09031936.00003409

Ballantyne, A. G., Wibeck, V., and Neset, T-S. (2016). Images of Climate Change – a Pilot Study of Young People's Perceptions of ICT-Based Climate Visualization. *Clim. Change* 134, 73–85. doi:10.1007/s10584-015-1533-9

Balogun, A. L., Marks, D., Sharma, R., Shekhar, H., Balmes, C., Maheng, D., et al. (2020). Assessing the Potentials of Digitalization as a Tool for Climate Change Adaptation and Sustainable Development in Urban Centres. *Sustain. Cities Soc.* 53, 101888. doi:10.1016/J.SCS.2019.101888

Balogun, A. L., Tella, A., Baloo, L., and Adebisi, N. (2021). A Review of the Inter-correlation of Climate Change, Air Pollution and Urban Sustainability Using Novel Machine Learning Algorithms and Spatial Information Science. *Urban Clim.* 40, 100989. doi:10.1016/J.UCLIM.2021.100989

Bandh, S. A., Shafi, S., Peerzada, M., Rehman, T., Bashir, S., Shahid, A., et al. (2021). Multidimensional Analysis of Global Climate Change: a Review. *Environ. Sci. Pollut. Res.* 28, 24872–24888. doi:10.1007/s11356-021-13139-7

Benhamaid, S., Bouabdallah, A., and Lakhlef, H. (2022). Recent Advances in Energy Management for Green-IoT: An Up-To-Date and Comprehensive Survey. *J. Netw. Comput. Appl.* 198, 103257. doi:10.1016/J.JNCA.2021.103257

Bertoglio, R., Corbo, C., Renga, F. M., and Matteucci, M. (2021). The Digital Agricultural Revolution: a Bibliometric Analysis Literature Review. *IEEE Access* 9, 134762–134782. doi:10.1109/ACCESS.2021.3115258

Bousquet, J., Schunemann, H. J., Fonseca, J., Samolinski, B., Bachert, C., Canonica, G. W., et al. (2015). MACVIA-ARIA Sentinel NetworK for Allergic rhinitis(MASK-Rhinitis): the New Generation Guidelineimplementation. *Allergy* 70, 1372–1392. doi:10.1111/all.12686

Braun, A. T., Colangelo, E., and Steckel, T. (2018). Farming in the Era of Industrie 4.0. *Procedia CIRP* 72, 979–984. doi:10.1016/J.PROCIR.2018.03.176

Chauhan, C., Parida, V., and Dhir, A. (2022). Linking Circular Economy and Digitalisation Technologies: A Systematic Literature Review of Past Achievements and Future Promises. *Technol. Forecast. Soc. Change* 177, 121508. doi:10.1016/J.TECHFORE.2022.121508

Cheng, Y. L., Lim, M. H., and Hui, K. H. (2022). Impact of Internet of Things Paradigm towards Energy Consumption Prediction: A Systematic Literature Review. *Sustain. Cities Soc.* 78, 103624. doi:10.1016/J.SCS.2021.103624

Collier, M. J., Nedović-Budić, Z., Aerts, J., Connop, S., Foley, D., Foley, K., et al. (2013). Transitioning to Resilience and Sustainability in Urban Communities. *Cities* 32, S21–S28. doi:10.1016/J.CITIES.2013.03.010

Crimmins, A., Balbus, J., Gamble, J. L., Beard, C. B., Bell, J. E., Dodgen, D., et al. (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. doi:10.7930/J0R49NQX

Darko, A., Chan, A. P., Adabre, M. A., Edwards, D. J., Hosseini, M. R., Ameyaw, E. E., et al. (2020). Artificial Intelligence in the AEC Industry: Scientometric Analysis and Visualization of Research Activities. *Autom. Constr.* 112, 103081.

D'amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., et al. (2007). Allergenic Pollen and Pollen Allergy in Europe. *Allergy* 62, 976–990. doi:10.1111/j.1398-9995.2007.01393.x

Djalante, R. (2019). Key Assessments from the IPCC Special Report on Global Warming of 1.5 °C and the Implications for the Sendai Framework for Disaster Risk Reduction. *Prog. Disaster Sci.* 1, 100001. doi:10.1016/J.PDISAS.2019.100001

Einecker, R., and Kirby, A. (2020). Climate Change: A Bibliometric Study of Adaptation, Mitigation and Resilience. *Sustainability* 12, 6935. doi:10.3390/su12176935

El Bilali, H., and Allahyari, M. S. (2018). Transition towards Sustainability in Agriculture and Food Systems: Role of Information and Communication Technologies. *Inf. Process. Agric.* 5, 456–464. doi:10.1016/j.inpa.2018.06.006

Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Bilir, T. E., et al. (2014). *Summary for Policymakers: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf.

Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., and Friday, A. (2021). The Real Climate and Transformative Impact of ICT: A Critique of Estimates, Trends, and Regulations. *Patterns* 2, 100340. doi:10.1016/J.PATTER.2021.100340

Galperin, H. (2017). Why Are Half of Latin Americans Not Online? A Four-Country Study of Reasons for Internet Non-adoption. *Int. J. Commun.* 11, 23.

Gangopadhyay, P. K., Khatri-Chhetri, A., Shirsath, P. B., and Aggarwal, P. K. (2019). Spatial Targeting of ICT-Based Weather and Agro-Advisory Services for Climate Risk Management in Agriculture. *Clim. Change* 154, 241–256. doi:10.1007/s10584-019-02426-5

Gill, S. S., Tuli, S., Xu, M., Singh, I., Singh, K. V., Lindsay, D., et al. (2019). Transformative Effects of IoT, Blockchain and Artificial Intelligence on Cloud Computing: Evolution, Vision, Trends and Open Challenges. *Internet Things* 8, 100118. doi:10.1016/J.IOT.2019.100118

Goel, R. K., and Vishnoi, S. (2022). Urbanization and Sustainable Development for Inclusiveness Using ICTs. *Telecommun. Policy* 46, 102311. doi:10.1016/J.TELPOL.2022.102311

Haahtela, T. (2009). Allergy Is Rare where Butterflies Flourish in a Biodiverse Environment. *Allergy* 64, 1799–1803. doi:10.1111/j.1398-9995.2009.02246.x

Hamad, W. B. (2018). The Role of ICT in Knowledge Management Processes: A Review. *Int. J. Eng. Sci. Comput.* 8, 16373–16380.

Haunschild, R., Bornmann, L., and Marx, W. (2016). Climate Change Research in View of Bibliometrics. *PLOS ONE* 11, e0160393. doi:10.1371/journal.pone.0160393

Hilty, L. M. (2008). *Information Technology and Sustainability : Essays on the Relationship between ICT and Sustainable Development*. 9783837019th ed. Norderstedt [Germany: Books on Demand GmbH.

Hou, Y., and Wang, Q. (2021). A Bibliometric Study about Energy, Environment, and Climate Change. *Environ. Sci. Pollut. Res.* 28, 34187–34199. doi:10.1007/s11356-021-14059-2

Jasiūnas, J., Lund, P. D., and Mikkola, J. (2021). Energy System Resilience – A Review. *Renew. Sustain. Energy Rev.* 150, 111476. doi:10.1016/J.RSER.2021.111476

Jolex, A., and Tufa, A. (2022). The Effect of ICT Use on the Profitability of Young Agripreneurs in Malawi. *Sustainability* 14, 2536. doi:10.3390/su14052536

Kamilaris, A., Gao, F., Prenafeta-Boldú, F. X., and Ali, M. I. (2016). "Agri-IoT: A Semantic Framework for Internet of Things-Enabled Smart Farming Applications; Agri-IoT: A Semantic Framework for Internet of Things-Enabled Smart Farming Applications," in Proceeding of the IEEE 3rd World Forum on Internet of Things (WF-IoT), Reston, VA, USA, Dec. 2016 (IEEE). doi:10.1109/WF-IoT.2016.7845467

Keith Dickerson, D., Jean-Manuel Canet, J. S., and Cristina Bueti, A. V. (2010). *Using Icts TO TACKLE CLIMATE CHANGE*. Available at: https://www.itu.int/dms_pub/itu-t/oth/4B/01/T4B010000010001PDFE.pdf.

Khan, A., Gupta, S., and Gupta, S. K. (2020). Multi-hazard Disaster Studies: Monitoring, Detection, Recovery, and Management, Based on Emerging Technologies and Optimal Techniques. *Int. J. Disaster Risk Reduct.* 47, 101642. doi:10.1016/J.IJDRR.2020.101642

Kim, K.-G. (2018). "Evolution of Climate Resilience and Low-Carbon Smart City Planning: A Process," in *Urban Book Series*, 1–76. doi:10.1007/978-3-319-59618-1_1

Klimova, A. (2018). "Systematic Literature Review of Using Knowledge Management Systems and Processes in Green ICT and ICT for Greening," in *Technology for Smart Futures*. Editor M. Dastbaz (Cham): Springer), 329–344. doi:10.1007/978-3-319-60137-3_16

Koliouska, C., and Andreopoulou, Z. (2020). A Multicriteria Approach for Assessing the Impact of ICT on EU Sustainable Regional Policy. *Sustainability* 12, 4869. doi:10.3390/su12124869

Kunkel, S., and Tyfield, D. (2021). Digitalisation, Sustainable Industrialisation and Digital Rebound – Asking the Right Questions for a Strategic Research Agenda. *Energy Res. Soc. Sci.* 82, 102295. doi:10.1016/J.ERSS.2021.102295

Lee, W.-J., and Mwebaza, R. (2022). Digitalization to Achieve Technology Innovation in Climate Technology Transfer. *Sustainability* 14, 63. doi:10.3390/su14010063

Leroux, C. G., Zo, H., and Rho, J. J. (2008). "Factors Affecting Internet Adoption in Latin America," in Proceeding of the 2008 Third International Conference on Convergence and Hybrid Information Technology, Busan, Korea (South), Nov. 2008 (IEEE). doi:10.1109/ICCIT.2008.386

Madurai Elavarasan, R., Pugazhendhi, R., Irfan, M., Mihet-Popa, L., Khan, I. A., and Campana, P. E. (2022). State-of-the-art Sustainable Approaches for Deeper Decarbonization in Europe – an Endowment to Climate Neutral Vision. *Renew. Sustain. Energy Rev.* 159, 112204. doi:10.1016/J.RSER.2022.112204

Majeed, U., Khan, L. U., Yaqoob, I., Kazmi, S. M. A., Salah, K., and Hong, C. S. (2021). Blockchain for IoT-Based Smart Cities: Recent Advances, Requirements, and Future Challenges. *J. Netw. Comput. Appl.* 181, 103007. doi:10.1016/J.JNCA.2021.103007

Malmodin, J., Moberg, Å., Lundén, D., Finnveden, G., and Lövehagen, N. (2010). Research and Analysis: Greenhouse Gas Emissions and Operational Electricity Use in the ICT and Entertainment & Media Sectors. *J. Industrial Ecology:Special Issue Environ. Appl. Inf. Commun. Technol.* 14, 770–790. doi:10.1111/j.1530-9290.2010.00278.x

Martín-Martín, A., Orduna-Malea, E., Thelwall, M., and Delgado López-Cózar, E. (2018). Google Scholar, Web of Science, and Scopus: A Systematic Comparison of Citations in 252 Subject Categories. *J. Inf.* 12, 1160–1177. doi:10.1016/j.joi.2018.09.002

McAllister, J. T., Lennertz, L., and Atencio Mojica, Z. (2021). Mapping A Discipline: A Guide to Using VOSviewer for Bibliometric and Visual Analysis. *Sci. Technol. Libr.* 15, 1–30. doi:10.1080/0194262X.2021.1991547

McNeil, R. (2011). Application of Knowledge Management for Sustainable Development in Institutions of Higher Education. *Dalhous. J. Interdiscip. Manag.* 7, 1–13. doi:10.5931/djim.v7i1.82

Mohamed, M., Murray, A., and Mohamed, M. (2010). The Role of Information and Communication Technology (ICT) in Mobilization of Sustainable Development Knowledge: a Quantitative Evaluation. *J. Knowl. Manag.* 14, 744–758. doi:10.1108/13673271011074872

Mondejar, M. E., Avtar, R., Diaz, H. L. B., Dubey, R. K., Esteban, J., Gómez-Morales, A., et al. (2021). Digitalization to Achieve Sustainable Development Goals: Steps towards a Smart Green Planet. *Sci. Total Environ.* 794, 148539. doi:10.1016/J.SCITOTENV.2021.148539

Moysiadis, V., Sarigiannidis, P., Vitsas, V., and Khelifi, A. (2021). Smart Farming in Europe. *Comput. Sci. Rev.* 39, 100345. doi:10.1016/J.COSREV.2020.100345

Munang, R., Nkem, J., and Han, Z. (2013). Using Data Digitalization to Inform Climate Change Adaptation Policy: Informing the Future Using the Present. *Weather Clim. Extrem.* 1, 17–18. doi:10.1016/j.wace.2013.07.001

Niyibizi, A., and Komakech, A. (2013). "Climate Change Mitigation in Developing Countries Using ICT as an Enabling Tool," in *Climate-Smart Technologies*. Editors W. Leal Filho, F. Mannke, R. Mohee, V. Schulte, and D. Surroop (Berlin, Heidelberg: Springer Berlin Heidelberg), 19–32. doi:10.1007/978-3-642-37753-2_2

Pappas, G., Papamichael, I., Zorpas, A., Siegel, J. E., Rutkowski, J., and Politopoulos, K. (2022). Modelling Key Performance Indicators in a Gamified Waste Management Tool. *Modelling* 3, 27–53. doi:10.3390/modelling3010003

Pick, J., Sarkar, A., and Parrish, E. (2021). The Latin American and Caribbean Digital Divide: a Geospatial and Multivariate Analysis. *Inf. Technol. Dev.* 27, 235–262. doi:10.1080/02681102.2020.1805398

Sahil, N., and Sood, S. K. (2021). Bibliometric Monitoring of Research Performance in ICT-Based Disaster Management Literature. *Qual. Quantity* 55, 103–132. doi:10.1007/s11135-020-00991-x

Silva, B. N., Khan, M., and Han, K. (2018). Towards Sustainable Smart Cities: A Review of Trends, Architectures, Components, and Open Challenges in Smart Cities. *Sustain. Cities Soc.* 38, 697–713. doi:10.1016/J.SCS.2018.01.053

Singh, D., Nar, S., and Sharma, R. (2015). "ICT Platform for Climate Change Adaptation in Agriculture," in Proceeding of the 2015 7th International Conference on Communication Systems and Networks (COMSNETS), Bangalore, India, Jan. 2015 (IEEE). doi:10.1109/COMSNETS.2015.7098723

Street, R. B., Buontempo, C., Mysiak, J., Karali, E., Pulquério, M., Murray, V., et al. (2019). How Could Climate Services Support Disaster Risk Reduction in the 21st Century. *Int. J. Disaster Risk Reduct.* 34, 28–33. doi:10.1016/J.IJDRR.2018.12.001

Talari, G., Cummins, E., McNamara, C., and O'Brien, J. (2021). State of the Art Review of Big Data and Web-Based Decision Support Systems (DSS) for Food Safety Risk Assessment with Respect to Climate Change. *Trends Food Sci. Technol.* doi:10.1016/J.TIFS.2021.08.032

Tian, F. (2016). "An Agri-Food Supply Chain Traceability System for China Based on RFID Amp; Blockchain Technology," in Proceeding of the 2016 13th International Conference on Service Systems and Service Management (ICSSSM), Kunming, June 2016 (IEEE), 1–6. doi:10.1109/ICSSSM.2016.7538424

Tongia, R., Subrahmanian, E., and Arunachalam, V. (2005). *Information and Communications Technology for Sustainable Development: Defining a Global Research Agenda*. Bangalore: Allied Publishers. Available at: https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=822313.

Touray, A., Salminen, A., and Mursu, A. (2013). *The Electronic Journal of Information Systems in Developing Countries ICT BARRIERS and CRITICAL SUCCESS FACTORS IN DEVELOPING COUNTRIES*. Available at: www.ejisdc.org.

Tuheirwe-Mukasa, D., Haveraaen, M., Sansa-Otim, J., Kanagwa, B., and Mujuni, G. R. (2019). "*The Efficacy of ICT in Weather Forecast Information Dissemination: Evidence from Farming Communities in Mbale and Rakai Districts, Uganda BT - Agriculture and Ecosystem Resilience in Sub Saharan Africa: Livelihood Pathways under Changing Climate*," in, eds. Y. Bamutaze, S. Kyamanywa, B. R. Singh, G. Nabanoga, and R. Lal (Cham: Springer International Publishing), 571–593. doi:10.1007/978-3-030-12974-3_25

Viitanen, J., and Kingston, R. (2014). Smart Cities and Green Growth: Outsourcing Democratic and Environmental Resilience to the Global Technology Sector. *Environ. Plan. A Econ. Space* 46, 803–819. doi:10.1068/a46242

Wang, B., Pan, S-Y., Ke, R-Y., Wang, K., and Wei, Y-M. (2014). An Overview of Climate Change Vulnerability: a Bibliometric Analysis Based on Web of Science Database. *Nat. Hazards* 74, 1649–1666. doi:10.1007/s11069-014-1260-y

Wolfert, S., Ge, L., Verdouw, C., and Bogaardt, M.-J. (2017). Big Data in Smart Farming – a Review. *Agric. Syst.* 153, 69–80. doi:10.1016/j.agsy.2017.01.023

Yataganbaba, A., and Kurtbaş, I. (2016). A Scientific Approach with Bibliometric Analysis Related to Brick and Tile Drying: A Review. *Renew. Sustain. Energy Rev.* 59, 206–224. doi:10.1016/J.RSER.2015.12.357

Zaung Nau, S., and Marinova, D. (2020). "A Bibliometric Analysis-Based Review on Green IT," in *Sustainability Awareness and Green Information Technologies*, ed. I. P. Issa Tomayessand Issa (Cham: Springer International Publishing), 239–256. doi:10.1007/978-3-030-47975-6_10

Zhang, C., Khan, I., Dagar, V., Saeed, A., and Zafar, M. W. (2022). Environmental Impact of Information and Communication Technology: Unveiling the Role of Education in Developing Countries. *Technol. Forecast. Soc. Change* 178, 121570. doi:10.1016/J.TECHFORE.2022.121570

Zhao, X., Zuo, J., Wu, G., and Huang, C. (2019). A Bibliometric Review of Green Building Research 2000–2016. *Archit. Sci. Rev.* 62 (1), 74–88.

Zuccaro, G., Leone, M. F., and Martucci, C. (2020). Future Research and Innovation Priorities in the Field of Natural Hazards, Disaster Risk Reduction, Disaster Risk Management and Climate Change Adaptation: a Shared Vision from the ESPREssO Project. *Int. J. Disaster Risk Reduct.* 51, 101783. doi:10.1016/J.IJDRR.2020.101783

Zyoud, S. H., and Fuchs-Hanusch, D. (2019). Mapping of Climate Change Research in the Arab World: a Bibliometric Analysis. *Environ. Sci. Pollut. Res.* 27, 3523–3540. doi:10.1007/s11356-019-07100-y

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