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The Link Between Innovation, Digitalization and the Energy Sector – a Bibliometric Analysis

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Abstract
Innovation is a key driver of the energy transition cycle nowadays and will help countries in achieving climate targets and in the fight towards decarbonization in the energy sector. At the same time, through energy conservation and involvement in flexible demand processes, digitalization benefits consumers by reducing energy bills for people and companies. The purpose of this paper is to provide a review of the evolution of existing research on the relationship between innovation, digitalization and the energy sector using bibliometric techniques. Therefore, more than 1,400 articles published after 2000 and indexed in the Web of Science database were analyzed. The research will be aiming to tackle the keywords and citations connected with the research area mentioned above, to study their spread over time and to relate them with various events that might have triggered a change in focus or interest for academia. Moreover, it will provide as being valuable to analyze a geographical spread of the papers related to author's affiliation as to observe in time the spread of knowledge for this subject in the world. This work can be valuable to researchers, academia and professionals interested in the topic being studied, helping to find new avenues for study beginning from a scientific literature review which is done in this paper.

Keywords: Innovation, Digitalisation, Energy Sector, Bibliometric Analysis, Keywords Map, VOSviewer

JEL classification: C88, M21, Q49.

1. Introduction

An early provider and user of emerging technologies was the energy market. Power utilities were technical leaders in the 1970s, to make network management and service simpler by using the new technologies available in those years. Since long times ago, companies that were into petroleum or gas industries have used emerging technology to enhance decision-making since research and development assets appeared such as pipelines and reservoirs. For decades, process controls and automation have been used by industry to maximize efficiency and yields while minimizing energy usage, particularly in the heavy industry. Digital technology is being used by intelligent transport networks to improve safety, reliability and efficiency in any mode of transport.

Digital technologies are everywhere and affect our way of living, working, or traveling, conducting our day to day activities. Digitization helps push worldwide energy systems and grids with efficiency, competitiveness, transparency and sustainability Nevertheless, it also raises new risks to security and privacy and disrupts economies, businesses and employees. Moreover, digital technology would increase interconnection, intelligence, performance, reliability and sustainability of energy systems around the world in the coming decades. Numerous emerging digital innovations, such as smart devices, automation and 3D printing, allow for amazing technical developments in analytics and communication. In the future, digitized energy grids are going to decide who needs electricity and who can generate it in the right place and time, with the lowest cost. But achieving this will not be very easy.

Digitalization is now improving energy system's efficiency, profitability, accessibility and sustainability. Yet digitalization also poses new challenges to security and privacy. The economies, industries and jobs are also evolving and changing. There are emerging new business models as several centuries old models come out of practice and use. In addition, leaders, managers of various companies and other stakeholders face new and complex, frequently incomplete or imprecise, data sources This challenge is further addressed by the extremely difficult structure of power systems, often based on massive and sustainable infrastructure and physical assets.

Trends in digitalization are absolutely astounding. Data are increasing at an unprecedented pace – in the last 5 years, internet traffic has multiplied 5 times and around 90% of the available data was generated in the last couple of years (IEA, 2020).

Emergent technology is now used at a bigger and wider scale in the energy field, following the rapid implementation of potentially groundbreaking horizon technologies, some of which were mentioned earlier, such as autonomous vehicles, intelligent home systems and innovative manufacturing (e.g. 3D printing). Although these innovations can decrease product-service energy intensity, other rebounding effects may also increase the overall usage of resources. The severity – and related obstacles – of possible impacts varies significantly depending on the specific application.

Therefore, energy security is a condition for the existence of European states, an inalienable and imprescriptible international law, resulting from the law of states on their energy resources and from the European and Euro-Atlantic treaties that must become one of the long-term governance objectives of all Member States in the European Union, and not only in this region. Energy security involves ensuring the necessary energy consumption in terms of accessibility to resources and the availability of long-term access and reserve formulas and procedures in case of emergency, calamity or crisis. Energy security is part of economic security and includes parts of critical energy infrastructure security. Energy security means the geographical diversification of supply, the use of several types of energy, the stability of demand and the predictability of prices.

The digitalization of renewable energies such as solar photovoltaic solar and storage would enable the production of renewable energy resources, provide greater opportunities and enable the storage and selling of surplus energy into the network for producers. New technologies such as blockchain are capable of facilitating peer-to-peer trading within local communities.

The thorough analysis of key energy sectors can show how digital technologies can affect and change employment and skills in the energy sector. Digitalization is expected to lead to improved efficiencies in the supply chain gradually, but substantial job requirements for comprehensive engineering and physical infrastructure building activities are less likely to be replaced. Jobs and activities that contain a significant share of automated work, for example those that include daily routine and repetitive physical exercise and data collection and processing, face a greater risk of automation than those that have less routine work.

All the latest data and reports from various organizations on the digital world, such as the Organisation for Economic Co-operation and Development, show that digital infrastructure employees will need specialized ICT skills such as encryption and information security, while all staff will need general ICT experience in the management of emerging technology in the energy sector. Complementary "soft" skills such as organizational skills, communication skills and collaboration skills are more and more important for ICT-enabled collaborative work with increased opportunities.

Digitalization's pace and scale and its effect on jobs in the energy sector remains highly unpredictable and depends on a variety of variables, which differ in regional, national and industrial contexts. Energy policy makers should be involved and respond to these impacts in wider government-to-government consultations (e.g. consultations that can happen at the

European Union's level or in between smaller regional players). The academia is expected to research more in this field while the knowledge in broadening and diversifying.

2. Literature Review

The digital infrastructure is sometimes referred to as the Fourth Industrial Revolution and will be the key component of the future smart grid. It will allow for the integration of renewable energy projects into the grid, selling their output either to local utilities or to corporate customers through a Power Purchase Agreement (PPA). Some of the most important, but least seen, advances of recent years have been the introduction of smart sensors to virtually any piece of equipment that uses or produces electricity. Such sensors upload information, providing an "Internet of Things" (IoT) that enables operators to see how different projects or pieces of equipment work, when they require repair – allowing issues to be resolved before they arise – and warnings when they do malfunction.

Grid operators can also, on a larger scale, improve network efficiency and incorporate more distributed and decentralized resources, which is the increased control provided by increasing transparency in the vast amount of data that becomes available. For example, when combined with developments in energy storage technologies, wind and solar have the ability to be drawn upon intermittently – and thus more effectively.

All of this data would have been left unanalyzed until recently because we lacked the resources to do so. Yet the emergence of techniques for big data processing, using artificial intelligence and machine learning, enables the knowledge to improve productivity across anything from individual devices to the entire grid. Moreover, the purpose of this article is to determine the existent connections between three concepts – Innovation, Digitalization and the Energy Sector – by studying them, from a academically point of view the articles published on this subject in the most influential journals and authors on this area, using bibliometric analysis.

An impetus for researchers to look for new ways to interpret such vast quantities of knowledge and data has been the plentiful scientific knowledge associated with emerging information technology, giving rise to an emerging discipline: bibliometrics. Bibliometric methods are capable of producing accurate and robust quality measures (Abramo & D'Angelo, 2011; Mimno et al., 2006) that are useful for comparing or classifying broad topics, although they are not appropriate for comparison of individual research (Castillo-Vergara et al., 2018; Merigó et al., 2015; Parida et al., 2018; Rey-Martí et al., 2016). For researchers assessing experimental behavior, this method of study provides valuable knowledge (Mourao & Martinho, 2020; Rey-Martí et al., 2016). A bibliometric analysis analyses bibliographic content from an analytical and quantitative perspective that proves useful in organizing knowledge within a specific field (Casprini et al., 2020; Castillo-Vergara et al., 2018; Modak et al., 2020; Xie et al., 2020); thus, a bibliometric analysis using keywords allows the analysis of data in the main research topics within a domain and micro-level relationships (Chen & Xiao, 2016; Zhang et al., 2020). In addition, it is assumed that attention is paid in bibliometric and scientometric research to the analysis of networks of papers, journals, writers or keywords, and that the mapping and clustering techniques are most commonly used to analyze these networks (Bascur et al., 2020; Waltman et al., 2010).

3. Research Methodology and Data Collection

This paper will be using VOSviewer as bibliometric research method. This is a free access information technology system for the creation and visualization of bibliometric maps (Waltman & Eck, 2012). The key benefit of this program, over other tools used for bibliometric mapping in information technology, is that it focuses on the maps' graphical representations.

This is particularly useful when viewing large maps, making analysis simple, and is primarily used when generating maps based on network data (Cobo et al., 2011; Jeong et al., 2016).

VOSviewer is a computer program for the development, visualization, and exploration of scientific bibliometric maps. The software can be found free of charge at www.vosviewer.com. VOSviewer lets term maps be created. A term map is a two-dimensional map in which the frequency of occurrence of a given word is defined by the size of the label and the distance between two terms can be interpreted as an indication of the relatedness of such terms based on the number of terms co-occurring in the corpus file(Cardona & Sanz, 2015; Castillo-Vergara et al., 2018). Through the software's research it lists countries, frequently cited writers and keywords.

In this respect, there shall be analyzed in this paper articles and reviews written in English published between 2000 and 2018 and indexed in the Web of Science (WoS) database. All the selected papers are examined with regard to the evolution in time of the articles and their dissemination by journals and countries. In addition, the writers and institutions will be presented with perspective on the analyzed subject. Instead, to assess its influence in the scientific literature, a study of the citations obtained by the publications is carried out. A chart of keywords was subsequently created using VOS viewer tools. Finally, the study findings and limitations will be discussed, and recommendations for future research will be given.

4. Data Analysis and Discussions

The purpose of this paper is to establish how the connection between the concept of "innovation" and the "energy sector" is reflected in scientific literature. The concept of "digitalization" was not used in the search as it is a concept being currently studied and not yet much debated in the academic literature, as it is more complex and it will surely develop more in the nearby future. In addition, this paper attempts to define which are the other ideas the two notions associate with and the relations are generated between them (especially in the light of "digitalization"), using the bibliometric techniques as a tool of study.

With regard to data collection for this paper and selection of papers for the bibliometric analysis, these were collected by a keywords search undertaken using the Social Sciences Citation Index (SSCI) database of the ISI - Web of Science (WoS) platform, provided by Clarivate Analytics. WoS database was chosen because of the quality of the information they provide.

The search was performed by the keywords "innovation" and "energy sector", using the "and" connector between them. The two keywords were searched by "Topic" section of the WoS database (includes searches in the following fields within a record: title, abstract, author keywords, and Keywords Plus). Moreover, the search was limited to the period 2000 and 2018.

According to these criteria, 1,922 articles were obtained. The search was refined by two options: document type – "article" or "review" and language – English. This filtering process reduced the number of articles from 1,922 to 1,480 (document type) and finally to 1,432 (language). Therefore, it was obtained a list of 1,432 documents that have innovation and energy sector in title, abstract or keywords from the period 2000 to 2018.

After the collection of papers and the review of the scientific literature (Castillo-Vergara et al., 2018; Gora, 2019), three forms of research were carried out with the aid of all 1,432 selected documents:

1. Analysis of the selected papers (the papers distributions by years and countries, topmost productive journals, top institutions and authors with contributions related to the subject, and papers' distribution according to research areas);

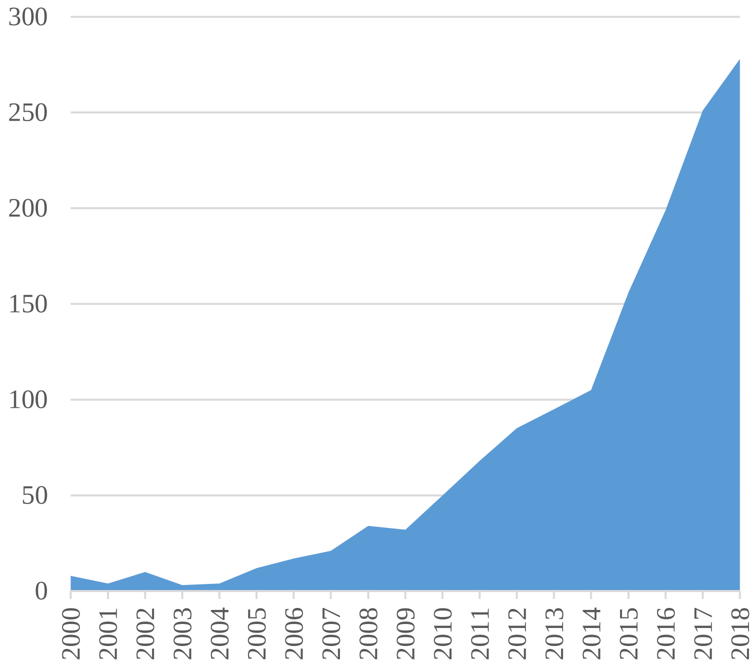
2. Analysis of the number of citations received by the selected papers (topmost cited scientific papers);

3. Keywords' analysis (including occurrence, links' strength and a keywords' map).

Therefore, considering these three forms of research planned to be carried out in this article, the data analysis and the findings obtained are discussed in the following sections.

4.1. Analysis of the selected papers

The research period 2000-2018 evolution of publications over time is presented in Figure 1where a steady rise in the number of publications can be seen over the last 5 years, and is continuously increasing. During the entire analyzed timespan, the number of articles and reviews published from one year to another has increased, except for years 2001, 2003 and 2009, in which there were slight decreases compared to the previous year. The year 2018 is the one when most papers were published (278 papers – 19.41% of 1,432 total papers). The smallest number of articles published in a year, more exactly 3 (0.20%) was registered in 2003. Moreover, almost two thirds of the published papers on the analyzed subjects were published between 2014 and 2018 (989 papers – 69.06% of 1,432 total papers).

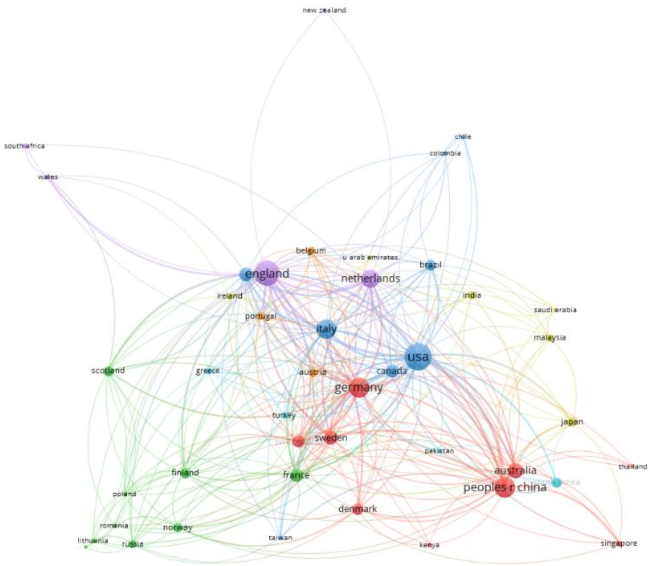


Publication Years	Record Count
2000	8
2001	4
2002	10
2003	3
2004	4
2005	12
2006	17
2007	21
2008	34
2009	32
2010	50
2011	68
2012	85
2013	95
2014	105
2015	156
2016	199
2017	251
2018	278

Figure 1. Published papers per year

Source: Computed by author with the information extracted from WoS, 2020

The country with the most innovation and energy sector related publications is the United States (251), followed by England with 210 papers and China 143 papers. The diagram shown in Figure 2 shows the remaining countries which published articles and reviews on the analyzed topic, and it is important to remember, as the figure shows, that there are some centers for these studies, namely United States, England, China, Germany, Italy and Netherlands.



Countries/Regions	Record Count
USA	251
England	210
Peoples R China	143
Germany	138
Italy	128
Netherlands	113
Australia	75
Sweden	68
Spain	66
Canada	59
France	58
Switzerland	49
Denmark	44
Brazil	39
Finland	36

Figure 2. Distribution of papers by country of authors' affiliation
Source: Computed by author with the information extracted from WoS, 2020

Table 1 presents the major 18 journals which have published scientific papers on the subject of energy and innovation, in the period 2000-2018. These 18 journals have published 48.04% of the 1,432 articles and reviews used in this research. In addition, the 1,432 selected papers have been published in 513 journals with issues related to the subject examined by my research.

Table 1. Topmost 18 productive journals

Source Titles	Record Count	% of 1,432
Energy Policy	181	12.64%
Journal of Cleaner Production	96	6.70%
Renewable Sustainable Energy Reviews	60	4.19%
Technological Forecasting and Social Change	54	3.77%
Sustainability	47	3.28%
Energy Research Social Science	43	3.00%
Energy Economics	31	2.17%
Applied Energy	29	2.03%
Energy	24	1.68%
Research Policy	22	1.54%
Energies	17	1.19%
Renewable Energy	17	1.19%
Ecological Economics	13	0.91%
Climate Policy	12	0.84%
Environmental Innovation and Societal Transitions	11	0.77%
Technology Analysis Strategic Management	11	0.77%
International Journal of Energy Sector Management	10	0.70%
International Journal of Hydrogen Energy	10	0.70%

Source: Computed by author with the information extracted from WoS, 2020

Top authors with contributions related to the topic of energy and innovation are presented in Table 2 (there are 3,605 authors that published papers on this subject and top 10 will be presented in the following Table).

Table 2. Topmost 10 productive authors

Authors	Record Count	% of 1,432
Anadon LD	10	0.70%
Mazzanti M	9	0.63%
Mlecnik E	9	0.63%
Soderholm P	9	0.63%
Bosetti V	8	0.56%
Costantini V	8	0.56%
Hoppe T	8	0.56%
Markard J	8	0.56%
Sovacool BK	8	0.56%
Lin BQ	7	0.49%

Source: Computed by author with the information extracted from WoS, 2020

From Table 2, it can be established that the highest number of individual contributions related to the analyzed topic is 10 articles and 1 author is in the top according to this criteria: Anadon L.D., who is from University of Cambridge – Environmental Energy & Natural Resource Governance, having a H-index of 21 and being cited 1,659 times. This author is followed by other 3, Mazzanti M., Mlecnik E. and Soderholm P., each having 9 written articles on the analyzed subject.

The variety of research areas (64) according to the number of articles published and associated with the search criteria is presented in Figure 3, although an article is able to be classified in several research areas at the same time.

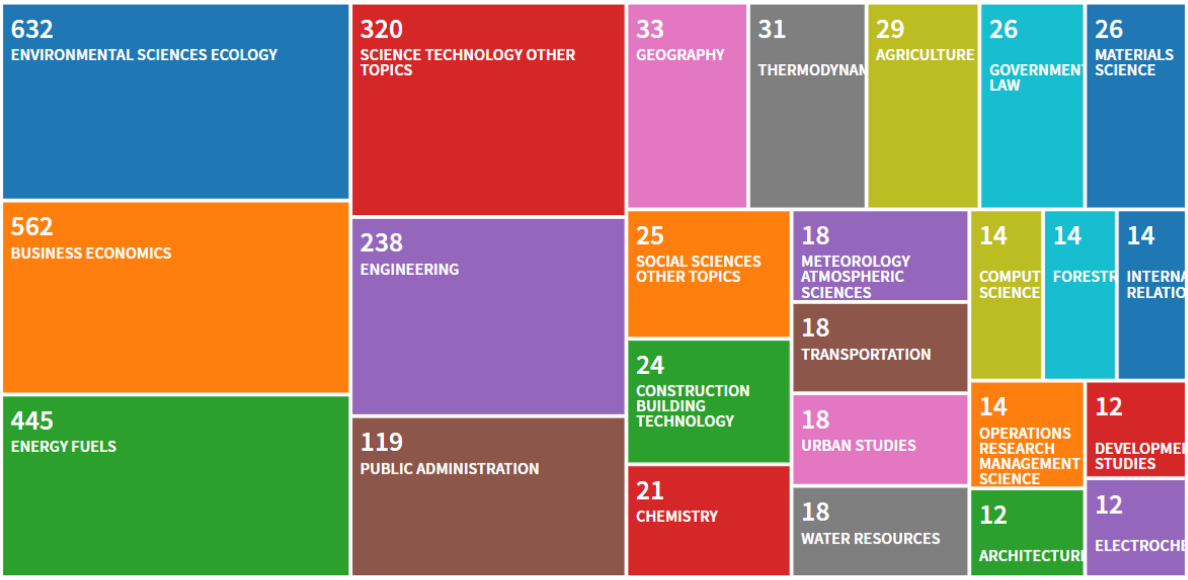


Figure 3. Top 25 research areas on basis of the number of published articles

Source: Computed by author with the information extracted from WoS, 2020

Top 6 research areas, with more than 100 attributions given to then, are: environmental sciences ecology (632 documents), business economics (562 documents), energy fuels (445 documents), science technology other topics (320 documents), engineering (238 documents) and public administration (119 documents).

4.2. Analysis of the Citations

The second analysis conducted in this research is to examine the number of citations obtained by the 1,432 selected articles and reviews the studied timeframe. In this regard, Table

3 presents the Top 10 most cited scientific papers on the topic of the energy and innovation, published in the 2000-2018 period.

Table 3. Topmost 10 cited articles and reviews

Title of the article	Authors	Publication Year	Total Citations 2000-2018	Average Citations per Year
Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges	Smith, Adrian; Voss, Jan-Peter; Grin, John	2010	642	58.36
Transport and climate change: a review	Chapman, Lee	2007	476	34
Environmental and technology policies for climate mitigation	Fischer, Carolyn; Newell, Richard G.	2008	391	30.08
Current options for the valorization of food manufacturing waste: a review	Mirabella, Nadia; Castellani, Valentina; Sala, Serenella	2014	319	45.57
Are agricultural land-use models able to predict changes in land-use intensity?	Lambin, EF; Rounsevell, MDA; Geist, HJ	2000	302	14.38
Tipping Toward Sustainability: Emerging Pathways of Transformation	Westley, Frances; Olsson, Per; Folke, Carl; et al.	2011	297	29.7
Physics at BES-III	Asner, D. M.; Barnes, T.; Bian, J. M.; et al.	2009	265	22.08
Renewable energy from palm oil - innovation on effective utilization of waste	Yusoff, S	2006	252	16.8
Smart manufacturing, manufacturing intelligence and demand-dynamic performance	Davis, Jim; Edgar, Thomas; Porter, James; Bernaden, John; Sarli, Michael	2012	233	25.89
Barriers and stimuli for ecodesign in SMEs	van Hemel, C; Cramer, J	2002	231	12.16

Source: Computed by author with the information extracted from WoS, 2020

Based on the information provided by "Create Citation Report" section of the WoS database, the 1,432 selected articles and reviews for analysis received a total number of 33,931 citations in the period 2000-2018, with an average of 1615.76 citations per year.

Table 3 indicates the cumulative number of citations received for each article from the time of publication until the end of 2018, taking into account the Top 10 of the most cited articles. Therefore it should be noted that the largest number of citations received is 642, belonging to the authors Smith, Adrian, Voss, Jan-Peter and Grin, John (2010), indicating that this article received an average of 58.36 citations per year.

4.3. Keywords' Analysis and Clustering

The last type of analysis conducted in this research applies to a keyword analysis among the 1.432 analyzed documents. All the keywords given by the authors and the keywords plus for each article were used to carry out this review. As described in another review of bibliometric analysis (Dabic et al., 2015; van Eck & Waltman, 2011, 2019), the WoS database automatically extracts a set of "keywords plus" from the titles of the papers that describe the best words that the program recognizes as matching the main theme the paper deals with.

VOSviewer software has been used to conduct the analyze of these keywords and to construct a computational keyword analysis map based on bibliographic data (van Eck & Waltman, 2019). A database with a collection of details about the 1,432 selected articles and reviews was created in advance of this research, with the information given by the WoS database. In this way, information about the name of the writer, article title, abstract, year of publication, keywords listed in each article and other relevant information have been extracted. The information collected from the WoS database was subsequently incorporated into VOSviewer software, which permitted an occurrence review of the keywords found in each analyzed document.

When VOSviewer software launched the extraction of the information contained in the 1,432 papers, it counted a total of 5,606 keywords mentioned in all examined papers, articles and reviews related to the subject of innovation and energy sector. Because of the large number of keywords cumulated from all analyzed papers, a minimum number of occurrences per keyword equivalent to 35 was chosen for the analysis (where occurrence implies the number of documents in which a keyword appears) and 42 keywords were therefore retained for analysis, meeting the threshold. Therefore, Table 4 highlights the 42 keywords sorted by their occurrence, along with the total link strength.

Analyzing Table 3 it can be shown that there are many keywords that appear written in different ways but they refer to the same term, and their clustering will better illustrate their occurrences or the number of papers in which that word is listed as a keyword. In this context, a first group will be made between the words “transition” and “transitions” which indicates that 91 papers include these words in total. The second grouping should be made between “climate change” and “climate-change” terms, which cumulate a total of 95 occurrences.

When evaluating the subject of this paper, it was possible to infer that research focuses on energy sector and innovation within digitalization (something that can be noticed in the keyword map of the analyzed research shown in Table 4 with the use of the word “technology”).

Given the classification mentioned above, it can be observed that the keyword “innovation” of the total of 1,432 selected articles and reviews was found as the keyword in 458 publications, reflecting a percentage of 31.98% of the total number of papers. With regard to the phrase “energy sector” it is noted that it is not written in the list of keywords in this form but segregated as “energy” and “sector”. In this context, it is observed that in 326 articles (22.77% of the total of 1,432 articles) this concept is used as a complete keyword.

Table 4. The keywords’ occurrences and links’ strength

Keyword	Occurrences	Total link strength
Innovation	458	1133
Energy	218	550
Policy	205	661
Renewable energy	162	438
Technology	123	377
Sustainability	116	361
Sector	108	313
Diffusion	105	311
Performance	96	261
Systems	93	306
Energy Efficiency	90	207
Research and Development	88	254
Industry	84	275
China	82	210
Management	81	242
Dynamics	77	264
Framework	72	234

Model	70	177
Impact	67	200
Power	60	172
Climate change	57	154
Governance	55	195
Efficiency	55	163
CO2 emissions	53	124
Transitions	51	184
Technologies	51	170
Consumption	51	149
Growth	51	131
Barriers	50	165
Perspective	45	167
Emissions	42	96
Electricity	41	128
Sustainability transitions	40	142
Innovation systems	40	140
Transition	40	133
Market	39	113
Environment	39	109
System	39	91
Multilevel perspective	38	149
Investment	38	122
Climate-change	38	108
Strategies	37	103

Source: Computed by author with the information extracted from WoS, 2020

The VOS clustering technique, a technique described in depth by various authors (Pan et al., 2018; van Eck & Waltman, 2007; Waltman et al., 2010), was used to move on to mapping keywords and grouping them into clusters. With regard to the VOS clustering strategy, it uses the number of nodes, the relations between them, the total number of relations and the total intensity between them to build the map. Beginning with these elements, the distance from other nodes for each node is determined, and each node is placed in a two-dimensional space (mapping technique). Figure 4 shows the visualization map of the 42 keywords listed in Table 4, related to the explanations given above.

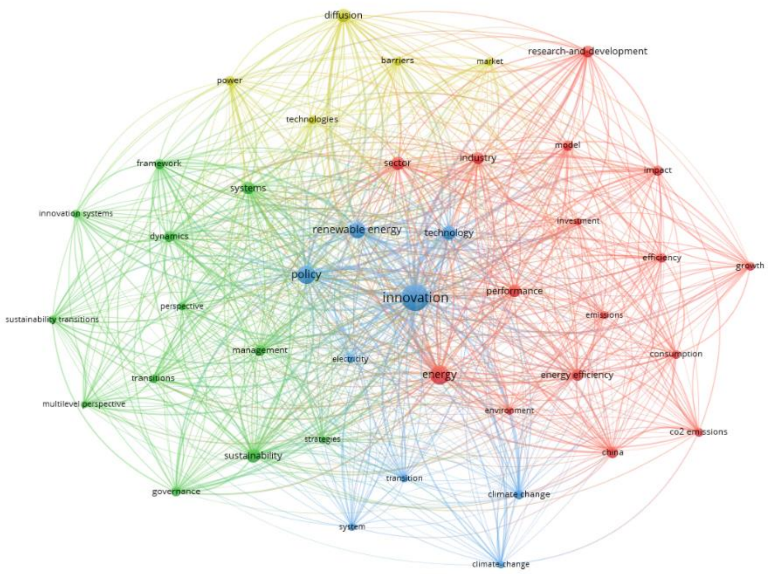


Figure 4. Keywords' map of the selected papers

Source: Computed by author with the information extracted from WoS, 2020

Regarding the clustering of the 42 keywords, Figure 4 reveals that there are 4 clusters outlined by different colors. The information given in Figure 4 shows that there is the largest number of nodes in the red cluster, namely 16, followed by the green cluster with 12 nodes, the blue one with 9 nodes and the smallest number of nodes in a cluster is 5 and can be found in the yellow cluster.

5. Conclusions

This paper, researching the links between innovation, digitalization and energy sector, evaluated and highlighted them using bibliometrics techniques. As can be seen from the section on research methods, 1,432 papers related to the studied subject have been reviewed, articles and reviews published between 2000 and 2018 which have been collected from the Web of Science database. Three types of analyzes are at the center of this analysis, carried out using various methods of research.

This analysis may be useful for researchers and practitioners interested in studying the relationship between the innovation (and also digitalization) and the energy sector. This research also presents the current situation of the work carried out on the subject under investigation and highlights new possibilities for continuing research on this topic, beginning from a bibliometric review of the scientific literature in the area. Further research might be aimed at evaluating innovation and digitalization in the energy sector, measuring it using other sources of data, such as other websites, such as Google Scholar, which contains citations from outlets other than the Web of Science.

About the study limitations, it should be noted that this review is based solely on the knowledge given by a single source, Web of Science, with the possibility of missing important papers relevant to the topic under review. The use of VOSviewer software which does not allow the pooling of information extracted from different other databases to perform keyword analysis has determined another limitation of the study.

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