

Innovation in the electricity sector in the age of Disruptive Technologies and renewable Energy Sources: A Bibliometric study from 1991 to 2019

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Abstract — This article aims to elaborate a bibliometric study about innovation in the electricity sector, in the era of disruptive technologies and renewable energy sources, to describe, quantify and analyze the studied themes, including their evolution, from 1991 to 2019. The following methodological procedures were used: a) definition of keywords and research in the Scopus and Web of Science databases; b) analysis of 159 selected texts, using Iramuteq with the R software statistical interface, for qualitative, quantitative and statistical data processing. As a result, it was possible to observe that innovation in the electricity sector in the world is incipient. In the USA, UK, Australia, China and 31 OECD countries including Brazil, renewable energy sources and technological innovation have found difficulties to make progress. In tightly regulated markets, regulation has yet to find the point and balance that can foster an enabling environment for sectoral technological innovation. The Brazilian electricity sector (SEB) also finds difficulty to innovate, as indicated in the studied literature. It was found that the research gap, which was the absence of bibliometric studies on innovation in the electricity sector in the world and in Brazil, was satisfactorily met.

Keywords — electricity sector; innovation; disruptive technologies.

I. INTRODUCTION

The study of innovation in the electricity sector began to draw attention in the last decade of the twentieth century, when a study on the technological reconversion of the oil refining industry was published, by gasification of heavy refinery waste with electricity generation, generating product and process innovation for both the oil and electricity sectors (Gulli, 1995).

From 1991 to 2010, the publication of literature on the subject remained relatively low, but from 2011 to 2019, scientific production accelerated and advanced rapidly.

In the same period (1991-2019), sector innovation shifted from product and process to companies, institutions, regulation and, more recently, to disruptive technologies, renewable energy sources such as solar photovoltaics, and Distributed Energy Resources (DER). (GVces, 2015; MME/SPE/EPE, 2018).

The type of innovation adopted, albeit incrementally, has shown that investing in new technologies has generated a combination of useful results or directed to both business and the environment. Business has been accounting for economic and financial gains and image

improvement with the consumer (Wiersma, 1991; Gulli, 1995; Fischer & Newell, 2008; Jusoh, 2017; Zhu *et al.*, 2018).

When a product and process innovation occurs in the electric sector, which implies a reduction in the use of fossil fuels for electricity generation, the environment receives a certain relief due to the reduction of greenhouse gas (GHG) emissions, since that GHG is one of the villains of global warming, which is one of the greatest challenges facing humanity today. However, this GHG reduction is still far from the ideal level (Gulli, 1995; Fischer & Newell, 2008; Jusoh, 2017; Zhu *et al.*, 2018).

Faced with the challenge of writing a thesis, whose theme is innovation in the Brazilian electricity sector in the era of disruptive technologies and renewable sources of energy, arose the need for a study that would understand the evolution of the theme in the world over time. After readings and discussions, the convenience of a systematic literature review through a bibliometric research was identified.

The bibliometric study is a quantitative and statistical technique used to measure the production and

dissemination of scientific knowledge that can also be a way of measuring the written communication patterns of the authors of these works. This type of study is recommended when the researcher is facing a large amount of bibliographic material published about the object of his research, as is the case shown (Araújo, 2006; Quevedo-Silva et al., 2016).

Thus, the aim of this paper is to elaborate a bibliometric study about innovation in the electricity sector in the age of disruptive technologies, to describe, quantify and analyze the studied themes, including their evolution from 1991 to 2019.

The justification for the application of bibliometric research in this article is the fact that this method is the most appropriate to present the vast published scientific production, in a summarized and systematized way, over a long period (Quevedo-Silva et al., 2016). The databases defined for this research were: Scopus and Web of Science, from 1991 to 2019, more specifically until June 2019. The choice of these two databases is due to their privileged position in the rankings of scientific publications in the world. The motivation for choosing the period is based on the fact that the 1990s (20th century) was a milestone in the study of business innovation in the world, and in 1991 the first publication (identified by this research) about innovation in the electricity sector occurred.

The contribution of this study is to structure the academic-scientific knowledge, on a global scale, on innovation in the electricity sector in the age of disruptive technologies, published in the Scopus and Web of Science databases, from 1991 to June 2019.

This article is structured in five parts, the first being this brief introduction. The second section presents a literature review involving the main concepts of the study. The third section describes the methodological procedures step by step. The fourth shows the results and the discussion of the bibliometric study. The fifth and last one describes the final considerations about the study accomplished.

II. LITERATURE REVIEW

The literature review presents the concepts of innovation, business model innovation, disruptive technologies (DT) of industry 4.0 (I4.0), Brazilian electricity sector (BES) and technological innovation.

2.1 Concepts

The main concepts that guided this study are presented.

2.1.1 Innovation

The concept of innovation for the purpose of this study followed the Oslo Manual, which is a proposal for guidelines for the collection and interpretation of data on

technological innovation in the scope of countries that are part of the 1997 Organization for Economic Cooperation and Development (OECD). In 2004, the innovation standard advocated by the Oslo Manual was adopted by Brazil as the benchmark for evaluating the technological innovation model at the national level, through an initiative of the Ministry of Science, Technology, Innovation and Communications (MCTIC) and the Financier of Studies and Projects (FINEP) (BRASIL, 2004; OCDE, 2004).

Currently, innovation is divided into three types: a) incremental innovation; b) creative destruction; and c) disruptive innovation.

The first two types were developed by Schumpeter in 1934 and are in the Oslo Manual. In it, incremental innovations are described as those that continually fill the process of change, while radical innovations bring about major changes in the world, the latter being responsible for the concept of creative destruction, coined by the same author (BRASIL, 2004; OCDE, 2004).

The third type of innovation is disruptive innovation, inspired by the concept of creative destruction, disruptive innovation means the transformation of a technology, product or service into something new, simpler, more convenient and affordable, that is, easily accessible and inexpensive (Christensen, 1997).

While disruptive innovation has emerged more than 20 years ago, it has started to build on the literature and the marketplace over the past 10 years, with the advent of start-up businesses in Silicon Valley, California, and within a new conception of business models, companies such as UBER, Netflix and others won over the world.

2.1.2 Innovation in business models

As there is no uniqueness as to the concept of business model, a broader search was necessary, since defining a business model implies on meeting complex organizational structures, that include internal (organizational) and external aspects. External aspects include the sector competitive environment, with potential for value creation for stakeholders, which can be translated into competitive advantage (Chesbrough, 2010; Gambardella & McGahan, 2010; Ostenwalder & Pigneur, 2009; Teece, 2010; Zott, Amit, & Massa, 2011).

Faced with a tangle of concepts that use similar terms, a concept for the theme arrived when Vils *et al.* (2008, p. 315) defined that Business Model “is an instrument by which companies make resources available, using internal and external structures and processes, aiming to create value propositions that solve their clients' existing problems or work”.

From the concept of Business Model, the search for what would be New Business Models began. It was concluded that it was the enterprises that were born using TD from the I.4.0's, some of them based on the sharing of goods and services supported by Information and Communications Technology (ICTs), but that fundamentally alter the traditional business configuration (Prause, 2015; Rifkin, 2012).

2.1.3 Disruptive Technologies (DT) and Industry 4.0 (I.4.0)

Industry 4.0 (I.4.0) is the combination of intelligent machines, production, processes, and systems that form a sophisticated interconnected network that emphasizes the idea of coherence, digitalization, and connection of all productive units in an economy, creating the virtualization of the real world in a large information system (Palma et al., 2017; Prause, 2015).

The first three industrial revolutions (IR) were responsible for mass production, assembly lines, electricity and ICTs, providing economic development never before seen in human history, increasing incomes and technological competition (Rifkin, 2012).

The fourth industrial revolution (FIR) is expected to have an even greater impact on an exponential scale, as it is supported by a set of technologies that allow the fusion of the physical, digital and biological world (ABDI, 2018; Schwab, 2018).

The combination of these technologies led to the transformation of existing products, services and even businesses into something newer, simpler and more affordable, modified by disruptive innovation, which required new business models. This change has reached the electricity sector in various places around the world and now it arrives at the Brazilian electricity sector (SEB).

2.1.4 Structure of the Brazilian Electricity Sector (SEB) and technological innovation

The strategic management of the Brazilian electricity sector is the responsibility of the National Energy Policy Council (CNPE). The Ministry of Mines and Energy (MME) is responsible for implementing the public policies of the sector. The Brazilian Energy Research Office (EPE) elaborates the system expansion planning, while the Electricity Sector Monitoring Committee (CMSE) takes care of the safety of the segment (BRASIL.MME, 2018).

The sector is regulated by the Brazilian Electricity Regulatory Agency (ANEEL), with the participation of the National Water Agency (ANA) and National Agency for Petroleum, Natural Gas and Biofuels (ANP), due to the

overlap caused by the resources involved (BRASIL.MME, 2018).

The technical operation of the electric system, as well as the coordination and control of the electricity generation and transmission facilities in the National Interconnected System (SIN), along with the planning of the operation of the isolated systems in the country, is performed by the Electric System National Operator (ONS), under the supervision and regulation of ANEEL (ONS, 2018).

The actors, agents in the electric system, are those involved in the generation, transmission, distribution, commercialization of energy, free consumers, importers or exporters of energy.

For several decades, the Brazilian electricity sector was dominated by power generation from water sources and maintained a traditional modeling, which highlighted the generation, transmission, distribution and commercialization (ANEEL, 2018).

However, there are signs that the current model has been changing configuration, as shown in the 2027 Ten-Year Energy Expansion Plan (PDE 2027). It predicts that technological advances are impacting the current market structure, which is beginning to change as new players or agents are included in this market segment, which are the independent producers or the energy prosumers¹, through Distributed Generation (DG), focusing on renewable energy sources, mainly solar photovoltaic (MME/EPE, 2018; MME/SPE/EPE, 2018).

The ramifications of these technological advances, together with the prospects for investment in SEB, show a change in the profile of the evolution of each source of electricity from 2018 to 2027, according to PDE 2027, Figure 1.

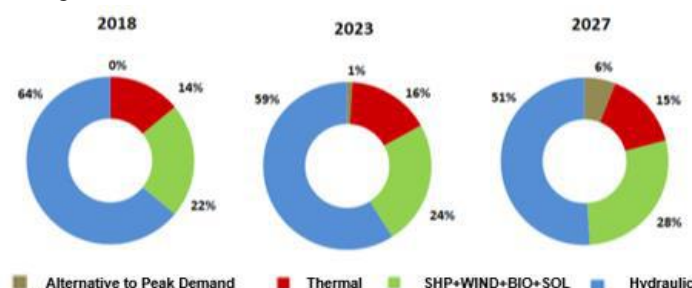


Fig.1: Evolution of the share of electricity sources PDE 2027

Source: Made by the author, based on data from MME/EPE, 2018.

It is noteworthy that, even with the significant drop in the share of water source, the forecast for the participation

¹ Prosumer is a neologism that comes from the combination of producer + consumer or professional + consumer (Rifkin, 2012).

of 80% of clean energy sources in the national electricity matrix is maintained, which is in line with the commitment of the Nationally Determined Contribution (NDC) signed by Brazil for 2030, under the Paris Agreement (MME/EPE, 2018).

Technological innovation in SEB is guided by the Energy Research, Development & Deployment, regulated by ANEEL, which determines that Generation, Transmission and Distribution (GTD) companies should invest at least 1.0% of their Net Operating Revenue (NOR) in the two programs: the R&D Program (R&D) and the Energy Efficiency Program (PEE) (ANEEL, 2018; De Castro *et al.*, 2015).

The R&D program aims to allocate appropriately human and financial resources to projects that demonstrate the originality, applicability, relevance and economic viability of products and services in the processes and end uses of energy. The aim of the PEE is to promote the efficient use of electricity in all sectors of the economy through projects that demonstrate the importance and economic viability of improving the energy efficiency of machines, processes and energy end uses (ANEEL, 2016, 2017).

The implementation of R&D, instituted by Law No. 9.991/2000, is divided into two phases. The first phase was based on Normative Resolutions 502/2001, 219/2006, which regulated the project cycles from 1999 to 2007. In this phase, R\$ 1.536 billion were invested in 4,555 projects, the main results of which were products (model/methodology and software/system), i.e. incremental process innovations accounted for 71% of what was generated, product/prototypes 9% and only 2% of the projects generated patents (Guedes, 2012).

Also in the first phase, these R&D projects also resulted in academic degrees of specialization, master and doctorate, in relation to the projects, in the order of 7%, 33% and 24%, respectively (Guedes, 2012).

The second phase of R&D, which covers the 2008-2017 cycle, regulated by Normative Resolutions 316/2008, 504/2012 and 754/2016, invested R\$ 4.070 billion in 1,643 projects. The PEE regulated by Normative Resolutions 556/2013 and 830/2018, generated 891 projects, with investments of R\$ 4.588 billion, according to ANEEL's project audit report (ANEEL, 2016, 2017). Therefore, the investment values of the two programs in this cycle amount to R\$ 8.658 billion.

III. METHODOLOGICAL PROCEDURES

To achieve the proposed objective, the following methodological procedures were established: definition of the research strategy and download of articles, according

to items “i” to “vii” (described below); qualitative, quantitative and statistical treatment of data using “R” and Iramuteq software, as recommended for bibliometric studies (Quevedo-Silva *et al.*, 2016; Camargo & Justo, 2013).

3.1 Database research, download and data processing

The research in the databases, including search, download and process of the articles obtained, used the following steps:

- i) search arguments: the definition of the keywords for the research was in line with the doctoral thesis project presented to the qualification board, at UnB's CDS: “electricity sector”; “innovation” and “disruptive technologies”;
- ii) database search strategy: the words were translated into English for query purposes: {[(“electricity sector”) AND (“innovation”)] OR (“disruptive technolog?”)};
- iii) refining search adjustment: a) Scopus = “TITLE-ABS-KEY” and Web of Science = “TOPIC”; v) export of the research results of the two databases in extension “.csv”; “.ris” and “.doc”;
- iv) handling of files in Excel sheets, according to the research interest: 242 articles downloaded;
- v) selection of articles to exclude duplicates (71 articles) and those outside the research scope (12 articles): 83 articles excluded;
- vi) research and download of articles defined as research interest: 159 articles;
- vii) inclusion of 159 articles in the Mendeley software;
- viii) reading of the abstracts of all articles.

3.2 Data processing: qualitative, quantitative and statistical

To analyze the 159 selected texts, Iramuteq (*Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires* – in french), a specific software that enables the identification of the context in which the words occur, was used, applying the R software statistical platform. In recent years, Iramuteq has been used as a data processing tool in scientific works and textual materials obtained in various ways, including articles published in journals, because it is free and effective in its results (Camargo & Justo, 2013; Salviati, 2017).

Initially, a database was prepared in Word, called “Corpus Geral”, with 159 texts, originated from the abstract of each article under analysis. In accordance with the Iramuteq method, each article abstract was identified with a title beginning with four asterisks, one space,

another asterisk. Then, the letter A (initial of the word Article) was placed, underline, AUTHOR'S NAME, underline, year of publication of the article. Example: ****
*A_MOORE_2004 (Camargo & Justo, 2013; Salviati, 2017).

The article abstracts were copied and pasted into a Notepad, and all blank lines between the title and abstract or between paragraphs of the abstract were deleted, leaving only one space line separating one abstract from the other. A folder named "Corpus_teste" was created and the file was saved in *.txt format with the encoding: UTF-8 (Salviati, 2017; Camargo & Justo, 2018).

Next, the Iramuteq application was used, which processed the data and presented the description of the corpus². From it, we proceeded to Text Analysis, involving the following parts: Statistics; Specifics and AFC; Classification - Reinert Method; Similarity Analysis; and Word Cloud (Salviati, 2017; Camargo & Justo, 2018).

It was requested a generation of a statistic by selecting definitions "lemmatization", the key properties "1 – active", for adjectives and nouns; "2 – supplementary" for supplementary adjectives and supplementary nouns; and "0 – eliminate" for the other word classes; and "indexing". Based on this statistic, only active forms (nouns and adjectives) were analyzed and 40 forms were selected, with at least 42 occurrences (Camargo & Justo, 2018).

The next moment, the word cloud was made, the similarity analysis was performed, and the text was categorized into three classes by the Reinert method and the study of the Specificities and Correspondence Factor Analysis (CFA) in Iramuteq.

The word cloud analysis shows a set of words that are grouped, organized, and structured in a cloud form. These words are presented in different sizes, and the larger words are those that are most important and appear most frequently in the textual corpus. Although it is a simple lexical analysis, it is quite interesting because it allows quick identification of the keywords of a corpus (Salviati, 2017).

The Similarity analysis is based on the theory of graphs whose results help in studying the relationships between objects of a mathematical model. It shows a graph representing the link between words in the textual corpus. From this analysis, it is possible to infer the structure of text construction and the themes of relative importance, from the co-occurrence between the words (Salviati, 2017).

Reinert's method proposes a descending hierarchical classification and aims to obtain classes of Text Segments

(TS) that, at the same time, present similar vocabulary and different vocabulary from other classes. Its analysis is based on lexical proximity and the idea that words used in similar context are associated with the same lexical world and are part of specific mental worlds or systems of representation (Salviati, 2017).

The Specificity analysis associates texts with variables and enables the analysis of textual production as a function of characterization variables. The corpus is associated with variables that the researcher wants to analyze, so that the database is divided according to the selected variable (Salviati, 2017).

The use of Iramuteq made it possible to obtain the number of texts in the corpus, number of text segments, total number of words occurrence, number of different words, and number of words that appeared only once in the corpus. It was also possible to elaborate a relation with the active words, to understand the specificities, associating the texts with the variables used, calculating their frequencies and the chi-square relation of each corpus word.

This tool showed the words in different sizes, according to the frequency with which they occur in the textual corpus, grouped in a cloud format and facilitated the presentation of the link between the words in the textual corpus, making the similarity analysis.

In addition, it made it possible to perform descending hierarchical classification (DHC) with Reinert's method for grouping words into thematic classes. In DHC, Iramuteq performed the chi-square test (X^2) to measure the association between words and their respective class. According to Souza *et al.* (2008), the association will be confirmed when the value of X^2 is greater than 3.84 and the value of p , which identifies the lowest level of significance in which the null hypothesis of the association of the word with the grammatical class would be rejected, is less than 5% ($p < 0.05$) and a minimum use of 70.00% of the ST. In the sequence, the correspondence factor analysis (CFA) was performed (Camargo & Justo, 2013; Camargo & Justo, 2018).

The results obtained with the support of Iramuteq were analyzed in order to establish the connection between the scientific production from 1991 to 2019 as a way of explaining to what extent published articles can contribute to the study of innovation in the electricity sector.

IV. RESULTS AND DISCUSSION

The analysis of the results was divided into quantitative and qualitative with content analysis using Iramuteq/R. Class analysis from DHC and CFA results.

² Corpus is a set of texts constructed by the researcher that form the object of analysis (Salviati, 2017).

4.1 Quantitative analysis: publications and citations from 1991 to 2019.

In both databases, 242 articles were obtained, in which 127 were in Scopus and 115 in Web of Science. Of these 242, 83 were excluded (71 because they were in duplicate and 12 because they were outside the scope of the research). This left 159 works of the search that performed properly related in an Excel sheet, with the following data: Publishing base; author or authors; title; year; periodic; DOI; total of citations; average of citations per year, distribution of citations from 1991 to 2019³, as shown in Figure 2.

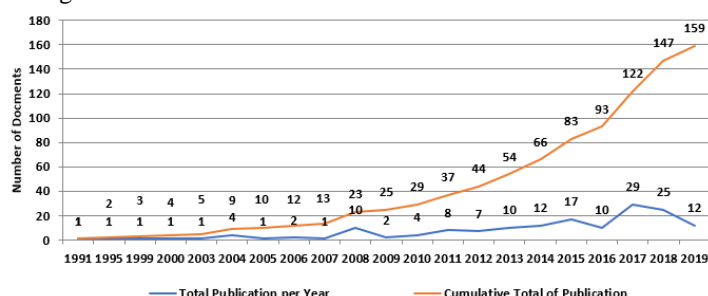


Fig.2: Number of articles published per year and accumulated in the period (1991-2019)

Source: Made by the authors.

The 159 articles generated 3,261 citations, whose annual and cumulative distribution can be analyzed in Figure 3. It should be clarified that the counting of citations started only in 2004, retroactive to 2002. Therefore, the period of citations registration ranges from 2002 to 2019 and the survey was conducted until June of this last year.

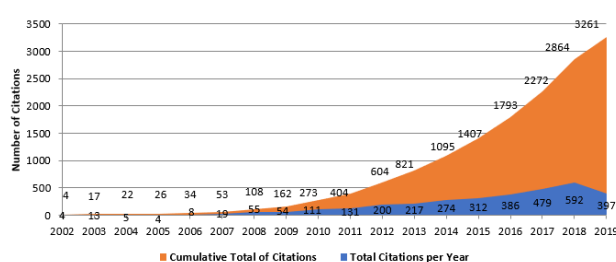


Fig.3: Number of citations of articles per year and accumulated in the period (2002-2019)

Source: Made by the authors.

Of these 3,261 citations, a single work contributed with 734 citations or 22.5% of identified citations. Another aspect verified is that there is a direct relationship between the growth of publications and citations in the analyzed period, which demonstrates the dissemination of

knowledge via publications in digital media, over the last two decades, enhanced by access via the Internet, as shown in Figures 2 and 3.

4.2 Content analysis of texts using “Iramuteq/R”

4.2.1 Statistical analysis of texts

The study was conducted through a General Corpus, consisting of 159 texts, separated into 861 text segments (TS). From it, 30,681 occurrences arose (words or forms), being 4,131 different words and 1,802 words with a single occurrence.

After defining the corpus, a statistic was generated, selecting as active properties only adjectives and nouns and using the lemmatization and indexation of these words. From this statistic, the following result was obtained: a) the number of forms that appeared only once was 1,303, which corresponds to 40.18% of the number of forms (3,243) and 4,25% of the number of occurrences (30,681); b) the 3,243 selected forms appeared on average 192.96 times per text, considering the number of 30,681 occurrences and the number of 159 texts.

Next, the 40 forms with more than 42 occurrences were selected, eliminating the forms “paper” and “study”, and a word cloud was formed on the theme under study, whose strongest word is “energy”, which appears highlighted in the central part. As can be seen in Figure 4, the twenty most frequently occurring words are: energy (298 occurrences), policy (186), innovation (177), technology (161), model (115), development (110), market (109), system (109), power (102), renewable (101), sector (98), transition (91), research (82), change (77), grid (76), project (74), carbon (71), process (69), emission (67) and business (61).

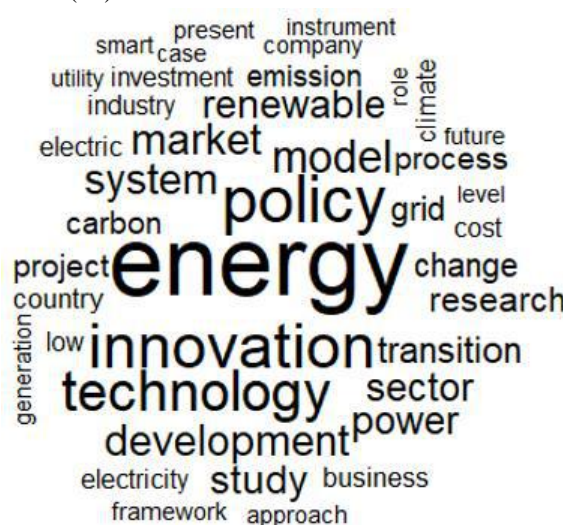


Fig.4: Word cloud of the general corpus of 159 texts

Source: Made by the authors, generated by Iramuteq.

³ Data extracted from the Scopus and Web Of Science databases refer to the period 1991 to June 2019.

4.2.2 Similarity Analysis

The Similarity analysis resulted in Figure 5, which resembles the roots of a tree, forming branches between the words that stand out as they appear closer to each other throughout the analyzed texts. From a central core formed by the word “energy”, it is possible to observe branches that form communities with “innovation”, “development”, “model”, “power” and “policy”. The stronger the root that connects the nucleus to communities, the greater and more frequent the relationship between them (Camargo & Justo, 2013; Camargo & Justo, 2018).

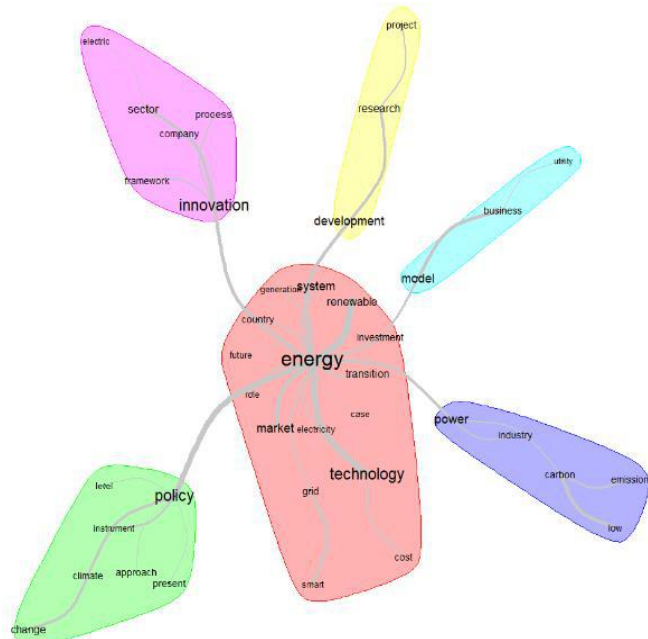


Fig.5: Keyword similarity and co-occurrence analysis - community and halo (1991-2019)

Source: Made by the authors, generated by “Iramuteq/R”.

Three of these communities form attention-grabbing nodes, such as: “policy”, with three branches, the most important being that consisting of “instrument”, “climate” and “change”; a second led by “power”, whose node is in “carbon”, distributing to “emission” and “low”; the last community is “innovation”, which has a node with “process”, “company”, “sector” and “electric”. This indicates that the analyzed literature addresses the relationship between these words in each community, by the proximity with which they appear in the texts, as well as by the frequency (Camargo & Justo, 2013; Camargo & Justo, 2018).

4.2.3 Descending Hierarchical Analysis (DHC)

The DHC is the most important analysis of texts or discourses performed by Iramuteq, because in it the TS are correlated, forming the hierarchical scheme of vocabulary classes (Camargo & Justo, 2018).

The analysis used the Reinert Method, where of the 861 TS found, 685 were classified, which means that 79.56% of the existing TS were classified, thus above the established minimum for the model to be validated, which is 70% (Camargo & Justo, 2013; Camargo & Justo, 2018).

Figure 6 shows the content analyzed and categorized into three classes: Class 1 with 255 TS (37.23%); Class 2 with 142 TS (20.73%) and Class 3 with 288 TS (42.04%).

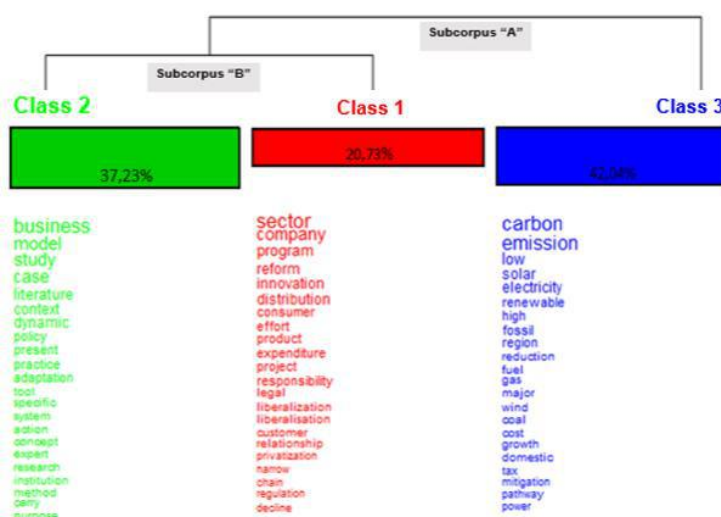


Fig.6: DHC classification of TS by Reinert's method categorized into classes (1991-2019)

Source: Made by the authors, generated by “Iramuteq/R”.

These three word classes are divided into two branches: A and B of the total corpus under analysis.

Subcorpus “A” has formed class 3 (“emission, carbon, low, solar and electricity”), called “Carbon”, which includes studies on CO₂ emissions from electrical power generation from fossil fuel, mitigation or emission reduction of CO₂ in the electricity sector, renewable sources of energy, with emphasis on solar energy as a source of low carbon electricity generation.

Subcorpus “B” has been divided into two classes: The first, “Sector”, contains the class 1 discourses (“innovation, sector, distribution and company”), that addresses innovation in the electricity sector, both in generation and distribution companies, and that demonstrates a new chain that focuses on the customer. The second, “Business”, composed by the words of class 2 (“business, model, policy and adaptation”), refers to the conception of new business models in the electricity sector, as well as the need for companies and institutions to adapt to this new market trend, with impacts on planning, management and regulation.

4.2.4 Specificity Study and Correspondence Factor Analysis (CFA)

To perform the study of specificities and CFA, 40 forms were selected and the variables chosen were: a) used forms: active; b) selected by: modalities (all modalities were selected); and c) minimum frequency: 42, according to the DHC analysis standard, Figure 6.

Figure 7 presented graphically the result of the analysis and formed three clusters in green, blue and red, which associates the words with the studied theme. The colors green and blue have groupings of terms closer than red, and red is well dispersed.

It should be noted that in the interpretation of clusters, font size is related to the frequency of the term, and the proximity between terms is a measure of how much they appear together. The results of the chi-square test (χ^2) and the value of "p" indicate that there was an association of each word with the respective class, since X^2 presented a result higher than 3.84, a "p" value of $< 0, 05$ and of the 861 TS, 685 were used, that is, 79.56% of the total, when the minimum acceptable is 70%, therefore, within the parameters indicated by Camargo & Justo (2018).

The groupings formed in the study of specificities and CFA are shown graphically in Figure 7, indicating to which class each group belongs, as defined by the DHC analysis.

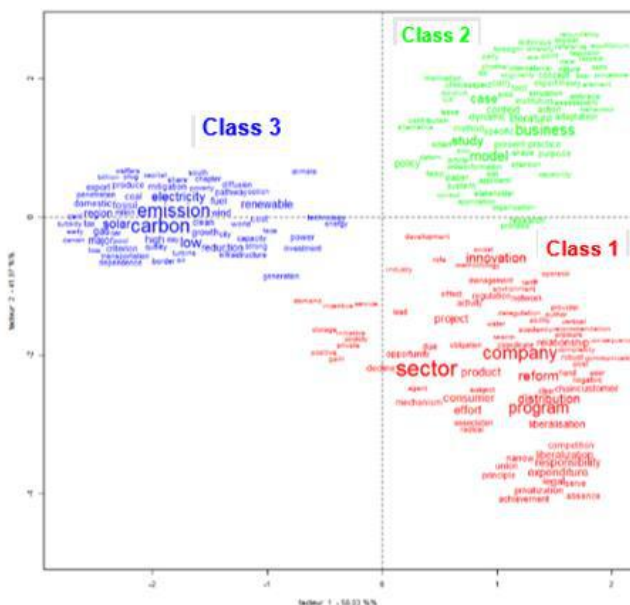


Fig.7: Study of Specificities and Correspondence Factor Analysis (CFA) (1991-2019)

Source: Made by the authors, generated by “Iramuteq/R”.

The green grouping has an intermediate density level when compared to the blue and red ones. The highlighted terms are: "business", "model", "case" and "study", and a little further from the core of the grouping "policy",

"adaptation" and "system" appear. Thus, the terms of the green grouping indicate the relevance of the study on innovation and disruptive technologies in the electricity sector on business models in the sector.

The blue color grouping has a greater density of the terms "emission" and "carbon", followed by "electricity", "low" and "solar", around this core are "reduction", "renewable", "power", "fossil", "mitigation", and more on the periphery "technology", "energy" and "climate" appear. This demonstrates that these studies focus on carbon emissions, electricity and solar energy.

The content analysis of the texts showed that the thickening of terms in green and blue colors indicates that there is a high correlation, both in frequency and in proximity to them, with the keywords used in the search for articles on innovation, electricity sector and disruptive technologies.

The terms grouped in red, whose densification has a higher degree of dispersion, show that “sector, company, program and distribution” appear in the same frequency and proximity, while “innovation” appears more in the periphery of the group, which indicates a low correlation. However, they are well aligned with the study of innovation and disruptive technologies in the electricity sector, staying between class 1 “sector” and class 2 “business”.

4.3 DHC and CFA analysis by classes: 1 - *innovation*, 2 - *business* and 3 - *carbon*

Next, an analysis of the results of DHC and CFA was performed, divided into three classes: class 1 - innovation, class 2 - business and class 3 - carbon.

4.3.1 Class 1 - *Innovation*

By analyzing the effect of public policies and market mechanisms for class 1, from the DHC and specificity analysis and CFA, “innovation”, on the electricity sector, including companies and institutions, Jamasb & Pollitt (2015), updated previous studies on the UK electricity sector, admitting that the effects of both liberalization and privatization time are not known.

In recent years, it has re-evaluated the sector and realized that energy innovation efforts were not performing as expected, but acknowledged that there is a new effort to create a sectoral technology and innovation policy that could properly calibrate the institutional structure and promote long term progress in the UK (Jamasb & Pollitt, 2008a, 2008b, 2011, 2015).

Other studies looked at the effect of deregulation on innovation in the electricity sector, but one in particular, one that used a sample of 31 OECD countries or countries

that adopt international regulation standards in the electricity sector, like Brazil, and their findings suggest that a decrease in regulatory intensity after significant reform has a negative impact on innovation. The main factor of this force seems to be the degree of contestability of the market. This shows that there is an inverted U-relationship between regulation and innovation, as represented by Figure 8 (Marino, Parrotta & Valletta, 2019).

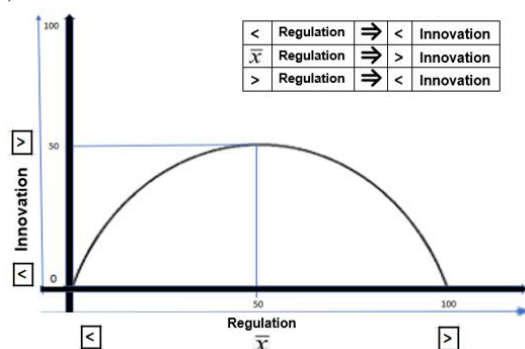


Fig.8: Graphical representation of the inverted U-shape of the regulation and innovation relationship

Source: Prepared by the authors.

The studies by Jamasb & Pollitt (2008b, 2015), conducted in the United Kingdom in 2008 and revisited in 2015, have shown that technological innovation has found difficulty to advance even in ultra-liberal markets such as the United Kingdom, where market mechanisms have failed to solve the problem. According to Marino, Parrotta & Valletta (2019), who studied 31 OECD countries or who use the OECD regulatory standard, where markets are regulated following international standards, regulation also could not find a break-even point that could account for advances in technology development and innovation in the electricity sector.

4.3.2 Class 2 - business

Regarding the studies done in DHC analysis and CFA classifications as class 2, renamed to “business”, with emphasis on the words (“model and policy”), there was a convergence of the authors as the possible impacts that disruptive technologies and renewable sources of energy will trigger in business models and public policies in the electricity sector on a global level (Fischer & Newell, 2008; Newell, Marsh & Sharma, 2011; Pereira & Soule, 2018; Pereira *et al.*, 2018).

It is noted that there is a growing concern with integrated resource management and a close look at the climate-energy-water nexus in countries such as Brazil and Australia, which increasingly requires a systemic and

multidisciplinary view on the subject (Fischer, Newell & Preonas, 2014; Nascimento *et al.*, 2017).

Smart grids can dramatically change the electricity sector by stimulating customer participation and allowing new players to enter as well as the admission of ICT companies. A critical analysis of existing smart grid studies assesses the consequences on the elements of the business model: value creation, value delivery and value capture, on which many uncertainties weigh, although there is reason to believe that electricity companies can innovate its business model and create the adequate conditions to operate with energy in a sustainable way (Shomali & Pinkse, 2016; Ausrød, Sinha & Widding, 2017).

As the same doubts also arise about the involvement of consumers and the support of governments and new players in this technological evolution, work must be done to reduce uncertainties so that innovation in business models in the electricity sector happens faster, since harnessing disruptive potential depends on quick decision-making for targeted and safe adaptation (Shomali & Pinkse, 2016; Pereira *et al.*, 2018; Pereira *et al.*, 2018).

4.3.3 Class 3 - Carbon

The scientific production submitted to DHC and specificity analysis and CFA, classified in Class 3, titled carbon (emission, electricity, renewable, solar), shows a very uniform positioning of the different authors, when considering that the generation of electricity is one of the most important sources when it comes to total CO₂ emissions, which is directly related to global warming. They also agree that large-scale implementation of innovative renewable energy technologies is key to reducing carbon emissions (Fuss & Szolgayová, 2010; Zhang, 2014).

China and the countries from the Association of Southeast Asian Nations (ASEAN) have a great potential for growth in renewable energy supply while at the same time holding even greater potential for reducing emissions by opting for a cleaner electricity matrix (Jusoh, 2017; Zhu *et al.*, 2018).

Published studies show that innovation in the electricity sector can deliver benefits to society by reducing CO₂ emissions, but all will depend on new business models in the sector, the increased use of renewable energy sources and the evolution on regulatory standards.

V. CONCLUSION

This bibliometric study on innovation in the electricity sector in the age of disruptive technologies and renewable energy sources, conducted with 159 articles published in

journals in the Scopus and Web of Science databases, covering the period from 1991 to July 2019, demonstrated that there are advances in innovation in the sector worldwide and especially in Brazil.

In the USA, studies analyzed the reduction of carbon dioxide emissions, the inclusion of renewable energy sources in the electric matrix, as well as the technological evolution in the electricity sector. These studies concluded that new technologies are impactful as they affect the desirability of ongoing sectoral policies (Fischer & Newell, 2008).

In Europe, innovation in ITGCC plants (“integrated tar gasification combined cycle plants”) was a milestone in the competitiveness of the oil industry in terms of cost and environmental impact reduction in electricity generation (Gulli, 1995).

These cases followed the same line as an empirical study carried out in the Netherlands on electricity-producing coal plants, which simulated for the period 1985-2000 and showed that in an evolving technological environment there would be a reduction in costs by reducing sulfur dioxide (SO₂) emissions per unit of electricity produced by these plants (Wiersma, 1991).

In Asia, notably China, there is a great potential for reducing CO₂ emissions by increasing the use of renewable energy sources, making the continent's electricity matrix cleaner (Jusoh, 2017; Zhu *et al.*, 2018).

In Brazil, the authors Bin *et al.* (2015) and Pereira *et al.* (2018) recognize the advances, but point out problems in the PD&I model adopted by SEB, especially regarding the results of the program regulated by ANEEL. Regarding the problems, the authors Bin and Pereira, can be aligned with Jamasb & Pollitt (2008b; 2015) and Marino, Parrotta & Valletta (2019) who identified that the difficulties faced by innovation models in the electricity sector are inherent in tightly regulated sectors.

Given the results of the studies analyzed, it can be concluded that for the society to reap the benefits of these new technologies, innovation must be able of generating new business models, capable of absorbing disruptive technologies and involve the new actors who will work in the electricity sector.

The study shows that new research should focus on new business models based on renewable energy sources, smart grids and consumer behavior, since these are the trends that will dominate the industry in the coming years.

Another barrier to be broken is the U-inverted effect, because the literature indicates that there is a knot to be untied in the regulation and innovation relationship. If regulations are not adequate to encourage innovation, countries that fail to advance in innovation may lose the

opportunity to have a more efficient electricity market and also lose the chance to benefit from the potential gains from innovation in three respects: economic, social and environmental.

ACKNOWLEDGEMENTS

I thank the Center for Sustainable Development (CSD) at the University of Brasilia (UnB), for their support in my doctoral studies and the Higher Education Personnel Improvement Coordination (CAPES), foundation under the ministry of Education of Brazil, which supports the Graduate Program in Sustainable Development (PPG-CDS) of UnB.

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