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Benefícios e limitações dos cenários baseados em Fuzzy Cognitive Maps: O caso da energia solar fotovoltaica brasileira

Benefits and limitations of Fuzzy Cognitive Maps based scenarios: the case of Brazilian solar photovoltaic energy

Gustavo Macedo de Carvalho

Orientador: Prof. Dr. Gilmar Masiero

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Prof. Dr. Marco Antonio Zago
Rector of University of São Paulo

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GUSTAVO MACEDO DE CARVALHO

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To my beloved family and my
sweet girlfriend whose supported
me day and night during all this
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RESUMO

Após a Segunda Guerra Mundial, houve um crescente de interesse no estudo do futuro. Para alcançar objetivos confiáveis, foram inventados vários métodos de planejamento de cenários. Esses métodos possuem abordagens qualitativas e quantitativas herdadas de sua própria escola de origem. Cada abordagem possui vantagens e limitações que podem ser observadas pelo estudo de cada método. No entanto, abordagens mistas muitas vezes mostram uma conexão fraca entre métodos qualitativos e quantitativos. O uso de fuzzy cognitive maps (FCMs), no planejamento de cenários, pode superar as limitações das técnicas qualitativas e quantitativas. Este estudo centrou-se no problema da falta de planejamento adequado de cenários baseados em FCMs nos setores de energia alternativa, levantando a questão de saber se esta situação vem da escassez de informações ou das limitações dos FCMs no planejamento estratégico. Para resolver este problema, este estudo investigou os benefícios e as limitações do planejamento de cenários baseado em FCM através da aplicação no setor fotovoltaico brasileiro. Foram estabelecidos os seguintes objetivos específicos: identificar os pontos fortes e fracos dos FCMs; analisar a expansão destes para diferentes áreas; identificar os principais stakeholders utilizados para desenvolver cenários baseados em FCMs; aplicar o método no setor de energia solar brasileira. Identificamos um número crescente de estudos sobre FCMs em várias novas áreas não consideradas em estudos anteriores. Isso sugere que os especialistas estão expandindo as fronteiras e reconhecendo o potencial interdisciplinar dos FCMs e sua robustez na resolução de diversos tipos de problemas. A principal contribuição desta pesquisa é apresentar os benefícios e as limitações do planejamento de cenário baseado em FCM. Para isso, foi apresentado um método de planejamento de cenários e a evidência empírica de sua eficácia foi apresentada no contexto do setor de energia solar fotovoltaica brasileira.

Palavra-chave: Planejamento estratégico, Fuzzy Cognitive Maps, Energia solar

ABSTRACT

After the Second World War, there was an expression of interest in the study of the future. In order to achieve reliable objectives, several methods of scenario planning were invented. These methods comprise of qualitative and quantitative approaches inherited from their own school of origin. Each approach has advantages and limitations that can be observed by the study of each method in progress. However, mixed approaches often show a weak connection between qualitative and quantitative methods. The use of fuzzy cognitive maps (FCMs), among scenario planning approaches, can overcome the limitations of qualitative and quantitative techniques. This study focused on the problem of the lack of proper planning of scenarios based on FCMs in the alternative energy sectors, raising the question of whether this situation comes from a shortage of information or limitations of the FCMs. To resolve this problem, this study investigated benefits and limitations of FCM-based scenario planning through the application in the Brazilian photovoltaic sector. The following specific objectives were established: identify the strong and weak points of FCMs; analyze the expansion of these to different areas; identification of the main stakeholders used to develop FCM-based scenarios; application of the method in the Brazilian solar energy sector. We identified an increasing number of studies on FCMs in several new areas not considered in previous studies. This suggests that experts are expanding frontiers and recognizing the interdisciplinary potential of FCMs and their robustness of solving diverse kinds of problems. The main contribution of the research is to present the benefits and limitations of FCM-based scenario planning. For that, a scenario planning method was presented and the empirical evidence of its effectiveness was presented in the context of the Brazilian photovoltaic solar energy sector.

Keywords: Strategic Planning, Fuzzy Cognitive Maps, Solar Energy

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LIST OF ABBREVIATIONS

ABSOLAR - Associação Brasileira de Energia Solar Fotovoltaica

ANEEL – Agência Nacional de Energia Elétrica

CONFAZ - Conselho Nacional de Política Fazendária

CP – Public Call

PSE – Photovoltaic solar energy

EPE – Empresa de pesquisa Energética

FCMs – Fuzzy Cognitive Maps

FEEC - Faculdade de Engenharia Elétrica e de Computação da Universidade Estadual de Campinas

GW – Gigawatt ou 10^9 Watts

TCG - Tax on Circulation of Goods

IEE - Instituto de Energia e Ambiente da Universidade de São Paulo

MME – Ministério de Minas e Energia

MW – Megawatt ou 10^6 Watts

POLI - Escola Politécnica da Universidade de São Paulo

ProGD - Programa de Geração Distribuída de Energia Elétrica

GDP - Gross domestic product

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1. INTRODUCTION

After the Second World War, there was an expression of interest in the study of the future. Such studies led to new approaches in the area of strategic planning (Georgantzias & Acar, 1995, Brown, 1968), decision making (Wright & Spers, 2006, Wilson, 1978) and the organizational learning (Bezold, 2010). During the 60s, the United States and France developed several techniques and created institutions intending to aid in making projections about the future (Bradfield, Wright, Burt, Cairns, & Heijden, 2005). The institutions and the techniques they developed were designed to envision multiple scenarios and outcomes.

The planning of scenarios is more effective when applied to a long term projections, for example 10 to 20 years, and from some macro analysis of uncertain environments, which are typified given the lack of data and a huge number of non-quantified factors (Huss, 1988). According to Schoemaker, Cornelius e Heijden (1992), scenario planning first started winning popularity in the 70s when the Royal Dutch/Shell Company made use of it during its process of generating and evaluating options.

After being popularized, scenario planning has become a fundamental tool for strategic planning. In order to create reliable objectives, several methods of scenario development were invented. These methods comprise of qualitative and quantitative approaches inherited from their own school of origin. Each approach has advantages and limitations that can be observed by the study of each method in progress. However, mixed approaches often show a weak connection between qualitative and quantitative methods (Kok, 2009, Kok & Van Delden, 2009). Many authors have sought to integrate and make use of qualitative and quantitative tools within the creation of mixed approaches, in a way that would mitigate the limitations and allow us to reap the benefits of each approach (Mietzner & Reger, 2004).

Aiming to overcome some of these limitations, Kok (2009), Van Vliet, Kok e Veldkamp (2010), Jetter e Schweinfort (2011) sought to integrate fuzzy cognitive maps to the practice of scenario planning. Fuzzy cognitive maps (FCMs) were developed by Kosko (1986) as an extension of the casual cognitive maps by Axlerod (1976). The FCMs are a mental model represented by a chart of concepts (variables) and connections within it, in which the weight of the connections indicates the perception that specialists or stakeholders have on the concepts' relation (Ozesmi & Ozesmi, 2004). The biggest benefit of this tool is to overcome limitations of qualitative and quantitative techniques, so it would integrate the benefits of both

techniques (Amer, Jetter, & Daim, 2011). Besides this benefit, scenario development based on FCMs has been featured, for being a simple, innovative and efficient approach.

The ability to adapt to different areas and to be used as a solution to several problems has made FCMs object of study in the most different areas of research (Stach, Kurgan, & Pedrycz, 2010). FCMs were initially more utilized in the Computer Science Engineering and Mathematics fields. However, in recent years FCMs have been gaining greater relevance in other areas of knowledge, such as Business, Management and Accounting. Decision Sciences and Social Sciences have shown considerable growth in the use of FCMs over the last five years. This demonstrates that the tool is proving itself indispensable for a growing number of uses. In the section 2 of this thesis it is presented the FCMs' expansion in different areas. This multidisciplinary is the result of dynamic characteristics and of the capability of promoting learning to its participants (Papageorgiou, 2011a). To the author, FCMs are essentials to the prediction models analysis and to the decision making, once they improve the performance of its systems.

Nevertheless, after some extensive research in specialized bases such as JSTOR and Science Direct periodic portal, it was not found a significant number of articles on the utilization of this technique on building scenarios. On another research, on Lattes Curriculum of the researchers from social and applied sciences, registered on Carlos Chagas Platform from Capes, no article was found. For those reasons, it appears that FCMs constitute some vast territory yet to be explored in the field of future studies, as well as its advantages and limitations, that when applied to this area of knowledge they are still little known.

Besides the scarcity of research material on Benefits and limitations of the use of FCMs when building scenarios, in Brazil its utilization in emerging energy sectors is nonexistent, and indeed little used in the rest of the world. It has not been found in any studies involving Brazilian energy sector.

On international studies, it is featured Amer et al. (2011) and Jetter and Schweinfort (2010). Both utilize FCMs building scenarios in the Energy sector of Pakistan and North American, respectively. Still, to these authors, FCMs have not reached enough maturity to be considered a fully proven technique. They suggest the need of a study in FCMs involving all stages of scenario planning.

Thus, it is questionable if it is the lack of knowledge on the possibility of application of the FCMs, or its limitations when applied to emergent energy sectors that would explain its

non-utilization by the specialists or stakeholders from Brazilian Photovoltaic Energy sector. Specialists in energy expect that by 2050 over 50% of all electricity would be generated through renewable sources (AB Kadir, Rafeeu, & Adam, 2010). Photovoltaic solar energy (PSE) has appearing as a strong candidate to be the main electric energy source, given its technologic, economic, social and environmental characteristics.

In Brazil, PSE has been stimulated in different ways. The elaboration of scenarios by the Brazilian electricity regulatory agency ANEEL is practically nonexistent, or by the major companies in the sector. For this reason, scenario construction based in FMCs in emergent energy sectors defines the issue discussed in this assignment. The objective being the investigation of benefits and limitations of FCM-based scenario planning. The present study will also seek to understand the following specific objectives: identify the strong and weak points of FCMs; analyze the expansion of FCMs to different areas; identification of the main stakeholders used to develop FCM-based scenarios; application of the method in the Brazilian solar energy sector.

1.1. Conceptual assumptions

The present research is prospective. Therefore, it will not seek to anticipate exactly what is going to happen in the future, like it is done in prediction (Silva, Spers, Wright, & Costa, 2013). So, the research goes beyond the prospection of multiple potential futures. This means that the future has to be possible and free of physical, technical and/or social boundaries.

Although scenarios planning is presented in literature as a synonym of foresight, in this study it is considered as narratives that connect the present to a plausible future in a concise and coherent way. Thus, we worry in knowing what could happen if such future becomes reality (Heinecke & Schwager, 1995; Godet, 1993), but we also care in consider carefully what have between the present and the future.

Although both terms, method and technique, are used in a interchangeable way in literature (Bishop, Hines, & Collins, 2007), in this study it will be adopted the term method as standard. Yet, it is not in the scope of this research to distinguish or solve the confusion between the terms.

1.2. Dissertation Structure

Accordingly to what was presented in Figure 1, the dissertation will be composed by five stages: introduction, three articles (here called chapters 1, 2 and 4), chapter 3 (Description of the photovoltaic solar energy sector), conclusion and recommendations, respectively. The chapters are structured to establish some logical and complimentary links among them.

Figure 1- Dissertation Stages

On chapter 1, “**Introduction**”, it was presented problematic, objectives that guided the research, current state of literature, justification and structure of the dissertation. Chapters 2, 3 and 4 were built as independent papers, with independent structures. Nevertheless, all subjects are interrelated and complimentary.

Chapter 2, “*Fuzzy Cognitive Maps: from origins to new frontiers*”, addresses the results of a survey on the most relevant literature of *Fuzzy Cognitive Maps (FCMs)*. It shows that FCMs have been adopted from their original applications in mathematics and computer science to address a wide range of questions in the social sciences. The analysis encompasses the use of *FCMs* since their original introduction until present. In this chapter, we show that variations of *FCMs* have been developed through a process of improvement and adaptation from the original *Expert-Based Methods* to current *Computational Methods*. It is also presented an increasing number of studies on *FCMs* in several new areas yet not considered in previous studies.

Chapter 3, “**The relevance of stakeholders in fuzzy cognitive map based scenarios: a bibliometric study**”, is an attempt to consolidate the previous studies on fuzzy cognitive map based scenario planning by reviewing the literature to identify the main stakeholders used to develop scenarios. We found and analyzed 14 articles related to the topic of interest. The results show that the field has not yet reached maturity, based on the relatively small number of articles published. The article contributes to future research by presenting the consolidated state of the literature and also the main trends in the field. It was also identified the set of stakeholders considered by the literature as the leading ones that develop FCM based scenario planning.

Chapter 4, “**Brazilian photovoltaic Energy sector**”, presents a brief revision of Brazilian photovoltaic energy sector. The PSE was chosen for having a relevant role in any country economy and it has stood out as the energy source of the future given its innumerable advantages. PSE is a classic case of emergent technology in a dynamic and innovative sector, in which the scenarios present themselves as a necessary tool to the anticipation of the unknown, when building strategic planning and in the process of decision-making. So, this chapter will approach the advantages and disadvantages of this energy source.

In Chapter 5, “**Benefits and limitations of FCMs based scenarios**”, it is explored a new approach in which Fuzzy Cognitive Maps are integrated to scenario planning. The method was applied to the photovoltaic energy sector and as result of it three scenarios were developed. It will also be discussed its theoretic and practical aspects, objectifying the identification of the major benefits and limitations of the use of FCMs in scenarios planning. It will be presented also, in a symbolical way, the behavior of the analyzed system, where the main variables and respective weights will be identified.

In the last chapter, chapter 6, it will be presented the final conclusion that integrates all the chapters. It will also be presented the implications, limitations and suggestions for further researches.

2. FUZZY COGNITIVE MAPS: FROM ORIGINS TO NEW FRONTIERS

2.1. Introduction

Originally introduced by Kosko (1986) as an extension of Axelrod's *cognitive maps* Axelrod (1976), *Fuzzy Cognitive Maps* emerged as a tool for modeling complex dynamic systems (Vaščák & Adarász, 2010), which combines elements of *neural networks* and *fuzzy logic* (Motlagh, Jamaludin, Tang, & Khaksar, 2015; Papageorgiou, 2012; Stach, Kurgan, & Pedrycz, 2010). The main contribution of *FCMs* was to analyze diffuse relations, that is, relations previously defined only as positive or negative were enriched with others of different degrees of influence (Stach et al., 2010).

FCMs are an unconventional qualitative approach for dynamic systems, composed of diffuse graphic structures and a matrix (Kosko, 1986). For classical authors (Kosko, 1986; Papageorgiou, 2011; Stach, Kurgan, & Pedrycz, 2005) it represents a belief system in a given domain. The major objective of building an *FCM* of a given problem is its ability to predict outputs through the interactions of relevant issues (Papageorgiou, 2011).

FCMs allow the gathering of knowledge through a single expert or a combination of a group of experts (Van Vliet, Kok, & Veldkamp, 2010; Azadeh, Zarrin, Abdollahi, Noury, & Farahmand, 2015). They also combine different information and ideas from historical data (Stach et al., 2010). The ability to accept additional mapping allows the accuracy and capacity of the system to be improved (Kosko, 1988; Dickerson & Kosko, 1994).

In their graphical form, *FCMs* facilitate the visualization of the structure of a system and render the model relatively simple and readable. In their algebraic form, derived from a mathematical base, *FCMs* allow for the expression of the dynamic behavior of the system (Song, Miao, Wuyts, Shen, & D'Hondt, 2011; Xirogiannis & Glykas, 2004). Other benefits are: the flexibility of the method (Salmeron, Vidal, & Mena, 2012), easy to use, simplicity in constructing and customizing (Rodriguez-Repiso, Setchi, & Salmeron, 2007) as well as being "adjustable" (Bertolini & Bevilacqua, 2010).

These characteristics of *FCMs* have attracted the growing interest of researchers (Papageorgiou, 2011) and resulted in the successful application of *FCMs* in a large number of disciplines (Stach, Kurgan, Pedrycz, & Reformat, 2005; Lee & Lee, 2015). Papageorgiou (2011) and Aguilar (2005) have sought to review the literature in order to consolidate the applications and knowledge domains where *FCMs* have been used. They were able to identify

applications in the areas of political and social sciences, medicine, engineering, business, environment and education, among others. Further than identify fields applications, Papageorgiou (2011) established six paradigms of typical problems solved by *FCMs*. These paradigms are reproduced in Table 1.

Table 1 - Paradigms of problems typically solved by *FCMs*

Paradigm	Typical problems solved by <i>FCMs</i> (description)
Control	Prediction, interpreting, monitoring
Business	Planning, management, decision-making, inference
Medicine	Decision support, modeling, prediction, classification
Robotics	Navigation, learning, prediction
Environment	Knowledge representation, reasoning, stakeholders' analysis, policy making
Information Technology	Modeling, analysis

Source: (Papageorgiou, 2011).

From its origins in the middle of 1980s, *FCMs* has been implemented in order in different areas to solve an increasing number of problems. At the beginning, *FCMs* were developed using *Expert-Based Methods* and nowadays they are being developed by *Computational Methods*. In order to outline this process, the study addresses the results of a survey on the most relevant literature of *FCMs*. Following this introduction, the first part presents the “Fuzzy Cognitive Maps and their applications”, as well as the second addresses a systematic classification of the literature on the above mentioned methods. In the conclusions we emphasize that experts are expanding frontiers and recognizing the interdisciplinary potential of *FCMs* and their robustness of solving diverse kinds of problems from their original applications in math sciences to social sciences.

2.2. Fuzzy Cognitive Maps and Their Applications

The design of *FCMs* should be a structure composed of nodes and intersecting edges that would represent knowledge of concept associations (Kosko, 1986). The concepts (Cn) are key determinants of the system (Kok, 2009) and represent an entity, variable or characteristic

of the system (Kosko, 1992). The nodes represent the variable state or behavior of the concepts (Carvalho & Tomé, 1999). The "Edges" (E), represented by an arrow, are the cause and effect relationships between two concepts. This relationship has diffuse weights and, according to Schneider, Shnaider, Kandel, and Chew (1998), can be represent: positive causality between two concepts ($W_{ij} > 0$), implying that the behavior of concepts reacts in a similar way. That is, when the value of C_i increases, the value of C_j also increases. On the other hand, in a case where negative causality occurs between two concepts ($W_{ij} < 0$), they react in an inverse way, that is, when the value of C_i increases (or decreases), the value of C_j decreases (or increases). There are cases where there is no relationship between the concepts ($W_{ij} = 0$) (Aguilar, 2005; Stylios, Georgopoulos & Groumpos, 1997).

When the knowledge of *FCMs* is presented in a matrix, we have the *State Vector* and the adjacent matrix. The set of values of the concepts C_1, C_2, C_3, C_n , (n is the number of the concept) is represented by the state vector (S), which generally has a value between 0 and 1. This value is dynamic and varies according to the context. The adjacent matrix is composed of the weights of the relationships between the concepts, usually between -1 and +1. The dynamic capacity of *FCMs* allows the concept values to vary. The new values of the concepts C_i are obtained through the threshold function that is the result of a multiplication in the interval $[0,1]$ or $[0,1]$. The four threshold functions most used in the literature are (Papageorgiou, 2012; Tsadiras, 2008).

1) *Bivalent*

$$T(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases}$$

2) *Trivalent*

$$T(x) = \begin{cases} -1, & x \leq -0,5 \\ 0, & -0,5 < x < 0,5 \\ 1, & x \geq 0,5 \end{cases}$$

3) *Logistic Signal* ($m=5$)

$$T(x) = \frac{1}{1+e^{-mx}}$$

4) *Hyperbolic Tangent Function* ($m=5$)

$$T(x) = \tanh(\delta x) = \frac{e^{\delta x} - e^{-\delta x}}{e^{\delta x} + e^{-\delta x}}$$

Figure 2 shows an example of FCMs in graphical and matrix form. In this example, the next state of the state vector was obtained through calibration, which occurred by multiplying the state vector and adjacent matrix.

Figure 2- Example of FCMs

Source: Research data

State vector = (1 1 0 1)

$$\text{Adjacent matrix} = \begin{pmatrix} 0 & -0,25 & 0 & 0 \\ 0,75 & 0 & 0,25 & 0 \\ 0,5 & 0 & 0 & 0 \\ 0 & 0,5 & 0 & 1 \end{pmatrix}$$

New State vector = State vector X Adjacent matrix = (0,75 0,25 0,25 1)

Normally the system stabilizes after 20 or 30 interactions, however, for total stabilization more than 100 interactions may be necessary (Kok, 2009). Figure 2 shows the stabilization of the values of concepts after 10 interactions.

Figure 3- Stabilization of concepts after 10 interactions

Source: Research data

By having the ability to include adjustments (feedback loops) and incorporate essential transformation functions, *FCMs* can be used for a variety of purposes (Codara, 1998), such as: to reconstruct the assumptions behind the behavior of a given agent; to understand the reasons for the decisions and actions taken, showing any distortion and limit in the representation of situations; to predict future decisions and actions, or the reasons an agent will use to justify a new fact; assist decision makers to reflect on the representation of a given situation for the purpose of verifying the adequacy or the possibility of any change; and to provide a precise description of a difficult situation.

The ability to adapt to different areas and to be used as a solution to several problems has made *FCMs* the object of study in the most varied areas of research. A search on the Scopus database (www.scopus.com) turned up 603 studies related to *FCMs* between 1986 and 2016. The history of the publication data shows a tendency of an increase in the number of studies on *FCMs*. 18% of the publications were published in the period from 1986 to 2006 and 81 % of the publications were from 2007 to 2016. Figure 3 presents the growing number of studies related to, or using, *FCMs*.

Figure 4- Number of studies per year

Source: Research data

Note that in the first 10 years, between 1986 and 1996, there were few publications about *FCMs* and some years without any publications at all. The chart also shows that the vast majority of publications and studies related to *FCMs* were published in the last 10 years. We can see an increase in the number of publications each year, with two great spikes in 2003 and especially from 2012 onward. These results indicate an increase in the interest of researchers and institutions in the use of Fuzzy Cognitive Maps in different areas. Figure 4 shows the evolution of the number of publications by area of knowledge.

Figure 5- Evolution of the number of publications by area of knowledge

Source: Research data

As shown in Figure 5, *FCMs* were initially more utilized in the areas of Computer Science (Glykas, 2013; Nápoles, Grau, Bello, & Grau, 2014; Pedrycz, 2010), Engineering (Arvan, Omidvar, & Ghodsi, 2016; Azadeh, Ziaei, & Moghaddam, 2012; Wee, Cheah, Tan, & Wee, 2015) and Mathematics (Chen, 2016; Chi & Liu, 2016; Pedrycz, Jastrzebska, & Homenda, 2016). However, in recent years, *FCMs* have been gaining greater relevance in other areas of knowledge. Areas such as Business, Management and Accounting (Amer, Daim, & Jetter, 2016; Ferreira, 2016; Salmeron & Froelich, 2016). Decision Sciences (Froelich & Pedrycz, 2017; Mezei, & Sarlin, 2016; Wu, & Liu, 2016) and Social Sciences (Kang, Zhang, & Gao, 2016; Olazabal, & Pascual, 2016; Omari, & Mohammadian, 2016) have shown considerable growth in the use of *FCMs* over the last five years, which demonstrates that the tool is proving itself for a growing number of uses.

This dissemination of the tool to other areas of knowledge may be seen as an indication that the tool already has a sufficient level of maturity to be applied to other areas of knowledge. The main authors who initially published in the areas of Computer Science, Engineering and Mathematics are now working with researchers from other areas. Table 2 shows the principal authors who use *FCMs* in their research.

Table 2 - Principal authors

Author	Number of articles
Papageorgiou, E.I.	53
Stylios, C.D.	21
Groumpos, P.P.	20
Salmeron, J.L.	19
Pedrycz, W.	12

Source: Research data

Papageorgiou, Stylios, Groumpos, Salmeron and Pedrycz are the researchers who have published the greatest number of articles related to *FCMs*. Figure 6 shows the collaboration of author Papageorgiou with authors from other areas of knowledge. The author has expanded his field of expertise and has published articles in the fields of medicine, engineering, environmental science, agricultural and biological sciences, mathematics, business, management and accounting. This has also occurred with other authors, who, in most cases, have specialized in *FCMs* and use them in other areas and for different purposes.

Figure 6- Collaboration with authors from different areas

Note: The Scopus database classifies the authors by the journals where they publish their articles. The above classification was made based on the institutional affiliations of the authors at the time of publication.

Source: Research data

Several variations of *FCMs* were developed as a way of adapting and adjusting to different purposes and areas where they are applied. Thus, new models have been developed, with the participation of specialists, or even developed by computer (Stach et al., 2005).

2.3. A Typology of FCMs

There are two major types of FCMs. The pioneers’ types are the Expert-based Methods, which have been developed manually by experts of different areas of scientific knowledge. The

others, more modern, are the Computational Methods, which use an automated learning method to manipulate the data. In this section we present the main characteristics of each type of FCMs and the main variations of computational methods.

2.3.1. Expert-based Methods

Expert-based methods are common used when there is little or no historical data. *FCMs* built with this method emphasize the utilization of expert knowledge. Therefore, it is recommended that the experts have a prior knowledge of the components and functioning of *FCMs* (Stach et al., 2010). In general, the process of *FCMs* development using this method must observe some steps: identification of the main concepts, identification of the causal relationships between different concepts and the estimation of the weight of relationships (Khan & Quaddus, 2004). These steps have been observed since the origins of building up *FCMs*.

The *FCMs* using expert-based methods can be developed by a single or a group of specialists. When developed by a single expert, *FCMs* can possibly be biased because it is built up in subjective judgments. After observing the above mentioned steps, the expert must judge the value of concepts as well as the weight of the relationships. However, *FCMs* are tools that allow for the consolidation of the judgments of a number of specialists, thus reducing the chances of a bias. Therefore, the *FCMs* developed by a group of specialists are more reliable than the ones built up by a single specialist. However, *FCMs* are tools that allow for the consolidation of the judgments of a number of specialists, thus reducing the chances of a bias.

FCMs developed by individual experts can also be merged (Khan & Quaddus, 2004; Stach et al., 2010). When made by a group of experts, they are usually developed from a dialogue in which experts reach a consensus regarding concepts, relationships and weights. The consensus may also come from a consolidation of several maps made individually by different specialists. When developed from the consolidation of several maps, one must verify the need to use corresponding weights with the credibility of each expert.

Expert-based *FCMs* can be difficult to construct and are limited when applied to very complex problems involving a large number of concepts. Although they are accurate in static analyses, they are not recommended when using a large volume of data. For these cases, *Computational Methods* are recommended. They are better suited for dynamic analyses with a large number of variables (Papageorgiou, 2014).

2.3.2. Computational Methods

When historical data is available, the *Computational Methods* approach that best fits the objectives of the phenomena being investigated. In their review, Stach *et al.* (2010) presented two generic types of *FCMs* using computational methods: *Hebbian-based* and *evolutionary algorithm-based*. Later, a *Hybrid learning methods* (Papageorgiou & Groumpos, 2005; Zhou & Zhang, 2008) approach emerged combining both methodologies: *Hebbian-based* and *evolutionary algorithm-based*.

Hebbian learning constitutes an unsupervised technique that states that the synaptic efficacy between two neurons should increase if they are simultaneously active and decrease if not. Thus, it was initially applied on the training of artificial neural networks (Papakostas, Polydoros, Koulouriotis, & Tourassis, 2011). In the *Hebbian-based Approach* category, the methods that have gained greater visibility are: *Differential Hebbian Learning* (DHL), *Balanced Differential Algorithm* (BDA), *Non-linear Hebbian Learning* (NHL), *Active Hebbian learning algorithm* (AHL) and *Data-Driven Non-linear Hebbian Learning* (DD-NHL).

The Hebbian-based approach emerged with the work of Dickerson and Kosko (1994) who introduced the simple DHL, by using the generalized Hebbian rule introduced by Oja (1989), based on Hebbian theory (Hebb, 1949). Dickerson and Kosko (1994) proposed it in order to find better interconnections weights than those provided by experts participated to the FCM design (Papakostas et al., 2011). The idea was that the weights of the relations be updated repeatedly until the desired structure was found (Papageorgiou, 2012). Dickerson and Kosko (1994) stated that each concept node can fire on its own time scale and fire in its own nonlinear way. The authors concluded that this behavior does not fit in a simple FCM with threshold concepts and constant edge weights.

Huerga (2002) proposed the BDA as an improved version of DHL. His contribution was that takes into account more than one concept in order to calculate the weights for causal-effect links between variables. That is, in DHL, the weight of an edge was updated only when the value of one of the concepts that it composes was changed, whereas in BDA, the weight of the edge changes, taking into account all the concepts of the system that change at the same time. Although BDA proved to be better than DHL, the algorithm has some restrictions and negative points. It is restricted to *FCMs* with binary-value concepts and it is a little bit slower,

to compute every weight it is necessary to consider the other concepts involved in the causal-effect relation for a target concept (Huerga, 2002).

Papageorgiou, Stylios and Groumpos (2003; 2004) introduced NHL and AHL, respectively. The NHL is based on the nonlinear Hebbian-type learning rule and adjust the weights (non-zero) based on initial experts' knowledge a set of conditions imposed on desired outputs concepts. However, it has the disadvantage of doesn't exploit any additional information that could improve learning and generate accurate models (Stach, Kurgan, & Pedrycz, 2008). And the AHL algorithm adjusts and modifies the weights of FCMs improving the FCM's efficiency and adaptability. This approach tries to overcome the dependence on expert's beliefs (Papageorgiou et al., 2004). Therefore, both extensions modify all weights in each interaction and use human intervention to delimit the set of concepts, relationships and initial structure. The differential of AHL is that experts identify the sequence in which the concepts are activated and the system is iteratively adjusted until it satisfies the stopping criteria (Stach et al., 2010).

Subsequently, Stach *et al.* (2010) proposed a novel extension to NHL called DD-NHL. According to the authors, the method has the advantage of employing historical data and output concepts to improve learning quality, thus producing better *FCMs* than the generic NHL. In other words, instead generating data used for learning only from the current model, it takes advantage of data available for a given system. Thus, the DD-NHL does not rely on derived initial map and a set of conditions on desired outputs concepts. However, it has the need of historical data.

The evolutionary algorithm approach is based on the axiom of evolutionary optimization that has emerged as a powerful tool for finding optimum solution of complex problem (Yildiz, 2013). Vaščák and Madarász (2010) also states that evolutionary optimization many times repeated computation should lead to results near the optimum and thus it should reach a stable state, too. In the evolutionary algorithm-based Approach category, the methods that have gained greater visibility are: Genetic strategies (GS) (Koulouriotis, Diakoulakis, & Emiris, 2001), Particle Swarm Optimization (PSO) (Parsopoulos, Papageorgiou, Groumpos, & Vrahatis, 2003), Genetic Algorithms (GA) (Khan & Chong, 2003), Differential evolution (DE) (Papageorgiou & Groumpos, 2003), Self-Organizing Migration Algorithm (SOMA) (Zelinka, 2002), Real-Coded Genetic Algorithm (RCGA) (Stach *et al.*, 2005), Tabu Search (Alizadeh et

al., 2007), and Simulated Annealing (Ghazanfari, Alizadeh, Fathian, M., & Koulouriotis, 2007).

In 2001, Koulouriotis *et al.* (2001) applied Genetic strategy (GS) to the FCM model structure using historical data. The historical data is used to obtain inputs and outputs, defined through a multiple sequence of state vectors. In mentioned model, they also focused on the development of an evolutionary strategies-based procedure that determines the causality relationships (Alizadeh, Ghazanfari, Jafari, & Hooshmand, 2007). However, this approach is limited to domains where it is possible to obtain the sequence of state vectors.

Later, PSO was proposed by Parsopoulos et al. (2003). It is inspired by the social behavior of migratory birds and executes its search for a solution through the maintenance and transformation of the swarm of individuals. The PSO algorithm is composed of a swarm of particles moving in the multi-dimensional search space which includes all possible candidate solutions (Salmeron & Froelich, 2016). And the goal of this method is the learning of the structure based on historical data that converge to a desired final state (Papageorgiou, 2012).

Observing this same approach Khan and Chong (2003) developed GA, which originates in the field of biology. Unlike other methods, it seeks to find an initial state vector that leads to specific high quality solutions. These algorithms search problems by relying on bio-inspired operators such as mutation, crossover and selection (Mitchell, 1996). From this initial stimulus state, the utilization of GAs are not only optimizing target solutions but are also making a vigorous contribution to the development of artificial intelligence.

Differential evolution is an approach that was proposed by Papageorgiou and Groumpos (2003). In their work, the authors applied the technique to help physicians manage and make decisions in radiotherapy treatments. The proposed algorithm determined the ideal weight matrix for the supervisor-FCM model with the synchronously satisfying objective criteria. The main advantages of DE are: robustness, speed, effective global optimization capability and not requiring that the objective function be differentiable (Nolle, Zelinka, Hopgooda, & Goodyear, 2005).

Another optimization approach is SOMA which was introduced by Zelinka (2002). This approach is based on intelligent cooperation as for instance wolf packs. In this approach, individuals are mutually influenced during the search process, which leads to forming or cancelling groups of individuals. Such groups organize themselves the movement of individuals. The main advantages of this approach are based on its ability to process diverse

data types of parameters like integers, real or discrete values, it is easily possible to modify it by customer's efforts and the system described by FCM is very comprehensive (Vaščák, 2012).

The Real-Coded Genetic Algorithm (RCGA) was presented by Stach *et al.* (2005) as a floating-point extension of GAs, which used binary vectors. The RCGA has the advantage of being able to use various strategies to subdivide the input data to accelerate the learning process. Froelich and Juszczuk (2009) carried out a comparative study in which the effectiveness and superior performance of the RCGA compared to other methods was proven when it comes to forecasting tasks. Although this approach is flexible with regard to input data, single or multiple times series, the more input data, the better the learning accuracy.

Glover in 1989 introduced tabu search (TS) as a method for escaping local optima, in which the goal is to obtain a list of forbidden solutions in the neighborhood of a solution to avoid cycling between solutions while allowing a direction (Alizadeh et al., 2007). In 2007, Alizadeh *et al.* (2007) developed an approach called Tabu Search (TS). In their work, the authors demonstrated that the TS approach not only produced a faster learning process, but also improved the quality of *FCMs* with large numbers of nodes. The efficiency of the method has been demonstrated by comparing numerical examples, so it still needs to be further tested.

Simulated Annealing (AS) is a robust general optimization method that was introduced by Kirkpatrick, Gelatt Jr. and Vecchi (1983). This name was chosen as it simulates the annealing of metal: where metal is heated to the melting point and then slowly cooled (Nolle et al., 2005). In 2007, Ghazanfari *et al.* (2007) proposed Simulated Annealing (AS) as an approach that produces better *FCMs* than GA in systems with large numbers of nodes. This approach aims to solving problems both unconstrained and bound-constrained (Salmeron & Froelich, 2016).

Table 3 presents a comparison of the main variations of the three categories of Computational Methods: Hebbian-based, Population-based approach and Hybrid learning methods. This table was built up departing from Papageorgiou (2012) to present the main objectives, the types of inputs and the need for human intervention. Normally, the different types of *Computational Methods* are fully automated and do not require human intervention. But in some cases such as NHL, AHL and others, related in the Table 3 represents what we can call hybrid methods.

Table 3 - Computational Methods and their variations

Category	Algorithms	Requires human intervention	Learning goal	Type of data used	Reference
Hebbian-based	DHL	No	Connection matrix	Single historical	(Dickerson & Kosko, 1994)
	BDA	No	Connection matrix	Single historical	(Huerga, 2002)
	NHL	Yes, in the first moment	Connection matrix	Single historical	(Papageorgiou et al., 2003)
	AHL	Yes, in the first moment	Connection matrix	Single historical	(Papageorgiou et al., 2004)
	DDNHL	No	Connection matrix	Single historical	(Stach et al., 2008)
evolutionary algorithm-based approach	GS	No	Connection matrix	Multiple historical	(Koulouriotis <i>et al.</i> , 2001)
	PSO	No	Connection matrix	Multiple historical	(Parsopoulos et al., 2003)
	GA	No	Initial input vector	N/A	(Khan & Chong, 2003)
	Differential evolution	No	Connection matrix	Single historical	(Papageorgiou & Groumpos, 2003)
	SOMA	No	Connection matrix	Single historical	(Zelinka, 2002)
	RCGA	No	Connection matrix	Single or multiple historical	(Stach et al., 2005a)
	Tabu search	No	Connection matrix	Multiple historical	(Alizadeh et al., 2007)
	Simulated annealing	No	Connection matrix	Multiple historical	(Ghazanfari et al., 2007)
Hybrid learning methods	NHL-DE	No	Connection matrix	Single historical	(Papageorgiou & Groumpos, 2005)
	NHL-RCGA	No	Connection matrix	Single historical	(Zhou & Zhang, 2008)

Source: based on Papageorgiou (2012).

Stach and his colleagues (2005b) in their survey highlight the main advantages of *Computational Methods*. For them they are free of human biases when fully automated; the

accuracy is greater; and there is the possibility of using historical data for the identification of causalities (edges) and their weights. More recent developments, in the hybrid methods are adding more advantages to these traditional automated methods. The possibility of human intervention on them may add the advantages related to the *Expert-Based Methods*.

2.4. Conclusions

Every year *FCMs* are being improved and adjusted to fit different objectives, problems and areas of application. After more than 30 years of development, *FCMs* are a consolidated approach for analyzing dynamic environments. An increasing number of publications represents the growing interest in this tool. We show in this paper that *Expert-Based Methods* have been used from the mid-1980s to a more complex of nowadays *Computational Methods*. We identified an increasing number of studies on *FCMs* in several new areas not considered in previous studies.

This new phenomenon may indicate that experts are recognizing the interdisciplinary potential of *FCMs* and their benefits for solving different kinds of problems. The areas with the greatest focus on Computer science, Engineering and Mathematics, continue expanding. However, areas such as Business, Management, Accounting, Decision and Social Sciences, which previously did not use *FCMs*, have shown considerable growth in the last 5 years. This is a clear confirmation of the maturity and the ability of *FCMs* to be useful for purposes other than those originally intended.

It has also been noted that of the two methods for developing *FCMs* *Expert-Based Methods* and *Computational Methods*, the latter has been undergoing constant adjustments and improvements. The great advantage of *Computational Methods* is that they mitigate human biases, are automated, and have been proven to be the most accurate for dynamics analyses. The use of one or the other depends on variables such as: feasibility of consulting historical data, number of specialists available to participate in the research, and research objective.

Besides highlighting the new phenomenon further studies must address some limitations of this one. The search for articles was performed solely and exclusively using the Scopus database. Therefore, this literature review is not expected to be a census, but to represent a global overview through data from a reliable source. Scopus classification was used to determine the areas in which the articles best fit. Another limitation is in the classification of authors, which was based on the institutional affiliation and not based on Scopus classification. Scopus classifies authors by the journals where they publish their articles.

Basically, our contribution in this article is an attempt to characterize the production of scientific literature and revise it in order to identify the main applications of *FCMs*. We expect that future research integrates *Expert-Based Methods* and historical data in order to mitigate the limitations of the first and better explore its advantages. We also have confidence that new hybrid learning algorithms will be developed and efficiently integrated in the *Computational Methods*. If so, their applications in the new frontiers of Business, Management, Accounting, Decision and Social Sciences will be expanding the knowledge in these fields as it used to do in the pioneering areas where FCMs were used.

References

- Aguilar, J.A. (2005). Survey about Fuzzy Cognitive Maps Papers. *International journal of computational cognition*, 3(2), 27-33.
- Alizadeh, S., Ghazanfari, M., Jafari, M., & Hooshmand, S. (2007). Learning FCM by tabu search. *International Journal of Computer Science Issues*, 2(2), 142–149.
- Amer, M., Daim, T.U., & Jetter, A. (2016). Technology roadmap through fuzzy cognitive map-based scenarios: the case of wind energy sector of a developing country. *Technology Analysis and Strategic Management*, 28(2), 131-155.
- Arvan, M., Omidvar, A., & Ghodsi, R. (2016). Intellectual capital evaluation using fuzzy cognitive maps: A scenario-based development planning. *Expert Systems with Applications*, 55, 21-36
- Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*. Princeton: Princeton University Press.
- Azadeh, A., Zarrin, M., Abdollahi, M., Noury, S., & Farahmand, S. (2015). Leanness assessment and optimization by fuzzy cognitive map and multivariate analysis. *Expert Systems with Applications*, 42(15), 6050 – 6064.
- Azadeh, A., Ziaei, B., & Moghaddam, M. (2012). A hybrid fuzzy regression-fuzzy cognitive map algorithm for forecasting and optimization of housing market fluctuations. *Expert Systems with Applications*, 39(1), 298-315.
- Bertolini M., & Bevilacqua, M. (2010). *Fuzzy cognitive maps for human reliability analysis in production systems*. In C. Kahraman, & M. Yavuz (Eds.). *Production Engineering and Management under Fuzziness: Studies in Fuzziness and Soft Computing*. (vol. 252, 381–415). New York: Springer-Verlag Berlin Heidelberg.
- Carvalho, J.P., & Tomé, J.A.B. (1999). Rule based *Fuzzy Cognitive Maps* and *Fuzzy Cognitive Maps* - a comparative study. *Proceedings of the 18th International Conference of the North American Fuzzy Information Processing Society, NAFIPS*, New York, USA, 18.
- Chen, R. Y. (2016). Fuzzy dual experience-based design evaluation model for integrating engineering design into customer responses. *International Journal on Interactive Design and Manufacturing*, 10(4), 439-458.
- Chi, Y., & Liu, J. (2016). Learning of fuzzy cognitive maps with varying densities using a multiobjective evolutionary algorithm. *IEEE Transactions on Fuzzy Systems*, 24(1), 71 – 81.
- Codara, L. (1998). *Le mappe cognitive*. Roma: Carrocci Editore.

- Dickerson, J.A., & Kosko, B. (1994). Virtual worlds as fuzzy cognitive maps. *Presence*, 3(2), 173–189.
- Ferreira, F.A.F. (2016). Are you pleased with your neighborhood? A fuzzy cognitive mapping-based approach for measuring residential neighborhood satisfaction in urban communities. *International Journal of Strategic Property Management*, 20(2), 130–141.
- Froelich, W., & Juszczuk, P. (2009). Predictive capabilities of adaptive and evolutionary fuzzy cognitive maps—a comparative study. In N.T. Nguyen, & E. Szczerbicki (eds.). *Intelligent Systems for Knowledge Management: Studies in Computational Intelligence* (vol. 252, 153–174). Berlin: Springer.
- Froelich, W., & Pedrycz, W. (2017). Fuzzy cognitive maps in the modeling of granular time series. *Knowledge-Based Systems*, 115, 110–122.
- Ghazanfari, M., Alizadeh, S., Fathian, M., & Koulouriotis, D.E. (2007). Comparing simulated annealing and genetic algorithm in learning FCM. *Applied Mathematics and Computation*, 192, 56–68.
- Glykas, M. (2013). Fuzzy cognitive strategic maps in business process performance measurement. *Expert Systems with Applications*, 40(1), 1–14.
- Hebb, D.O. (1949). *The Organization of Behavior*. New York: Wiley.
- Huerga, A.V. (2002). A balanced differential learning algorithm in fuzzy cognitive maps. *Proceedings of the 16th International Workshop on Qualitative Reasoning*, Catalonia, Spain.
- Kang, J., Zhang, J., & Gao, J. (2016). Improving performance evaluation of health, safety and environment management system by combining fuzzy cognitive maps and relative degree analysis. *Safety Science*, 87, 92–100.
- Kirkpatrick S, Gelatt Jr., C.D., & Vecchi, M.P. (1983). Optimization by simulated annealing. *Science*, 220(4598), 671–680.
- Khan, M., & Quaddus, M. (2004). Group decision support using fuzzy cognitive maps for causal reasoning. *Group Decision and Negotiation*, 13(5), 463–480.
- Khan, M. S., & Chong, A. (2003). Fuzzy cognitive map analysis with genetic algorithm. *Proceedings of the Indian International Conference on Artificial Intelligence*, Hyderabad, India.
- Koulouriotis, D. E., Diakoulakis, I. E., & Emiris, D. M. (2001). Learning fuzzy cognitive maps using evolution strategies: a novel schema for modeling and simulating high-level behavior. *Proceedings of the IEEE Congress on Evolutionary Computation*, Seoul, South Korea, 1.

- Kok, K. (2009). The potential of *Fuzzy Cognitive Maps* for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change*, 19(1), 122–133.
- Kosko, B. (1986). *Fuzzy Cognitive Maps*. *International Journal of Man-Machine Studies*, 24(1), 65-75.
- Kosko, B. (1988). Hidden patterns in combined and adaptive knowledge networks. *Internet. International Journal of Approximate Reasoning*, 4(2), 377–393.
- Kosko, B. (1992). *Neural Networks and Fuzzy Systems*. New Jersey: Prentice-Hall.
- Lee, D.H., & Lee, H. (2015). Construction of holistic Fuzzy Cognitive Maps using ontology matching method. *Expert Systems with Applications*, 42(14), 5954 – 5962.
- Mezei, J., & Sarlin, P. (2016). Aggregating expert knowledge for the measurement of systemic risk. *Decision Support Systems*, 88, 38-50.
- Motlagh, O., Jamaludin, Z., Tang, S. H., & Khaksar, W. (2015). An agile FCM for real- time modeling of dynamic and real-life systems. *Evolving Systems*, 6(3), 153–165
- Nápoles, G., Grau, I., Bello, R., & Grau, R. (2014). Two-steps learning of Fuzzy Cognitive Maps for prediction and knowledge discovery on the HIV-1 drug resistance. *Expert Systems with Applications*, 41(3), 821-830.
- Nolle, L., Zelinka, I., Hopgooda, A. A., & Goodyear, A. (2005). Comparison of an self-organizing migration algorithm with simulated annealing and differential evolution for automated waveform tuning. *Advances in Engineering Software*, 36(10), 645-653.
- Olazabal, M., & Pascual, U. (2016). Use of fuzzy cognitive maps to study urban resilience and transformation. *Environmental Innovation and Societal Transitions*, 18, 18-40.
- Omari, R.M., & Mohammadian, M. (2016). Rule based fuzzy cognitive maps and natural language processing in machine ethics. *Journal of Information, Communication and Ethics in Society*, 14(3), 231-253.
- Papageorgiou, E. I. (2011). Review study on *Fuzzy Cognitive Maps* and their applications during the last decade. *IEEE International Conference on Fuzzy Systems*, 828 – 835.
- Papageorgiou, E. I. (2012). Learning Algorithms for *Fuzzy Cognitive Maps*—A Review Study. *IEEE transactions on systems*, 4(2), 150 – 163.
- Papageorgiou, E. I. (2014). *Fuzzy Cognitive Maps for Applied Sciences and Engineering*. Greece: Springer.

- Papageorgiou, E. I., & Groumpos, P. P. (2003). Optimization of fuzzy cognitive map model in clinical radiotherapy through the differential evolution algorithm. *Biomedical soft computing and human sciences*, 9(2), 25–31.
- Papageorgiou, E. I., & Groumpos, P. P. (2005). A new hybrid learning algorithm for fuzzy cognitive maps learning. *Applied Soft Computing*, 5, 409 - 431.
- Papageorgiou, E. I., Stylios C. D., & Groumpos P. P. (2003). Fuzzy Cognitive Map Learning Based on Nonlinear Hebbian Rule. *Proceedings of the Australian Conference on Artificial Intelligence*, Perth, Australia, 16.
- Papageorgiou, E. I., Stylios C. D., & Groumpos P. P. (2004). Active Hebbian Learning Algorithm to Train Fuzzy Cognitive Maps. *International Journal of Approximate Reasoning*, 37(3), 219-249.
- Parsopoulos, K. E., Papageorgiou, E. I., Groumpos, P. P., & Vrahatis, M. N. (2003). A first study of fuzzy cognitive maps learning using particle swarm optimization. *Proceedings of the IEEE Congress on Evolutionary Computation*, Canberra, Australia, 3.
- Pedrycz, W. (2010). The design of cognitive maps: A study in synergy of granular computing and evolutionary optimization. *Expert Systems with Applications*, 37(10), 7288-7294.
- Pedrycz, W., Jastrzebska, A., & Homenda, W. (2016). Design of fuzzy cognitive maps for modeling time series. *IEEE Transactions on Fuzzy Systems*, 24(1), 120-130.
- Rodriguez-Repiso, L., Setchi, R., & Salmeron, J. L. (2007). Modelling IT Projects success with Fuzzy Cognitive Maps. *Expert Systems with Applications*, 32(2), 543-559.
- Salmeron, J. L., Vidal, R., & Mena, A. (2012). Ranking fuzzy cognitive map based scenarios with TOPSIS. *Expert Systems with Applications*, 39(3), 2443 – 2450.
- Salmeron, J.L., & Froelich, W. (2016). Dynamic optimization of fuzzy cognitive maps for time series forecasting. *Knowledge-Based Systems*, 105, 29-37.
- Schneider, M., Shnaider, E., Kandel, A., & Chew, G. (1998). Automatic construction of FCMS. *Fuzzy Sets and Systems*, 93(2), 161–172.
- Song, H. J., Miao, C. Y., Wuyts, R., Shen, Z. Q., & D'Hondt, M. (2011). An Extension to *Fuzzy Cognitive Maps* for Classification and Prediction. *IEEE transactions on fuzzy systems*, 19(1), 116 – 135.
- Stach, W., Kurgan, L.A., Pedrycz, W., & Reformat, M. (2005a). Genetic learning of Fuzzy Cognitive Maps. *Fuzzy Sets and Systems*, 153(3), 371–401.

- Stach, W., Kurgan, L.A., & Pedrycz, W. (2005b). A survey of fuzzy cognitive map learning methods. In: Grzegorzewski, P., Krawczak, M., Zadrozny, Z. (eds.) *Issues in Soft Computing: Theory and Applications*. Berlin: Springer.
- Stach, W., Kurgan, L.A., & Pedrycz, W. (2008). Data driven nonlinear Hebbian learning method for fuzzy cognitive maps. *Proceedings of the IEEE World Congress Computational Intelligence*, Hong Kong, China.
- Stach, W., Kurgan, L.A., & Pedrycz, W. (2010). Expert-based and Computational Methods for Developing Fuzzy Cognitive Maps. In: Glykas, M. (Ed.). *Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications*. Berlin: Springer.
- Stylios, C. D., Georgopoulos, V. C., & Groumpos, P. P. (1997). Introducing the theory of Fuzzy Cognitive Maps in distributed systems. *Proceedings of the 12th IEEE International Symposium on intelligent control*, Istanbul, Turkey.
- Tsadiras, A. K. (2008). Comparing the inference capabilities of binary, trivalent and sigmoid fuzzy cognitive maps. *Information Sciences*, 178(20), 3880–3894
- Van Vliet, M., Kok, K. & Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies: the use of *Fuzzy Cognitive Maps* as a communication and learning tool. *Futures*, 42(1), 1-14.
- Vaščák, J., & Adarász, L. (2010). Adaptation of *Fuzzy Cognitive Maps*: a comparison study. *Acta Polytechnica Hungarica*, 7(3), 109–122.
- Wee, Y.Y., Cheah, W.P., Tan, S.C., & Wee, K. (2015). A method for root cause analysis with a Bayesian belief network and fuzzy cognitive map. *Expert Systems with Applications*, 42(1), 468-487.
- Wu, K., & Liu, J. (2016). Robust learning of large-scale fuzzy cognitive maps via the lasso from noisy time series. *Knowledge-Based Systems*, 113, 23-38.
- Xirogiannis, G., & Glykas, M. (2004). Fuzzy cognitive maps in business analysis and performance-driven change. *IEEE Transactions on Engineering Management*, 51(3), 334–351
- Zhou, X., & Zhang, H. (2008). An algorithm of text categorization based on similar rough set and fuzzy cognitive map. *Proceedings of the 5th International Conference on Fuzzy Systems and Knowledge Discovery*. Shandong, China.
- Mitchell, M. (1996). *An Introduction to Genetic Algorithms*. Cambridge, MA: MIT Press.
- Oja, E. (1989). Neural networks, principal components and subspaces. *International Journal of Neural Systems*, 1, 61-68.

- Papakostas, G. A., Polydoros, A. S., Koulouriotis, D. E., & Tourassis, V. D. (2011). Training Fuzzy Cognitive Maps by using Hebbian learning algorithms: A comparative study. *Proceedings of IEEE International Conference on Fuzzy Systems*, Taipei, 851-858.
- Haykin, S. (1999). *Neural networks: A comprehensive foundation*. India: Prentice-Hall.
- Yildiz, A. R. (2013). Comparison of evolutionary-based optimization algorithms for structural design optimization. *Engineering Applications of Artificial Intelligence*, 26(1), 327-333.
- Zelinka, I. (2002). *Artificial Intelligence in Problems of Global Optimization*. Prague: Ben.
- Vaščák, J. (2012). Adaptation of fuzzy cognitive maps by migration algorithms. *Kybernetes*, 41(3/4), 429-443.

3. THE RELEVANCE OF STAKEHOLDERS IN FUZZY COGNITIVE MAP BASED SCENARIOS: A BIBLIOMETRIC STUDY

3.1. Introduction

In recent years, scenario planning has grown in importance in the management of companies and nations. In order to create reliable objectives, several methods of scenario development have been created. These methods comprise qualitative and quantitative approaches inherited from their own school of origin. Each approach has advantages and limitations that can be observed by studying each method.

However, mixed approaches often show a weak connection between qualitative and quantitative methods (Kok, 2009, Kok & Van Delden, 2009). Many authors have sought to integrate and make use of qualitative and quantitative tools within the creation of mixed approaches, so as to mitigate the limitations and allow reaping the benefits of each approach (Mietzner & Reger, 2004).

The use of fuzzy cognitive maps (FCMs), among various scenario development approaches, has the benefit of overcoming the limitations of qualitative and quantitative techniques (Amer, Jetter & Daim, 2011) by combining qualitative knowledge and a quantitative structuring process (Kim, Han, Lee & Park, 2016). Although the method can be operated without human involvement, when used in scenario planning, human contribution is at the heart of the method. Therefore, the utility and usefulness of the FCM model largely depends on the selection of appropriate experts and stakeholders, who are the key people responsible for the quality of the system design (Hans-Horst & Jetter, 2003).

Therefore, considering the relevance of specialists and stakeholders in fuzzy cognitive map based scenario planning, together with the lack of a study to characterize the specific sub-area of the topic studied, a need exists to conduct a study on the identification of stakeholders in this scenario planning approach. The objective of this article is to characterize the scientific production on fuzzy cognitive map based scenario planning, to analyse the inherent participation of experts and stakeholders in developing scenarios. To achieve this objective, we analyze and consolidate the previous empirical studies in order to address the following questions:

- Which stakeholders prevail in the development of FCMs?
- What are the main subjects of the studies in this area?

- In what areas is the method applied?
- What are the trends for future studies?

This study contributes by identifying the set of stakeholders considered by the literature as the leading ones that develop FCM based scenario planning. This information is useful for researchers interested in developing their own studies using this approach. It also presents the identification of what types of stakeholders prevail in developing FCMs, verification of the main subjects of the studies, determination of the areas where the method is applied and indication of trends for future studies.

3.2. Theoretical foundation

In this study we focus on three theoretical frameworks for scenario planning, starting with a brief explanation of the “la prospective school”, “probabilistic modified trends school” and “intuitive logics school” (Bradfield, Wright, Burt, Cairns & Heijden, 2005). Then we discuss FCMs, because their preparation for scenario planning is the focus of this study. Finally, we address stakeholder theory and the prioritization of stakeholders.

3.2.1. Scenario planning

Scenario planning dates back to the dawn of humanity. The historical record reveals that early human societies had great concern about the future and used scenarios as a tool to indirectly explore the future of society and its institutions (Bradfield et al., 2005). It can be said that the ancient Greek oracles gained their fame by trying to imagine the future, because predicting the future was a strong political instrument (Cuhls, 2003). It is also possible to note the use of scenarios in the writings of the first philosophers, like Plato (Von Reibnitz, 1988, Wilson, 1978), and of visionaries like Thomas More and George Orwell (Bradfield et al., 2005).

Although efforts to speculate about and predict the future go back thousands of years, the study of scenarios as a scientific discipline only gained fame in the years after World War II (Robinson, 2003), emerging out of the development of military strategies in history (Brown, 1968). Initially, the tool was formally introduced by Herman Kahn (Schwartz, 2000), a military strategist and systems theorist with the RAND Corporation, who used it in military studies conducted by the American government (Georgantzas & Acar, 1995). As a consequence, Herman Kahn often is called the father of modern scenario planning (Cooke, 1991).

In the 1960s, with growing worry about the environment, methods to develop scenarios started to be applied to investigate the extent of environmental problems (Tiley & Fuller, 2000). Academics and analysts also used the tool to forecast the behavior of various markets (Ringland, 2006). At that time, studies of the future reached a new level, such as those conducted by Pierre Wack, an employee of Royal Dutch Shell (Schwartz, 2000). Based on the work of a group of strategic planners, Shell popularized the idea of analyzing scenarios (Wack, 1985).

In the early 1970s, Pierre Wack's team developed many scenarios for strategic planning (Georgantzas & Acar, 1995). In this period, two countries gained prominence in the development of scenario planning techniques, the United States and France. The work done in these two countries together is considered as forming pillars supporting practically all the concepts and techniques involving scenarios. From the United States came the "probabilistic modified trends school" and the "intuitive logics school", while virtually in parallel, France chimed in with "la prospective school" (Bradfield et al., 2005). These three schools are responsible for almost all we know and have developed about scenarios. Since then, various formal techniques have been developed and used in a wide range of sectors. According the *Fortune*, three-fourths of the world's largest companies had adopted the tool in the 1970s, helping to spread it around the world (Ringland, 2006).

The 1980s saw a decline in the use of scenarios, because the forecasts and judgments about the future involving various problems, such as the environment and economics, did not materialize as foreseen (Tiley & Fuller, 2000). They lost force mainly for having failed to predict the global recession of the early 80s (Ringland, 2006). Then in the 1990s, futurist methods underwent reformulation and changed their focus, to be less predictive and more prospective and exploratory (Tiley & Fuller, 2000). In this context, construction of scenarios is based on concern for providing information about the future, to support decision making (Robinson, 2003), through an impressive range of techniques and methods.

In recent years, scenario planning has enjoyed a renaissance, as indicated by the growing attention paid to the theme by academics and business and government planners (Bradfield et al., 2005). The many techniques and methods are highly creative and varied, ranging from very simple to highly sophisticated (Godet, 2000), so as to meet different objectives.

3.2.1.1. Probabilistic modified trends school (PMT)

The probabilistic modified trends school is composed by two distinct sub-groups, trend-impact analysis (TIA) and cross-impact analysis (CIA), which were developed by Olaf Helmer, Ted Gordon and others at the RAND Corporation in the USA (Bradfield et al., 2005; Amer, Daim & Jetter, 2013). Both sub-groups are quantitative, involving probabilistic modification of extrapolated trends and were developed by the same people (Bishop, Hines & Collins, 2007; Amer et al., 2013). Although it requires knowledge and statistical tools, making the methods of this school more restricted, they are used frequently (Huss & Honton, 1987; Gordon, 1994a).

In 1966, Theodore Gordon and Olaf Helmer developed the CIA in a game for Kaiser Aluminum Company, in order to answer the question: “Can forecasting be based on perceptions about how future events may interact?” (Huss & Honton, 1987, Gordon, 1994b). Since then, the CIA has been used in many different contexts (Amer et al., 2013). The CIA introduces casual and correlational cross-impact relationships that evaluate the changes in the probability of events’ occurrence. Therefore, these methods take cognizance of the interdependencies of events, moving from a system of unprocessed initial probabilities to a set of corrected probabilities (Bradfield et al., 2005; Godet, 1987). The main advantage of this sub-group is the estimation of interdependency among events. In addition, a number of experts’ opinions can be used to enrich the probabilities and increase the knowledge of future developments. On the other hand, it has some limitations. There is a limitation in the number of hypotheses and it can be tedious when a large number of events are involved in judging the probability. Another common negative point is the bias of experts’ opinions, so good experts are needed.

Since the early 1970s, TIA has been practiced by futurists and corporations (Abbasi, Saken & Bahrami, 2015) for extrapolative prediction and policy evaluation (Bradfield et al., 2005). The similarity between a TIA method and other quantitative methods is that the forecast is based on quantitative tools. However, the difference between TIA and other quantitative methods is the use of experts’ opinions about probable events in the future to improve the basic forecast (Abbasi et al., 2015). Therefore, TIA is “a simple approach to forecasting in which a time series is modified to take into account perceptions about how future events may change extrapolations that would otherwise be surprise-free” (Gordon, 1994a). This is the main advantage of this sub-group, because it combines more traditional forecasting techniques such as time series and econometrics with qualitative factors such as analysts’ opinions (Huss &

Honton, 1987; Gordon, 1994a), in order to avoid the bias of using only historical data. And as disadvantages, it needs historical data, does not evaluate possible impacts the events may have on each other and requires a good expert accurately set probabilities and a complete list of events.

3.2.1.2. Intuitive logics school

The history of the intuitive logics approach can be traced even further back to the work of Kahn and Wiener (1967), who proposed it in the 1960s. They explored the intuitive and subjective aspect of scenarios. But this school, also called the Anglo-American school of scenario planning, was only popularized by Royal Dutch-Shell Corporation to develop the scenarios described by Pierre Wack (1985a, 1985b) (Joshi, 2015; Huss & Honton, 1987).

Since then it has become the most popular school (Bradfield et al., 2005). A main characteristic is that instead of considering the probability of each scenario being irrelevant (Ramirez & Selin, 2013), scholars instead focus on their plausibility (Millet, 2009). Paying heed to plausibility recognizes reflexive attention to the logic of what might be emerging as described in the scenario

The intuitive logics school also has some limitations. Scenario studies working within the premises of the intuitive logics school do not have a particularly strong track record of dealing with major developments, and in particular, discontinuities that have not been thought of before (van Notten, Slegers & Van Asselt, 2005). This school has a high-level scenario development process, but without a theoretical basis or prescriptions for executing different process steps. The lack of theoretical grounding has led to a proliferation of methods for developing scenarios, but without any basis for comparing them (Phadnis, Caplice, Singh & Sheffi, 2014).

3.2.1.3. La prospective school

Around the same time, the la prospective school emerged in France to oppose the limitations of classic forecasting (Postma & Bood, 2015). The philosopher Gaston Berger, founded the Centre d'Etudes Prospectives and introduced the French method as a scenario planning approach (Chermack, Lynham & Ruona, 2001). It was subsequently developed by Godet and researchers at the French Office for Regional Planning and Development (DATAR) (Durance & Godet, 2010; Godet, 2001)

The big difference between the American and French schools is that the American schools tend to have a global scope, while the French school is more focused on socio-political foundations of France (van Vught, 1987; Bradfield et al., 2005). For this school, the future is not written in stone, but can be constructed by those willing to make a sacrifice to turn their projects into reality. Thus, the decisions of the present are justified by possible and desirable futures (Godet, 1982; Durance & Godet, 2010; Martin, 2010). It usually uses an approach based on mathematics, statistics and computers for scenario creation (Bradfield, Wright, Burt, Cairns & Heijden, 2005). Thus, it is more focused on the desired end state.

The French school of scenario planning is based on four essential steps: the base, external context, progression, and images (Durand, 1972; Amer, 2013). The most popular methods and tools of this school are Morphol, Smic Prob-expert, Micmac and Mactor. Therefore, the la prospective school applies a blend of many tools and has some characteristics of the intuitive logics school and the probabilistic modified trends school.

3.2.2. Fuzzy cognitive mapping

Fuzzy cognitive mapping (FCM) is a method for modeling the world or a phenomenon as a collection of concepts and casual relations between them through human knowledge or experience. FCM has its roots in the theories of fuzzy logic and neural networks (Aguilar, 2005; Papageorgiou, 2012; Napoles, Grau, Papageorgiou, Bello & Vanhoof, 2016). It was first proposed by Kosko (1986) as an extension to the cognitive mapping already introduced by Axelrod (1976), which only works with binary values. The main contribution of FCM was to enriched the relations with different degrees and analyze it in a diffuse way (Stach, Kurgan & Pedrycz, 2010).

In the graphical form, FCM consists of a set of concepts that represent key variables or characteristics of a system (Kosko, 1992). These concepts have an interactive causality that represents the relationships among them. The relationships (edges) can take positive and negatives values in the interval $[-1,1]$. A positive value shows a positive causal relationship while a negative value shows that two concepts have opposite relationship (Huerga, 2002). The data in the graphs can also be presented in matrix form. This form facilitates mathematical operations, because the values of concepts are represented by a state vector and the weights of causal relationships are represented by an adjacent matrix (Kosko, 1986).

There are two ways to develop fuzzy cognitive maps: deductive and inductive modeling. The deductive (conventional) way involves the application of human expertise. The

second is the inductive way, which was introduced relatively recently, uses available data and a learning algorithm in a given domain (Stach, Kurgan & Pedrycz, 2005).

FCM is a flexible tool that has been applied successfully in a large number of disciplines (Stach et al., 2005), ranging from electrical engineering to medicine (Kok, 2009). Although the tool is used in many fields, its application in scenario planning is still embryonic and needs to be further analyzed.

3.2.3. Stakeholder theory

The word “stakeholder” was first used by researchers at the Stanford Research Institute in 1963 (Freeman, 1984). Since then it has been employed in different ways and contexts (Donaldson & Preston, 1995; Friedman & Miles, 2006). However, the most accepted definition of stakeholder is that of Freeman (1984), as all the people and groups that affect or are affected by the organizational objectives.

In contrast to the objective preached by the theory of the firm – maximization of value for stockholders – stakeholder theory considers the outcomes as they affect all interested parties. Therefore, according to stakeholder theory, firms will not survive over the long run unless they pay heed to creating value for all stakeholders, not necessarily with priority on the shareholders (Campbell, 1997).

3.2.3.1. Stakeholders prioritization

Stakeholders can be classified as primary and secondary. Primary stakeholders have a high degree of interdependence with the company, such as shareholders, investors, employees, customers, community and government. Secondary stakeholders can influence or be influenced by the firm, but do not have a direct link with it. Examples are interest groups and media vehicles. Figure 7 presents a map with the classification of primary and secondary stakeholders (Clarkson, 1995).

Figure 7- Map of primary and secondary stakeholders

Source: Clarkson (1995).

The ranking can be done according to the perception of importance of the stakeholders by managers, salience of stakeholders (Mitchell, Agle & Wood, 1997) or the dominance or need to serve the interest of stakeholders (Boaventura, 2012). Although models to prioritize stakeholders have not been explicitly presented in studies involving fuzzy cognitive map based scenario planning, these models can still be very useful to select the participants to develop FCMs.

Most future studies have involved stakeholders in the scenario development process. In scenario planning, stakeholder input is a major aspect in many integrated scenario studies (Van Vliet, Kok & Veldkamp, 2010). Also, direct stakeholder participation ensures higher credibility of scenarios (Lital, Voronova & Klõga, 2011). Hence, the scenarios should be built in collaboration among people with different expertise and backgrounds (Roubelat, 2000). The utility and usefulness of a FCM model also depends on the quality of the underlying causal map, in which the selection of appropriate experts and the combination of their cognitive maps is critical (Hans-Horst & Jetter, 2003).

3.3. Methodology

This paper is an attempt to consolidate the previous studies on fuzzy cognitive map based scenario planning by reviewing the literature to identify the main stakeholders used to

develop scenarios. This goal is justified by the need to characterize the heterogeneity of the literature on this issue. The bibliometric research to analyze the evolution of the literature was based on the main bibliometric laws: Bradford's law (productivity of periodicals), Lotka's law (scientific productivity of authors) and Zipf's law (frequency of words). We also verified the temporal evolution of the number of publications with the aim to identify some trends in scientific production (Andrés, 2009).

To select the articles, we searched the Scopus database, which is multidisciplinary, containing publications ranging from the basic sciences to engineering and including administration and other social sciences (Yoshida, 2009). Because the term "scenario" is often used indiscriminately and erroneously (Godet & Roubelat, 1996), we selected a range of terms used in the literature (Varum & Melo, 2010). The key expressions used were "fuzzy cognitive map" or "FCM", combined with "scenario planning" or "scenario development" or "scenario thinking" or "scenario building" or "scenario analysis", as well as their variations in the plural, applied in the fields "article title", "abstract" and "keywords". This wide variety of terms was used to avoid missing relevant articles. The database search was limited only to "articles" published until July 2017.

Subsequent detailed analysis of the articles revealed 14 that were published in the period from 1999 to 2017, all of them at least partially empirical (no purely theoretical articles). All the articles found were in English and described the use of scenario planning, although in very summarized form in some cases.

3.4. Analysis of the results

We found 14 articles published in 11 different periodicals, written by 17 authors of 11 nationalities. In this section we present the temporal evolution of the publications, collaboration of authors, productivity of the periodicals, an analysis of keywords and the most common stakeholders.

3.4.1. Temporal evolution of the publications

The historical publication data present an increasing tendency in the number of empirical publications that address the subject of this study. The temporal analysis of the number of publications helps to identify trends in scientific productivity in this area (Andrés, 2009). The 14 articles found and analyzed were published over a period of 18 years, from the beginning of 1999 to June 2017. Figure 8 presents the graph of the evolution of publications.

Figure 8- Graph of the evolution of publications

Source: Research data

Due to the characteristics of the tool, the use of FCMs in scenario planning has become attractive. However, so far few articles have been published, so the field is immature. In 1999, Kardaras and Karakostas (1999) presented the first insights from the use of fuzzy cognitive maps in scenario planning. However, like the great majority of studies since then, the authors did not describe the possible scenarios in detail. Related studies only returned in 2009, when Kok (2009) applied the tool to prospect deforestation in the Brazilian Amazon. Since then, the application of FCM based scenarios has grown irregularly.

3.4.2. Collaboration of authors

Among the articles analyzed, only one was written by a single author. The great majority of the articles (79 percent) had two or three authors. Table 4 presents the number of authors per publication.

Table 4 - Number of authors per article

Number of Authors	Articles	Percentage
1	1	7%
2	5	36%
3	6	43%
4	2	14%
Total	14	100%

Source: Research data

Since the authors that have been most active in publishing, Amer, Jetter and Kok, have three publications, it can be stated that they likely have a high degree of cooperation. These main authors are present in half of the published articles related to the subject of interest here.

3.4.3. Productivity of the periodicals

The most productive periodicals are *Journal of Water and Climate Change* and *Futures*, together accounting for 35% of the publications. The list of the periodicals that have published articles on FCM-based scenarios is presented in Table 5

Table 5 - Periodicals that published articles in the period

Journal	Number of publications
Journal of Water and Climate Change	3
Futures	2
Foresight	1
Energy	1
International Journal of Energy Sector Management	1
Global Environmental Change	1
Kybernetes	1
Expert Systems	1
Expert Systems with Applications	1
Information and Software Technology	1
Technology Analysis and Strategic Management	1

Source: Research data

As can be observed, the publications are dispersed in various periodicals. However, it is possible to state that the publications are concentrated in periodicals in the areas of future studies, environmental science, energy, and computer science. This concentration can be explained both because the method that unifies fuzzy cognitive maps and scenario planning, and the main areas where this combination of methods are typically applied, energy and the environment.

3.4.4. Analysis of keywords

In the 14 articles evaluated, the authors used a total of 52 keywords or key expressions. As shown in Table 6, the ones most used were “Fuzzy Cognitive Map(s)”, “Scenario(s)” and “Stakeholder(s)”. The first two are descriptive of the method utilized, namely application of FCMs to develop scenarios. In turn, the term “Stakeholder(s)” indicates a trend, since there is growing realization that the efficacy of the method is strongly related to the selection of the stakeholders.

Table 6 - Frequency of keywords

Keyword	Frequency	Keyword	Frequency
Fuzzy Cognitive Map(s)	8	Map	1
Scenario(s)	5	Mapping method	1
Stakeholder(s)	3	Multi attribute decision making	1
Delphi method	2	Multi-cyclical stability	1
Fuzzy logic	2	Oil production	1
Fuzzy mathematics	2	Political drivers	1
Participation	2	Post-sanction	1
Scenario planning	2	Public participation	1
Analytic hierarchy process	1	Qualitative analysis	1
Analytical hierarchy process	1	Quantitative analysis	1
Baltic	1	Ranking	1
Brazil	1	Resilience	1
Climatology	1	River basin management	1
Cognitive mapping	1	Scenario development	1
Dynamic fuzzy cognitive maps	1	Simulation	1
ELECTRE III	1	Socio-economic	1
Electric vehicle	1	Solar power	1
Energy industry	1	Story-and-simulation approach	1
Forecasting	1	Strategic information systems planning	1
Futuristic data	1	Technology policy	1
Fuzzy association rule mining	1	Technology roadmap	1
Global warming	1	Text mining	1
Integrated global model	1	Toolbox	1
Iran	1	Water resources	1
Large lake	1	Wind energy	1
Learning	1	Wind power	1

Source: Research data

The other key words/expressions are related to studies of the future, tools utilized and subjects of the studies. This finding corroborates the findings presented in the previous section.

3.4.5. Most common stakeholders

In all the studies where FCMs were constructed exclusively based on human beliefs, the participants were called experts. However, in some cases the FCMs were developed based on the expertise of potential consumers, the community in general or the authors themselves. The great majority of studies developed the FCMs from the knowledge and beliefs of scientists and academics. Among the primary stakeholders presented in Figure 7, the following participated in the studies: consumers, community, government, manufacturers and private sector.

Although some studies relied on a wide range of stakeholders, so as to mitigate the bias of human beliefs, we did not find any efficient method to for efficient selection of the research participants. This is a gap in these studies, despite the strong knowledge of the authors regarding the importance of stakeholders.

3.5. Conclusion

The objective of this study was to investigate the scientific production regarding scenario planning based on fuzzy cognitive maps, to analyze the inherent participation of specialists (experts) and stakeholders in developing scenarios. The specific aspects examined were: identification of what types of stakeholders prevail in developing FCMs; verification of the main subjects of the studies; determination of the areas where the method is applied; and indication of trends for future studies.

We found and analyzed 14 articles related to the topic of interest. The results show that the field has not yet reached maturity, based on the relatively small number of articles published. Furthermore, in all the studies, the FCMs were constructed exclusively from human beliefs, and the participants were called experts. However, we also found the participation of other primary stakeholders. Through the keywords, frequency of publication in periodicals and detailed analysis of each article, we identified energy and the environment as the main areas for application of the method.

The article contributes to future research by presenting the consolidated state of the literature and also the main trends in the field. Also, the identification of the main stakeholders is another important contribution of the study, since they are the main players in FCM based scenario planning. Furthermore, we identified a diversity of keywords associated with the subjects of study of the articles of this sample and also the fields where the method is used.

The main limitation of this study is the small number of articles used in the analysis. We believe this is due to the relatively recent emergence of applying FCMs to develop scenarios. Another limitation is the identification of the search terms. Although we utilized various terms referring to scenario planning, our intention was to focus only on publications in English, so the search terms were all in English.

Thus, in future empirical studies these stakeholders could be selected by some method in order to increase the quality of FCMs. Another suggestion is to include other databases, such as ISI and Ebsco.

Reference

- Aguilar, J.A. (2005). Survey about Fuzzy Cognitive Maps Papers. *International journal of computational cognition*, 3(2), 27-33.
- Andrés, A. (2009). *Measuring academic research: how to undertake a bibliometric study*. Oxford: Chandos Publishing.
- Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*. Princeton: Princeton University Press.
- Boaventura, J.M.G. (2012). *Dominância de stakeholders em empresas Brasileiras: contribuições à teoria dos stakeholders*. Tese de livre docência. Universidade de São Paulo, São Paulo, SP, Brasil.
- Campbell, A. (1997). Stakeholders: the case in favour. *Long range planning*, 30(3), 446-449.
- Clarkson, M.B.E. (1995). A stakeholder framework for analyzing and evaluating corporate social performance. *Academy of Management Review*, 20(1), 92-117.
- Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, 20(1), 65-91.
- Durance, P. & Godet, M. (2010). Scenario building: Uses and abuses. *Technological Forecasting and Social Change*, 77 (9), 1488-1492. DOI: 10.1016/j.techfore.2010.06.007
- Durand, J. (1972). A new method for constructing scenarios. *Futures*, 4, 325–330.
- Freeman, R. E. (1984). *Strategic management: a stakeholder approach*. Boston: Pitman.
- Friedman, A. L., & Miles, S. (2006). *Stakeholders: Theory and Practice*. Oxford: Oxford University Press.
- Godet, M. (1982) From Forecasting to ‘La Prospective’ A New Way of Looking at Futures. *Journal of Forecasting*, 3(1), 293-301. DOI: 10.1002/for.3980010308
- Godet, M. (2001). *Creating Futures: Scenario Planning as a Strategic Management Tool*. Economica: London.
- Hans-Horst, S., & Jetter, A.J.M. (2003). Integrating market and technological knowledge in the fuzzy front end: an FCM-based action support system. *International Journal of Technology Management*, 26, 517–539.
- Huerga, A.V. (2002). A balanced differential learning algorithm in fuzzy cognitive maps. *Proceedings of the 16th International Workshop on Qualitative Reasoning*, Catalonia, Spain.

- Kim, J., Han, M., Lee, Y., & Park, Y. (2016). Futuristic data-driven scenario building: Incorporating text mining and fuzzy association rule mining into fuzzy cognitive map. *Expert Systems with Applications*, 17, 311-323.
- Kosko, B. (1986). *Fuzzy Cognitive Maps*. *International Journal of Man-Machine Studies*, 24(1), 65-75.
- Kosko, B. (1992). *Neural Networks and Fuzzy Systems*. New Jersey: Prentice-Hall.
- Iital, A., Voronova, V., Klõga, M. (2011). Development of water scenarios for large lakes in Europe: the case of Lake Peipsi. *Journal of water and climate change*, 2(2-3), 154-165.
- Papageorgiou, E. I. (2012). Learning Algorithms for *Fuzzy Cognitive Maps*—A Review Study. *IEEE transactions on systems*, 4(2), 150 – 163.
- Martin, B.R. (2010). The origins of the concept of ‘foresight’ in science and technology: an insider’s perspective. *Technological Forecasting and Social Change*, 77, 1438–1447.
- Millet, S.M. (2009). Should probabilities be used with scenarios? *Journal of Future Studies*, 13(4), 61-68.
- Mitchell, R.K., Agle, B.R., Wood, D.J. (1997). Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts. *Academy of Management Review*, 22(4), 853-886.
- Napoles, G., Grau, I., Papageorgiou, E., Bello, R., & Vanhoof, K. (2016). Rough cognitive networks. *Knowledge-Based Systems*, 91, 46–61.
- Phadnis, S., Caplice, C., Singh, M., & Sheffi, Y. (2014). Axiomatic foundation and a structured process for developing firm-specific Intuitive Logics scenarios. *Technological Forecasting and Social Change*, 88, 122-139.
- Roubelat, F. (2000). Scenario planning as a networking process. *Technological Forecasting and Social Change*, 65 (1), 99–112. DOI: 10.1016/S0040-1625(99)00125-0.
- Stach. W., Kurgan, L.A., & Pedrycz, W. (2005). A survey of fuzzy cognitive map learning methods. In: Grzegorzewski, P., Krawczak, M., Zadrozny, Z. (eds.) *Issues in Soft Computing: Theory and Applications*. Berlin: Springer.
- Stach. W., Kurgan, L.A., & Pedrycz, W. (2010). Expert-based and Computational Methods for Developing Fuzzy Cognitive Maps. In: Glykas, M. (Ed.). *Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications*. Berlin: Springer.
- Van Vliet, M., Kok, K. & Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies: the use of fuzzy cognitive maps as a communication and learning tool. *Futures*, 42(1), 1-14. DOI:10.1016/j.futures.2009.08.005

- Van Vught, F.A. (1987). Pitfalls of forecasting: fundamental problems for the methodology of forecasting from the philosophy of science. *Futures*, 19(2), 184–196.
- Varum, C.A., & Melo, C. (2010). Directions in scenario planning literature - A review of the past decades. *Futures*, 42, 355–369.
- Yoshida, N. D. (2009). Análise bibliométrica: um estudo aplicado à previsão tecnológica. *Future Studies Research Journal*, 2(1), 52-84.

4. BRAZILIAN PHOTOVOLTAIC ENERGY SECTOR

The challenges of the electric sector are every day bigger. Worldwide, there is a chain for that the renewable energy sources take place over fossil fuel. Environmental degradation caused by deforestation, gas emission and environmental pollution have taken countries to rethink their electric systems. Countries such as Brazil, where 70% of the Energy matrix is made off renewable energy, hydroelectric (WWF-Brasil, 2015), are also in seek of diversification of its matrixes. To this purpose, the solar photovoltaic energy arises as the best option.

4.1. Sector background

Humans have always sought for new tools that would help them to perform its tasks in a most efficient and effective way. Electric energy discovery caused a revolution in different industrial sectors, allowing this way, a radical change in people's life, providing the increase of economic activities as the population well-being (Goldemberg & Moreira, 2005). During the second half of XIX century, industrial revolution presented a procedural, technologic and scientific improvement in electric sector. Since then this sector has been stabilized as a key piece in world economy and a strong competitive advantage to countries and companies (Amer, 2013).

When facing the oil crisis during the 70s, the world realized that fossil fuel is finite and subject to huge perturbations in its suppliers. An awakening to the imposed limitations of conventional energy sources and the need of search alternative sources had happened then. From this moment, initial efforts to develop photovoltaic started to be done (Varella, Cavaliero & Silva, 2008).

The sector development allowed that the production of electric energy started to be obtained through different process and sources. Fossil fuel and its derivatives, largely explored since XIX century up to current days, are responsible for carbon dioxide, main responsible for the greenhouse effect (IPCC, 2007; Hammond, 2000). The unsustainable exploration of non-renewable energy resources resulted in consequences to the environment, to the sector on its own and to the economy in general, whereas if the unrestrained use will terminate the nonrenewable resources.

As a solution to the problems caused by this unsustainable exploration, the group of cultural, social, economic, environmental and politics variables have influenced to thing the

renewable energy as a necessity. It imposed the government and companies to have obligation of adhering, so they could fit to this new reality. Therefore, pioneer countries and companies are innovating and diversifying their energy matrix. Higher levels of participation of renewable energy sources in the energy matrix has been encouraged to a world level. Series of public policies have been adopted by different countries in order to find better energy safety and sustainability. Energy specialists expect that by 2050 over 50% of all electricity can be generated through renewable energy (Ab Kadir, Rafeeu, & Adam, 2010).

In this context, photovoltaic solar energy performs, potentially, an important role in evolution of the participation of alternative sources in the world energy matrix, given its abundance and wide availability on the Earth surface (Nakabayashi, 2014). Photovoltaic solar energy (PSE) is a classic case of emergent technology in a dynamic and innovative sector, in which the scenarios present themselves as a necessary tool to the anticipation of the unknown, when building strategic planning and in the process of decision-making. Photovoltaic solar energy is an energy source that produces renewable electricity, obtained directly from solar radiation through a semiconductor device called photovoltaic cell, or through the deposition of metals over a substrate called solar cell of thin film (Pearce, 2002).

In the past 10 years photovoltaic technology has shown potential to become one of the predominant electricity sources in the world, with a stiff and continuous increase, even in times of financial and economic crisis. Since 2010 it is observed that the world installed capability of photovoltaic energy has risen more than during the 40 previous decades (IEA, 2014). It is expected this growth to continue in the following years, backed by raising awareness on the advantages of photovoltaic energy (EPIA, 2012). In Brazil, given its innumerable advantages and positive characteristics, PSE has been establishing itself as strong candidate as an alternative option to hydroelectric power.

4.2. Photovoltaic solar energy in Brazil

Despite PSE generation still presents itself in an embryonic form, it is expected that it has relevant participation in the national energy offer. Brazil has huge potential to develop it given to its long territorial extension, 8.515.767,049 km² (IBGE, 2017), to the sunny days with high levels of solar radiation during most of the year and superior to European radiations for most of its territory (Martins, Pereira, & Abreu, 2007).

Based on Renewable Energy Country Attractiveness Index (RECAI, 2015) information, Brazil is 8th in the raking of attractiveness when speaking of photovoltaic solar energy. In 2014,

Brazil presented had its total installed power up to 15 MW, in 2015 the same number surpassed 32MW (MME, 2015a). The number was over the double in only 12 months.

According to Mines and Energy Ministry (MME, 2015c), in 2018 Brazil should be between the 20 countries with the biggest generation of solar energy, considering the power already contracted (2,6 GW) and the other countries' scale of expansion. The Ten Year Energy Expansion Plan (PDE 2024) estimates that the installed capability to generate solar energy reaches to 8.300 MW in 2024, resulting in the proportion of generation of solar energy equivalent to 1% of the total electric energy to be produced in the country.

Since the end of last century, the significance and utilization of alternative renewable energy has gained more highlights given its need of diversification in the energy matrix (Varella et al., 2008). In Brazil, where the renewable sources in the electric matrix represents 74,6% (EPE, 2016), the adoption of photovoltaic solar energy has been motivated not only by energy matrix diversification, but because of the diversity of problems and barriers that the Brazilian energy sector has faced.

In several countries the investment in photovoltaic solar energy was boosted by environmental concerns, by the fact of it is an inexhaustible raw material and it does not emit pollutants while generating electricity (di Souza, 2016). Among other solutions, PSE appears as a solution to blackouts in the main Brazilian cities and also shows up as source of electric energy viable to the inaccessible properties.

4.2.1. Advantages and Disadvantages

In Brazil, like in other countries, there are innumerable benefits and advantages of producing photovoltaic energy. Regarding socio-economic benefits we have: job creation, lower noise pollution, low maintenance, low cost considering its shelf life, possibility of installation in remote areas and alternative places, diversification of the electric matrix and electricity self-sufficiency to its users.

Only in 2011 1.435.000 direct and indirect jobs were created to the installation of 30K MW (EPIA, 2012). So, it is featured among the sources with better prospects for job creation. Other than that, in the past years Brazil has activated systematically the thermoelectric plants to supply the energy demand. This activation generated a big cost to the government and the emission of 70 billion of tons of CO₂ (Miranda, 2012).

Regarding environmental benefits there are: low greenhouse gas emissions, low environmental impact within the installation area, no pollution, and capability of substitution of non-renewable and environmentally aggressive type of sources, once it is a renewable one. PSE has great potential of generation in smaller areas, which mitigates even more the environmental impact. It is estimated that a 2.400Km² area of photovoltaic panels is enough to produce and generate nearly everything that the country needs (EPE, 2012)

Despite several benefits, electric energy obtained from photovoltaic solar technology requires a high initial investment, which makes it more expensive than conventional energy (Varella et al, 2008). However, this scenery has changed, acquisition costs are now cheaper and photovoltaic solar energy has won economic competitiveness compared to other energy sources (Nakabayashi, 2014). Another downside is the need of equipment that storage its energy, in case of using it in periods without solar radiation, once photovoltaic solar production slows down in rainy periods (WWF-Brasil, 2015).

Added to natural advantages of Brazilian territory, several incentives, initiatives and regulatory mechanisms, companies and associations were created to foment and empower Brazilians to adhere to photovoltaic solar energy. The Brazilian Photovoltaic Solar Energy Association (ABSOLAR) was funded in 2013 to foment the market, break the sector barriers, defend the industry interests and represent the sector in the government, other entities of the sector, press, NGOs and companies (ABSOLAR, 2016); Also, the Energy Research Company (EPE) aims to serve studies and research in this field, which are destined to subsidize Brazilian energy sector' planning, such as electric energy and renewable energy sources (EPE, 2016).

Within the major programs developed by EPE it is found the social program, that objectives provide access to this renewable energy source to all citizens. The Program of Distributed Generation of Electric Energy (ProGD) was launched to foment the generation of renewable energy by the final users (homes, industrial and commercial facilities, public organs) (MME 2015b); The Program of Incentive to Alternative Sources (PROINFA) has as its function to diversify the Brazilian energy matrix, in a way it increases the security in supplying, the appreciation of regional characteristic and potentialities, generation new jobs and training for skilled labor (MME, 2009).

To develop these programs, several initiatives and incentives are being implemented, such as: the recent Public Call (PC) by ANEEL so that in 2014 and 2015 new photovoltaic plants start to operate in PC nº 013/2011 – Strategic Projects: “Technical and Commercial

Arrangement to Insert Photovoltaic Solar Generation in the Brazilian Energy Matrix”; IPI exemption, according to Decret n° 7.212, 15/06/2010 where electric energy, oil derivatives, fuel and minerals have tax exemptions over its industrialized products; Tax on Circulation of Goods (TCG) exemption – TCG agreement 101/97, by State Treasure Office to all Brazilian states and extended to 31/12/2012, the operations with equipment and components to utilize aeolic and solar energy are Tax on Circulation of Goods (TCG) exempt (MME, 2015a).

Other than these measures, according to MME (2015a) the Normative Resolution 481/2012 by ANEEL extended to 80% the discount in fees to use transmission/distribution systems in business with power inferior to 30 MW. This resolution also establishes rules that include microgeneration, up to 10KW, and minigeneration, from 100KW to 1MW. In addition, it was created a compensation system, where the consumer is able to install small individual energy generators and exchange power with its local distributor (PDE, 2024).

As well it was created the Program to Support Technologic Development of Semiconductors Industry (PADIS). This program exempts taxes and federal contributions on the production of semiconductors, including photovoltaic cells and modules. In addition to that, some Brazilian states have taken measures to incentive the sector through TCG, PIS, COFINS tax exemptions. The agreements TCG 16, 44 and 52 – 2015, National Council of Finance Policy (CONFAZ), signed by the states SP, GO, PE, RN, CE and TO, exempt TCG tax on the energy the user utilizes. This tax applies only to the surplus consumption. The same applies to PIS and COFINS (Law 13.169, 6/10/2015), extended to all states (MME, 2015a).

5. BENEFITS AND LIMITATIONS OF FCMs BASED SCENARIOS: THE CASE OF BRAZILIAN SOLAR PHOTOVOLTAIC ENERGY

5.1. Introduction

Today's complex, dynamic and strongly interconnected environment imposes new challenges to companies, governments and society. This highly volatile and competitive environment also is filled with uncertainties and risks. Although these have always been present, the speed and magnitude of the changes are greater than ever before (Kotler & Caslione, 2009). Therefore, the ability to innovate and predict future needs is essential to create and maintain a competitive advantage (Amer, Jetter & Daim, 2011).

Although many leaders underestimate the ability to control the future, even minimally, it can be controlled or influenced to some extent by the actions of firms (Fifield, 2006). For this purpose, scenario planning is a fundamental tool (Schoemaker, 1991). The scenarios should be plausible, consistent, pertinent and creative (Alcamo & Henrichs, 2009; Van der Heijden, 1996; Wilson, 1978; Heinecke & Schwager, 1995), aiming to support strategic planning (Georgantzias & Acar, 1995, Brown, 1968), decision making (Wright & Spers, 2006; Wilson, 1978) and organizational learning (Bezold, 2010).

In recent years, a novel approach to creating scenarios using fuzzy cognitive maps (FCMs) has been explored in the literature (Amer et al., 2011; Jetter & Schweinfort, 2011). However, the need has been noted to deepen some aspects of FCM-based scenarios. This paper explores the benefits and limitations of this new approach through its application in the solar photovoltaic energy business and also examines whether the approach can fulfill the objectives of assisting in strategic planning, decision making and organizational learning.

The remainder of this paper is organized as follows: sections 2 and 3 present a brief review of scenario planning and fuzzy cognitive maps; section 4 proposes a method employing FCMs to develop scenarios; section 5 describes application of the method to study solar energy development through the analysis of three scenarios; and section 6 reports the results of the research and discusses the benefits and limitations of FCM-based scenarios. The final section presents the conclusions and an outlook for future research.

5.2. Scenarios Planning

Scenario planning can be traced back to the origins of recorded history. Humans have always been hugely concerned about the future and have used scenarios as a tool to explore the future of society and its institutions (Bradfield, Wright, Burt, Cairns & Heijden, 2005). For example, it can be said that the ancient Greek oracles gained fame by attempting to imagine the future, mainly because predicting the future was used as a strong political instrument (Cuhls, 2003). It is also possible to note the use of scenarios in the writings of the ancient philosophers, such as Plato (Von Reibnitz, 1988; Wilson, 1978), and in later visionaries like Thomas More and George Orwell (Bradfield et al., 2005).

In recent years, the use of scenario planning has increased markedly (Rigby & Bilodeau, 2007; Coates, 2000). However, nowadays scenario planning plays a different role and its goals have changed. Its formal origins as a strategic planning tool go back to the Rand Corporation with Herman Kahn, the father of modern scenarios (Cooke, 1991). In that case it played a key role in raising the awareness of the military and the U.S. Department of Defense in the 1950s (Kahn & Wiener, 1967; Brown, 1968; Schwartz, 1977).

Scenario planning is a tool for future studies in which the goal is related to foresight, not to forecasting. This means that it does not focus on accurately predicting the future, but rather is a means to represent it with the aim of clarifying present action in light of possible, desirable and still uncertain futures (Keough & Shanahan, 2008; Durance & Godet, 2010). It is also a course of events which allows one to move forward from the original to the future situation (Godet & Roubelat, 1996). Figure 9 presents a schematic view of scenario planning starting from the concepts found in the literature.

Figure 9- Schematic view of the concept of scenario planning

In the figure, P^0 , P^1 , P^2 and P^∞ represent the past from various viewpoints and P represents the past that actually occurred. N represents the present, affected by several variables, which also can be seen from different points of view. F^2 , F^3 , F^4 , F^5 , F^6 and F^∞ represent the scenarios whose occurrence is considered plausible. This set of futures contains several futures, such as the most probable, the preferable, optimistic, pessimistic and the unthinkable. F^0 and F^1 are in the set of futures that are momentarily impossible for going beyond the current physical, technological or social limits.

The line labeled L represents the boundary, which due to physical, technical and/or social reasons cannot be overcome and that renders the scenarios lying beyond that boundary impossible. X and Y denote the driving and constraining variables, respectively. These variables can be religious, political economic, social, technological or environmental, among others, and are generally dynamic, so that their status as drivers or constraints is malleable in relation to the degree of importance and uncertainty. I represents the interaction of various characteristics of the organization, such as its environment. Therefore, the task of prospecting for or predicting scenarios with the objective of reaching the desirable scenario and being prepared for the other scenarios is extremely complex and dynamic.

The broken lines represent the scenarios that connect the present to the future. Therefore, scenario planning is not concerned with identifying the futures of interest. Rather, its objective is to peruse the history that connects the present to the multiple futures, from the most expected to the most remote, in ways that are analytically coherent and imaginably

engaging (Bishop, Hines & Collins, 2007), so as to complement the prospection process (Bezold, 2010).

However, the most important result of the tool, according to Huss (1988), is not to exactly predict the sequence of events, but rather to offer insight about the dynamics of a particular setting, the key trends to be monitored and the limits of the future outcomes for which planning is intended. This enables better preparation for and faster adaptation to new realities.

With the passage of time, individuals have improved their cognitive ability and thus the ability to speculate about the future (Cuhls, 2003). Various methods have been created for the purpose of meeting expected objectives as best as possible. These methods are mainly derived from the French “la prospective school” and the American “probabilistic modified trends school” and “intuitive logics school” (Bradfield et al., 2005). These three schools are responsible for almost all that is known and has been developed about scenarios. The “intuitive logics school” produces methods that are mainly qualitative, while the “probabilistic modified trends school” produces mainly quantitative methods and the “la prospective school” seeks to combine these two types of methods.

Both quantitative and qualitative methods have some limitations. Therefore, mixed methods have been created to overcome these limits, but these methods have a weak link between the qualitative and quantitative areas for developing scenarios (Kok & Van Delden, 2009; Van Vliet, Kok & Veldkamp, 2010). Therefore, fuzzy cognitive maps (FCMs), which were initially more utilized in the areas of computer science (Nápoles, Grau, Bello & Grau, 2014; Glykas, 2013; Pedrycz, 2010), engineering (Arvan, Omidvar & Ghodsi, 2016; Wee, Cheah, Tan & Wee, 2015; Azadeh, Ziaei & Moghaddam, 2012) and mathematics (Chen, 2016; Chi & Liu, 2016; Pedrycz, Jastrzebska & Homenda, 2016), have been used to overcome this weakness.

5.3. Fuzzy Cognitive Maps

Fuzzy cognitive maps are fuzzy-graph structures (Kosko, 1986) that represent a belief system in a determined domain (Kok, 2009). Originally introduced by Kosko (1986) as an extension of Axelrod's cognitive maps (Axelrod, 1976), FCMs emerged as a tool for modeling complex dynamic systems (Vaščák & Madarász, 2010), which combines elements of neural networks and fuzzy logic (Stach, Kurgan & Pedrycz, 2010; Motlagh, Jamaludin, Tang & Khaksar, 2015; Papageorgiou, 2012). Their main contribution was to express relations in

diffuse form, i.e., relations previously defined only as positive or negative were enriched with relations having different degrees of influence (Stach et al., 2010).

In their graphical form, FCMs provide knowledge in a symbolic way that is easy to visualize and analyze. They are composed of nodes and weighted arcs. Nodes of the graph stand for the concepts describing behavioral characteristics of the components and variables of the system (Stylios & Groumpos, 2004). The weighted arcs are edges and they represent the relationship between two concepts. This interconnection has diffuse weights, which can be positive or negative. A positive weight means that the causality relation is also positive. Thus, when one concept increases, the other concept also increases. On the other hand, a negative weight represents negative causality. Hence, when one concept increases, the other concept decreases (Shnaider, Kandel & Chew, 1998). And the third case, where there is no relationship between the concepts, the weight is 0 (Aguilar, 2005; Stylios, Georgopoulos & Groumpos, 1997).

The knowledge of FCMs can also be presented as a matrix. This setup has a state vector and adjacent matrix. The state vector denotes a set of concepts' values, generally between 0 and 1, and these values are the nodes' state. The adjacent matrix is composed of the weights of the edges that link to concepts, and this weight takes values usually between -1 and +1 (Tsadiras, 2008; Papageorgiou, 2008). The dynamic capacity of FCMs allows the concept values to vary. The new values of the concepts are obtained through the threshold function, which is the result of a multiplication in the interval [0,1].

The four threshold functions most used in the literature are:

5) *Bivalent*

$$T(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases}$$

7) *Logistic Signal*

$$T(x) = \frac{1}{1+e^{-mx}}$$

6) *Trivalent*

$$T(x) = \begin{cases} -1, & x \leq -0.5 \\ 0, & -0.5 < x < 0.5 \\ 1, & x \geq 0.5 \end{cases}$$

8) *Hyperbolic Tangent Function*

$$T(x) = \tanh(\delta x) = \frac{e^{\delta x} - e^{-\delta x}}{e^{\delta x} + e^{-\delta x}}$$

Figure 10 and Figure 11 show examples of FCMs in graphical and matrix form, respectively. In this example, the next state of the state vector was obtained through calibration, which occurred by multiplying the state vector and adjacent matrix. After that a threshold function is used.

Figure 10- Example of FCMs in graphical form

Figure 11- Example of FCM in matrix form

State vector = (0 0 0 1)

Adjacent matrix = $\begin{pmatrix} 0.25 & 0 & 0 & 0 \\ 0.5 & 0 & 0.75 & 0 \\ 0.75 & 0 & 0 & 0 \\ -0.75 & -0.5 & -0.25 & 0 \end{pmatrix}$

New state vector = (-0.75 -0.5 -0.25 0)

Normally the system stabilizes after 20 or 30 iterations. However, for total stabilization more than 100 iterations may be necessary (Kok, 2009). In this simple example, the system stabilized after seven iterations. Figure 12 shows the stabilization of the values of concepts after ten iterations.

Figure 12- Stabilization of concepts after ten iterations

Source: Research data

There are two major methods for applying FCMs, expert-based methods and computational methods. The first one is developed manually by experts (Stach et al., 2010). The second one uses an automated learning method to manipulate the data (Papageorgiou & Groumpos, 2005). This study explores expert-based methods because they do not need data available to be developed.

FCMs developed by individual experts can be combined together (Khan & Quaddus, 2004; Stach et al., 2010) to capture knowledge from different scientific areas. Therefore, merged FCMs are considered stronger and more robust than an individual FCM, and they also have less chance of error (Taber, 1991). When combining individual FCMs, one can attribute different weights to experts' opinions. FCMs developed by experts with stronger credibility must have a higher weight than those developed by experts with weak credibility (Taber & Siegel, 1987). However, choosing only the most credible experts can undermine the idea of a combined FCM. This problem can be overcome by merging FCMs by taking the average of their inputs.

5.4. Method framework

Although FCMs are employed in many fields, this approach was not originally used for scenario planning (Amer et al., 2011). Scenarios based on FCMs only started to be used after

the works of Kok (2009), Van Vliet et al. (2010) and Jetter and Schweinfort (2010). These researchers concluded that FCMs are an attractive tool to improve the quality of scenarios. The following framework presents an update for integrating scenario planning and fuzzy cognitive maps. This framework can be divided into four interconnected steps.

5.4.1. Defining scope

The first step is to define the scope of the project. Before establishing the final goal, it is highly recommended to do a brief overview of the project and determine the essential independent variables that affect the dependent variable studied. Other issues such as an appropriate time frame, team members, deadlines, cost and other restrictions must be defined. After this previous overview, a well-defined goal is established, and the strategies used in the next steps are formulated.

5.4.2. Environmental analysis

In the second step, the FCMs are developed. Thus, a complete system analysis is conducted. This analysis includes identification and prioritization of major stakeholders (or other data sources), as well as the key forces (propulsive and restrictive) and the casual relationship between them. Analysis of the historical behaviors of the variables (if available), as well as their behavior in the current context and possible future trends, has to be done.

There are three possible approaches to develop them: strictly stakeholder analysis, partial stakeholder analysis and stakeholder-free analysis. When using strictly stakeholder analysis, the system analysis is based only in stakeholders' perceptions. Consequently, the most important issue is the identification and prioritization of major stakeholders or experts. They will determine the concepts (key factors) of the system, which will in turn determine the success or failure of the critical issue (Schwartz, 2000). If a huge number of variables exist, they can be ranked by some criteria (e.g., importance and uncertainty). Subsequently, the relationships between concepts as well as their weights are established.

There are some strategies to obtain FCMs based strictly on stakeholder analysis. A workshop can be held to instigate a discussion. Consequently, views are automatically integrated into only one FCM. The stakeholders can also be interviewed alone and then the FCMs can be merged. In this approach, the stakeholders identify the key forces.

When historical data are available, the second and third approaches can be used. The partial stakeholder analysis uses the stakeholders' knowledge only in part of the process. This

knowledge can be used to determine the concepts and their relationship with the system. In this approach, the values of concepts (nodes) are obtained through historical data. Finally, the stakeholder-free analysis uses the scientific literature and historical data to develop FCMs.

5.4.3. Development of scenarios

In the third step, the behavioral characteristics of the components are simulated. Normally a set of alternative scenarios is recommended, usually ranging from three to six (Amer, Daim & Jetter, 2013). There are many variations on how to deal with this issue, but the researchers or practitioners frequently choose the most likely scenario, two extreme scenarios, or multiple possible futures that cover the range of futures that are held to be strategically relevant. After certain futures have been determined, narratives have to be created linking the present to the chosen future.

5.4.4. Validation and implementation

The scenarios developed must be validated. In studies involving scenario planning, scientific validation can be problematic (Ramos, 2002), since studies of the future are considered more art than science (Mietzner & Reger, 2005). The main criteria used for validation of scenarios are (Wilson, 1978):

- Plausibility, meaning each scenario must be feasible, with a reasonable chance of occurring;
- Consistency and coherence, referring to the logical combinations that compose each scenario and the assurance that there are no contradictions in them;
- Creativity and innovation, meaning that organizations need to find new ways of acting and thinking outside the conventional envelope; and
- Relevance and pertinence, referring to the contribution of specific types of knowledge to each scenario regarding the future, to support decisions.

After validation, the results should be reported to the participants and they should prepare the strategic planning for the possible futures. But more than just helping in making decisions (Wright & Spers, 2006; Wilson, 1978), this will also promote organizational learning (Burt & Chermack, 2008; van der Heijden, Bradfield, Burt, Cairns & Wright, 2002).

5.5. Applying FCMs-based scenarios: the case of Brazilian solar photovoltaic energy

One of the sectors that can benefit the most from the scenario planning approach is the renewable energy sector (Amer et al., 2013), since it has a relevant role in most countries and crucially depends on future developments regarding governmental policy decisions, technologies to exploit fossil energy sources and energy demand. It is expected that in 2050, more than 50% of the world's electricity can come from renewable sources (AB Kadir, Rafeeu & Adam, 2010). In particular, photovoltaic solar energy (PSE) is a strong candidate to be the main source of renewable energy, due to its technological, economic and environmental characteristics.

PSE is generated directly from sunlight through a semiconductor device called a photovoltaic cell or a thin-film solar cell, created by deposition of metals on a fine substrate (Pearce, 2002). PSE is a classic case of an emerging technology in a dynamic and innovative sector, in which envisioning scenarios is a necessary way to anticipate uncertainties and risks for strategic planning and decision making. The scenarios here are developed from the steps described in the fourth section of this paper.

5.5.1. Defining scope

A brief review of the state of the art of PSE in Brazil and the rest of the world was conducted, as described in the fourth section. The dependent variable was defined as "development of PSE in Brazil". In turn, the main independent variables, drawn from the literature, are identified in Table 7.

Table 7 - Factors related to development of PSE

Concepts	Source	Description
Government incentives	Jetter & Schweinfert, (2011); Medinaa, Arcea, & Mahía, (2015); WWF (2015)	They are benefits granted by governments to foment the progress of the sector. (Tax exemptions, financing lines, demand creation, among others.)
Energy price	Çoban & Onar (2017). Shahbazfar (2006)	Expresses the value of the energy in monetary terms.
Energy demand	Joint Research Center (2010); Çoban & Onar (2017).	The quantity of energy that consumers wish to acquire for a set price in a market.
Global treaties	Çoban & Onar (2017).	Formal agreement between two or more independent governments that impact in the energy sector. (Kyoto protocol, UN Framework Convention on Climate Change, Montreal Protocol, among others.)
Economic growth	Amer, Daim & Jetter (2015).	It is an increase in the capacity of an economy to produce goods and services, compared from one period of time to another. In Brazil, the most common proxy used is Gross domestic product (GDP)
Energy dependence concerns		Possible difficulties of energy source dependence. Need to diversification of the energy matrix.
Potential generating jobs	WWF (2015)	Refers to the capacity to generate employment.
Professional technical qualifications	WWF (2015); Medinaa, Arcea & Mahía, (2015).	It is associated to how good are the skills of the professional. It means the attributes and characteristics of a worker.
Geographic location	Miranda, Gomes & Guimarães (2005); Martins, Pereira & Abreu (2007).	Refers to a position of the country on Earth. Its defined by longitude and latitude.

Based on the brief literature review, the FCM-based scenarios were developed with the aim of identifying the possible scenarios for the future evolution of PSE in Brazil. The project was carried out by researchers of the University of São Paulo (USP), lasted one year and was financed by the Office to Improve University Personnel (CAPES) of the Ministry of Education.

Because of the dearth of historical data, the study mainly relied on the “strictly stakeholder analysis” approach. However, a pretest was carried out with a potential consumer,

leading to development of a FCM based on the concepts presented in Table 7. Then the FCMs were developed based on the knowledge of various experts and stakeholders with different backgrounds. Interviews were conducted individually or with pairs of specialists from the National Electric Energy Agency (government), the World Wildlife Fund (NGO), Brazilian Solar Energy Association (professionals) and researchers from the University of São Paulo and University of Brasília (specialists). For comparison, a workshop was held with a group of eight graduate students of the Institute for Energy and the Environment of the University of São Paulo.

5.5.2. Environmental analysis

As mentioned, a pretest was first carried out with a potential consumer with a business background, through an individual interview, during which the dynamics of FCMs and the proposed method were explained. Then he was asked to identify the main variables (concepts) that affect the development of PSE in Brazil. Since the respondent had trouble identifying these concepts, we proposed to use the variables presented in Table 7. The respondent removed the variables “energy dependence concerns” and “energy price”, and added eight other variables, making a total of 15 concepts identified. Another difficulty encountered was trying to establish the exact weights of the causal relations. Figure 13 presents the FCM developed by the potential consumer.

Figure 13- FCM of the potential consumer

Source: Research data

Aiming to overcome the difficulty of establishing the weights of the causal relations, we developed all the new FCMs based on the scale presented in Appendix D. The second FCM was constructed by a specialist in SPE from the University of Brasília (UNB). He was interviewed individually, during which the dynamics of FCMs and the proposed method were explained. Then we asked this specialist to identify the main variables (concepts) that affect the development of PSE in Brazil. Initially he had some difficulty in identifying the concepts, but after a conversation about the sector, he managed to identify them with greater facility. Indeed, he became enthusiastic with the activity and explained in detail the reasons for choosing the concepts. A consensus was reached for 12 interrelated concepts, and the causal relations and respective weights were established. Figure 14 depicts the FCM developed by the researcher from UNB.

Figure 14- FCM of the researcher from UNB

Source: Research data

The FCMs were developed by the other experts and stakeholders following the same method described above. However, due to the initial difficulty of finding the concepts, we adopted the procedure of starting with the variables identified in Table 7. All the maps presented new variables and established a large number of connections between them. In general, the activity was very profitable and the participants were enthusiastic to learn the final result. Only one participant showed tedium with the work of establishing the causal relations. However, this did not influence the quality of his FCM.

For purposes of comparison, in the last FCM we tested the proposed method with a group of SPE specialists from USP. This involved a workshop in which the dynamics of FCMs and the proposed method were explained. The other steps were identical to those for construction of the FCMs of the other specialists. After a long debate, these specialists identified 12 main concepts and established their connections and weights. In this type of approach (workshop), the biggest advantage came from the debate among the participants. One of the main objectives of scenario planning, organizational learning, was accomplished successfully, because the debate led to richer knowledge than for the FCMs obtained individually. However,

the FCM developed by the group of specialists from USP, presented in Figure 15, was not a big improvement in terms of complexity and robustness in comparison with the others.

Figure 15– FCM of the group respondents

Source: Research data

The FCMs developed individually by the specialists and stakeholders were integrated in a single FCM. Table 8 presents the list of the concepts contained in this consolidated FCM. In some cases, when developing the consolidated FCM, multiple concepts present in the individual FCMs were integrated in a single, broader, concept. For this purpose, the FCM developed in the pretest was disregarded and the others received equal weights. Therefore, the final weight of the connections was equal to the average of the weights established by the specialists and stakeholders.

Table 8 – List of concepts integrating the consolidated FCM

Concepts	ID	Concepts	ID
Development of solar photovoltaic energy	C - 1	Payback Period	C - 16
Potential generating jobs	C - 2	Environmental pollution	C - 17
Market competition	C - 3	Energy price	C - 18
Public knowledge of SPE	C - 4	National production equipment	C - 19
Public opinion (ecological and social consciousness)	C - 5	Equipment Performance	C - 20
Purchase cost	C - 6	Companies' qualifications	C - 21
Maintenance costs	C - 7	Professional technical qualifications	C - 22
Energy demand	C - 8	Availability of alternative energies	C - 23
Energy availability	C - 9	Market regulations	C - 24
Decentralized energy creation	C - 10	Economic situation	C - 25
Government incentives	C - 11	Global treaties	C - 26
Private sector involvement	C - 12	Taxation	C - 27
Geographical location	C - 13	Political situation	C - 28
Energy dependence concerns	C - 14	Technological maturity	C - 29
ABNT (Brazilian Technical Standards)	C - 15		

Source: Research data

The average numbers of concepts and connections in the individual maps were, respectively, 15.3 and 20.3. The consolidated FCM contained 29 concepts and 84 connections, denoting strong density and feedback loops. The complexity of this model made the graphical representation hard to visualize, so it lost its main function. However, the graphs of the individual FCMs were very useful and fulfilled their roles. The matrix form of the consolidated FCM, which presents the causal relationships between the concepts and their weight, is shown in Figure 16.

In the first scenario, “expectable”, the variables “government incentives” and “energy dependence concerns” were activated. Therefore, the initial state was defined as [000000000010010000000000000000]. This reflects Brazil’s recent history, during which the country, which mainly relies on hydro power, has had to regularly activate thermoelectric plants fired by fuel oil, coal and natural gas (in the worst case this backup capacity was insufficient and rationing had to be imposed). To avoid another “blackout crisis”, the government decided to create a set of initiatives to encourage the growth of PSE, through the establishment of subsidized credit lines and tax reductions/exemptions. These incentives reduce the acquisition costs and the payback time, causing a modest positive impact on the development of solar photovoltaic energy.

In the “pessimistic” scenario, the variables “economic situation” and “payback period” were activated. Thus, the initial state was defined as [0000000000000000100000000-10000]. In this scenario, the price of energy and acquisition cost of solar systems are higher, negatively affecting the development of solar photovoltaic energy, which presents slight retraction. When the economy is weak, consumers are generally reluctant to make the investments necessary to install a photovoltaic system, despite savings over the long run.

In the “optimistic” scenario, all the key concepts were activated to benefit development of solar photovoltaic energy, which showed strong growth. Thus, the initial state was defined as [000000000010010-10100000010000]. In this scenario, the Brazilian economy resumes showing strong growth and consumers have higher purchasing power. This is accompanied by a rise in electricity rates, prompting consumers to search for alternatives to reduce their energy bills. The government creates various initiatives and programs to foster growth of the sector, reducing the payback time of the investment. Photovoltaic energy becomes more attractive and consumers acquire more residential solar energy systems.

5.5.4. Validation and implementation

We validated the scenarios and concluded they meet the criteria presented in section 4.4 of this paper. The FCMs developed by the participants corroborated to create coherent and consistent scenarios. Even the optimistic scenario, in which all the key concepts were activated for development of solar photovoltaic energy, was plausible.

The implementation step is not covered here, since this is a task for companies and the government. However, the next section presents some possible implications and purposes of the FCM-based scenarios for stakeholders, as well as the benefits and limitations.

5.6. Conclusion

The scenario planning described in this paper has a good possibility of supporting strategic planning and decision making, by proposing possible combinations of strategic futures that are very plausible. Its main advantage was shown to be organizational learning, both for the participants (the main potential beneficiaries) and those who can use it for making decisions.

The use of scenarios base on FCMs can overcome the obstacles mentioned by Kok and Van Delden (2009), since these maps can combine the benefits of the qualitative and quantitative techniques (Amer et al., 2011). They also satisfy the proposal of Roubelat (2000), that the scenarios should be constructed in collaboration by people having different expertise and backgrounds. The main benefits and limitations of the FCM-based scenarios are presented in Table 9.

Table 9 - Benefits and limitations of FCM-based scenarios

Benefits
They are easy to construct.
They can be constructed collaboratively.
FCMs built individually can be integrated in a single FCM.
They can be easily and quickly updated.
They can be developed without historical data.
They incorporate the viewpoints of different specialists and stakeholders (mitigating the biases of knowledge of a single individual)
In graphical form, they clarify the vision of the future and present of the developers and beneficiaries.
In matrix form, they facilitate quantitative procedures.
They combine the benefits of qualitative and quantitative techniques.
They represent knowledge in a symbolic way that is simple and easy to understand.
They can explore uncertainties.
Minority opinions are taken onto consideration.
Limitations
In highly complex and dense systems, the graphical form does not provide a clear vision of the system.
Developing very complex FCNs can be tedious.
They do not clearly represent time.
For being developed based on subjective knowledge, they can have bias. However, when various stakeholders participate, this bias tends to be mitigated.
When developed in a group, the opinion of one participant can have either a positive or negative influence on the opinions of the other participants.

Source: Research data

As a practical result, the effort showed that solar photovoltaic energy has several positive points that make it a strong candidate to be the main source of complementary electricity in the Brazilian energy mix. The pollution caused by thermal power plants, the rising domestic environmental concerns and global treaties all encourage the government and society to look for alternative energy sources. However, the up-front cost to consumers of photovoltaic systems is still very high, so the development of the sector strongly depends on governmental incentives. Therefore, strong growth in Brazil is intrinsically related to the government and the country's economic situation.

As avenues for future research, we suggest developing FCM-based scenarios using historical data exclusively, without the participation of experts or stakeholders. The main limitation of this study was the lack of a method to select the participants. Therefore, it would be worthwhile planning new scenarios using a method to select the stakeholders and specialists.

References

- Ab Kadir, M. Z. A., Rafeeu, Y., Adam, N. M. (2010). Prospective scenarios for the full solar energy development in Malaysia. *Renewable and Sustainable Energy Reviews*, 14 (1), 3023–3031. DOI: 10.1016/j.rser.2010.07.062
- Aguilar, J. (2005). A Survey about Fuzzy Cognitive Maps Papers. *International journal of computational cognition*, 3(2), 27-33. DOI: 1542-5908(05)10204-8/\$20.00
- Alcamo, J., & Henrichs, T. (2009). *Towards guidelines for environmental scenario analysis in Environmental Futures: The Practice of Environmental Scenario Analysis*. Amsterdam, The Netherlands: Elsevier.
- Amer, M., Daim, T., & Jetter, A. (2015). Technology roadmap through fuzzy cognitive map-based scenarios: the case of wind energy sector of a developing country. *Technology Analysis & Strategic Management*, 28(2), 131-155. DOI: 10.1080/09537325.2015.1073250
- Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures*, 46, 23–40. DOI: 10.1016/j.futures.2012.10.003.
- Amer, M., Jetter, A., & Daim, T. (2011). Development of fuzzy cognitive map (FCMs)-based scenarios for wind energy. *International Journal of Energy Sector Management*, 5(4), 564 – 584. DOI: 10.1108/17506221111186378.
- Arvan, M., Omidvar, A., & Ghodsi, R. (2016). Intellectual capital evaluation using fuzzy cognitive maps: A scenario-based development planning. *Expert Systems with Applications*, 55, 21-36. DOI: 10.1016/j.eswa.2015.12.044
- Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*. Princeton University Press, Princeton.
- Azadeh, A., Ziaei, B., & Moghaddam, M., (2012). A hybrid fuzzy regression-fuzzy cognitive map algorithm for forecasting and optimization of housing market fluctuations. *Expert Systems with Applications*, 39(1), 298-315.
- Bezold, C. (2010). Lessons from using scenarios for strategic foresight. *Technological Forecasting and Social Change*, 77, 1513-1518. DOI: 10.1016/j.techfore.2010.06.012
- Bishop, P., Hines, A., & Collins, T. (2007). The current state of scenario development: an overview of techniques. *Foresight*, 9(1), 5-25. DOI: 10.1108/14636680710727516
- Bradfield, R., Wright, G., Burt, G., Cairns, G., & Heijden, K. V. D. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures*, 37(8), 795–812. DOI: 10.1016/j.futures.2005.01.003
- Brown, S. (1968). Scenarios in systems analysis. In: E.S. Quade, W.I. Boucher (Eds.), *Systems analysis and policy planning: Applications in defense*. New York, American Elsevier Publishing Co.
- Burt, G., & Chermack, T. J. (2008). Learning with scenarios: summary and critical issues. *Advances in Developing Human Resources*, 10(2), 285-295.

- Coates, J. F. (2000). Scenario planning. *Technological Forecasting and Social Change*, 65(1) 115–123.
- Chen, R. Y. (2016). Fuzzy dual experience-based design evaluation model for integrating engineering design into customer responses. *International Journal on Interactive Design and Manufacturing*, 10(4), 439-458. DOI: /10.1007/s1200
- Chi, Y., & Liu, J. (2016) Learning of fuzzy cognitive maps with varying densities using a multiobjective evolutionary algorithm. *IEEE Transactions on Fuzzy Systems*, 24(1), 71 – 81.
- Çoban, V & Onar, C. S. (2017). Modeling renewable energy usage with hesitant Fuzzy cognitive map. *Complex & Intelligent Systems*, 1-12. DOI: 10.1007/s40747-017-0043-y
- Cooke, R. M. (1991). *Experts in Uncertainty: Opinion and Subjective Probability in Science*. New York, Oxford University Press.
- Cuhls, K. (2003). From forecasting to foresight processes - new participative foresight activities in Germany. *Journal of Forecasting*, 22, 93–111.
- Durance, P., & Godet, M. (2010). Scenario building: Uses and abuses. *Technological Forecasting and Social Change*, 77(9), 1488-1492. DOI: 10.1016/j.techfore.2010.06.007
- Georgantzas, N. C., & Acar, W. (1995) *Scenario-driven planning: Learning to manage strategic uncertainty*. Westport, Connecticut: Quorum Books.
- Glykas, M. (2013). Fuzzy cognitive strategic maps in business process performance measurement. *Expert Systems with Applications*, 40(1), 1-14.
- Godet, M., & Roubelat, F. (1996). Creating the future: The use and misuse of scenarios. *Long Range Planning*, 29(2), 164 – 171. DOI: 10.1016/0024-6301(96)00004-0
- Hans-Horst, S., & Jetter, A. J. M. (2003), Integrating market and technological knowledge in the fuzzy front end: an FCM-based action support system. *International Journal of Technology Management*, 26(5/6), 517-539.
- Heinecke, A., & Schwager, M. (1995). *Die szenario-technik als instrument der strategischen planung*. Germany: Braunschweig
- Huss, W. R. (1988). A move toward scenario analysis. *International Journal of Forecasting*, 4(3), 377-388. DOI: 10.1016/0169-2070(88)90105-7
- Jetter, A. J., & Schweinfort, W. (2011). Building scenarios with Fuzzy Cognitive Maps: An exploratory study of solar energy. *Futures*, 43(1), 52 – 66. DOI: 10.1016/j.futures.2010.05.002
- Joseph, C.F. (2000). Scenario planning. *Technological Forecasting and Social Change*, 65, 115–123.
- Khan, M., & Quaddus, M. (2004). Group decision support using fuzzy cognitive maps for causal reasoning. *Group Decision and Negotiation*, 13(5) 463–480.

- Kahn, H., & Wiener, A.J. (1967). *The Year 2000: A framework for speculation on the next thirty-three years*. New York: Macmillan.
- Keough, S.M., & Shanahan, K.J. (2008). Scenario planning: toward a more complete model for practice. *Advances in Developing Human Resources*, 10(2), 166-78.
- Schwartz, B. (1977). Long-range planning in the public sector. *Futures*, 9, 115–127.
- Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change*, 19(1), 122–133. DOI: 10.1016/j.gloenvcha.2008.08.003
- Kok, K., & van Delden, H. (2009). Combining two approaches of integrated scenario development to combat desertification in the Guadalentin watershed, Spain. *Environment and Planning B: Planning and Design*, 36 (1), 49-66. DOI: 10.1068/b32137
- Kosko, B. (1986). Fuzzy Cognitive Maps. *International Journal of Man-Machine Studies*, 24(1), 65-75. DOI: 10.1016/S0020-7373(86)80040-2
- Martins, F. R., Pereira, E. B., & Abreu S. L. (2007). Satellite-derived solar resource maps for Brazil under SWERA project. *Solar Energy*, 81, 517-528.
- Medinaa, E, Arcea, R., & Mahía, R. (2015). Barriers to the investment in the Concentrated Solar Power sector in Morocco: A foresight approach using the Cross Impact Analysis for a large number of events. *Futures*, 71, 36-56. DOI: 10.1016/j.futures.2015.06.005
- Mietzner D., & Reger G. (2005). Advantages and disadvantages of scenario approaches for strategic foresight. *International Journal of Technology Intelligence and Planning* 2 (1), 220 - 239.
- Miranda, E. E.; Gomes, E. G.; Guimarães, M. (2005). Mapeamento e estimativa da área urbanizada do Brasil com base em imagens orbitais e modelos estatísticos. Campinas: Embrapa Monitoramento por satélite.
- Motlagh, O., Jamaludin, Z., Tang, S.H., & Khaksar, W. (2015). An agile FCM for real- time modeling of dynamic and real-life systems. *Evolving Systems*, 6(3), 153–165. DOI: /10.1007/s12530-013-9077-6.
- Nápoles, G., Grau, I., Bello, R., & Grau, R. (2014). Two-steps learning of Fuzzy Cognitive Maps for prediction and knowledge discovery on the HIV-1 drug resistance. *Expert Systems with Applications*, 41(3), 821-830.
- Papageorgiou, E. I. (2011). A new methodology for Decisions in Medical Informatics using Fuzzy Cognitive Maps based on Fuzzy Rule - Extraction techniques. *Applied Soft Computing*, 11, 500–513. DOI:10.1016/j.asoc.2009.12.010
- Papageorgiou, E. I. (2012). Learning Algorithms for Fuzzy Cognitive Maps—A Review Study. *IEEE Transactions on Fuzzy Systems*, 4(2), 150 – 163.
- Papageorgiou, E. I., & Groumpos, P. P. (2005). A new hybrid learning algorithm for fuzzy cognitive maps learning. *Applied Soft Computing*, 5, 409 - 431.

- Pearce, J. (2002). Photovoltaics - A Path to Sustainable Futures. *Futures*, 34 (7), 663-674. DOI: 10.1016/S0016-3287(02)00008-3
- Pedrycz, W. (2010). The design of cognitive maps: A study in synergy of granular computing and evolutionary optimization. *Expert Systems with Applications*, 37(10), 7288-7294.
- Pedrycz, W., Jastrzebska, A., & Homenda, W. (2016). Design of fuzzy cognitive maps for modeling time series. *IEEE Transactions on Fuzzy Systems*, 24(1), 120-130.
- Ramos, J. M. (2002). Action research as foresight methodology. *Futures*, 7(1), 1-24. DOI: 10.1016/j.futures.2005.10.008
- Rigby, D., & Bilodeau, B. (2007). *Selecting management tools wisely*. Harvard Business Review, 85, 20–22.
- Schoemaker, P.J.H. (1991). When and how to use scenario planning: a heuristic approach with illustration. *Journal of Forecasting*, 10(6), 549-64.
- Schneider, M., Shnaider, E., Kandel, A., & Chew, G. (1998). Automatic construction of FCMs. *Fuzzy Sets and Systems*, 93(2) 161–172.
- Schwartz, P. (1996). *The Art of the Long View: Planning for the Future in an Uncertain World* Doubleday. Currency Doubleday, New York, NY.
- Stach, W., Kurgan, L.A., & Pedrycz, W. (2010). Expert-based and Computational Methods for Developing Fuzzy Cognitive Maps, In: Glykas, M., *Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications*, Springer (ISBN-10: 36-42032- 19-2), 2010. DOI: 10.1007/978-3-642-03220-2_2
- Stylios, C. D. Groumpos, P. P. (2004). Modeling complex systems using fuzzy cognitive Maps. *IEEE Transactions on Systems, Man, and Cybernetics*, 34(1), 155–162. DOI: 10.1109/TSMCA.2003.818878
- Stylios, C.D., Georgopoulos, V.C., & Groumpos, P.P. (1997). Introducing the theory of Fuzzy Cognitive Maps in distributed systems, in: Proceedings of the 12th IEEE International Symposium on intelligent control, Istanbul, Turkey.
- Taber, R. (1991). Knowledge processing with fuzzy cognitive maps. *Expert Systems with Applications*, 2, 83-87.
- Taber, W. and Siegel, M. (1987). Estimation of experts' weights using fuzzy cognitive maps. in: Proceedings of the IEEE International Conference on Neural Networks, San Diego, CA, 319-26.
- Tsadiras, A.K. (2008). Comparing the inference capabilities of binary, trivalent and sigmoid fuzzy cognitive maps. *Information Science*, 178(20), 3880–3894.
- Van Der Heijden, K. (1996). *Scenarios: The Art of Strategic Conversation*. Chichester, England: John Wiley.
- Van der Heijden, K., Bradfield, R., Burt, G., Cairns, G., & Wright, G. (2002). *The sixth sense: Accelerating organisational learning with scenarios*. Chichester, UK: John Wiley.

- Van Vliet, M., Kok, K. & Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies: the use of fuzzy cognitive maps as a communication and learning tool. *Futures*, 42(1), 1-14. DOI:10.1016/j.futures.2009.08.005 59.
- Vaščák, J., & Madarász, L. (2010). Adaptation of Fuzzy Cognitive Maps: a comparison study. *Acta Polytechnica Hungarica*, 7(3), 109–122.
- Wee, Y.Y., Cheah, W.P., Tan, S.C., & Wee, K. (2015). A method for root cause analysis with a Bayesian belief network and fuzzy cognitive map. *Expert Systems with Applications*, 42 (1) 468-487.
- Wilson, I. (1978). Scenarios, In: J. Fowles (Ed.), *Handbook for Futures Research*, Connecticut Greenwood Press.
- Wright, J.T.C., & Spers, R.G. (2006). O país no futuro: aspectos metodológicos e cenários. *Estudos Avançados*, 20(56), 13-28.

6. CONCLUSIONS AND FINAL CONSIDERATIONS

Some conclusions can be drawn from the three articles that compose this dissertation. This section presents the final considerations about the articles presented in chapters 2, 3 and 5, as well as some limitations and proposals for future research. All the three chapter were built as independent papers with a complete structure. However, all of the themes were interrelated, synergistic and deliberate on common issues. This thesis showed the attractiveness of Fuzzy Cognitive Maps as a tool for scenario planning.

6.1. Considerations about the research objectives

This study focused on the problem of the lack of proper planning of scenarios based on FCMs in the alternative energy sectors, raising the question of whether this situation comes from a shortage of information or limitations of the FCMs. To resolve this problem, this study investigated benefits and limitations of FCM-based scenario planning through the application in the Brazilian photovoltaic sector. The following specific objectives were established: identify the strong and weak points of FCMs; analyze the expansion of these to different areas; identification of the main stakeholders used to develop FCM-based scenarios; Application of the method in the Brazilian solar energy sector.

The specific objectives “identify the strong and weak points of FCMs” and “analyze the expansion of these to different areas” were achieved in chapter 2, “Fuzzy Cognitive Maps: from origins to new frontiers”. This chapter summarized the results of a review of the most relevant literature on fuzzy cognitive maps. It showed that the use of FCMs has spread from their original applications in mathematics and computer science to address a wide range of questions in the social sciences. The analysis encompassed the use of FCMs since their original introduction until the present.

It showed that variations of FCMs have been developed through a process of improvement and adaptation from the original expert-based methods to the current computational methods. An increasing number of studies on FCMs were identified in several new areas not considered in previous studies. This suggests that experts are expanding frontiers and recognizing the interdisciplinary potential of FCMs and their robustness in solving diverse kinds of problems.

The specific objective “identification of the main stakeholders used to develop FCM-based scenarios” were accomplished in chapter 3, “The relevance of stakeholders in fuzzy

cognitive map based scenarios: a bibliometric study”. The objective of this study was to investigate the scientific production regarding scenario planning based on fuzzy cognitive maps, to analyze the inherent participation of specialists (experts) and stakeholders in developing scenarios. We found and analyzed 14 articles related to the topic of interest. In all the studies where FCMs were constructed exclusively based on human beliefs, the participants were called experts. The great majority of studies developed the FCMs from the knowledge and beliefs of scientists and academics. Among the primary stakeholders presented in Figure 7, the following participated in the studies: consumers, community, government, manufacturers and private sector.

The specific objectives “investigate the benefits and limitations of FCM-based scenario planning” and “test the method in the Brazilian solar energy sector” were attained in chapter 5, “Benefits and limitations of FCM-based scenarios”. This chapter presented a method for planning scenarios based on FCM, which was applied to the Brazilian solar energy sector. The results showed that the method overcomes a weak link between qualitative and quantitative scenarios, allowing the development of integrated scenarios, as identified by Kok and Van Delden (2009), since this can combine the benefits of qualitative and quantitative techniques (Kok & Van Delden, 2009; Van Vliet, Kok & Veldkamp, 2010; Amer et al., 2011; Salmeron et al., 2012). The scenarios developed also met the proposal of Roubelat (2000), that scenarios should be constructed in collaboration by people with different areas of expertise and backgrounds. For this purpose, the scenarios were developed by incorporating the viewpoints of different specialists and stakeholders (Stach, Kurgan & Pedrycz, 2010), combining and transforming preliminary information into rich and robust knowledge (Papageorgiou, 2011b). Besides this, the FCMs were easily constructed and updated.

Three strategic scenarios were constructed based on key factors identified by specialists and stakeholders. In the first scenario, “expectable”, the variables “government incentives” and “energy dependence concerns”, when activated in positive form, showed strong positive influence in the sector. In the second scenario, “pessimistic”, the variables “economic situation” and “payback Period” were activated positively and negatively, respectively. This scenario was based on the current Brazilian economic situation of recession, in which consumers are reluctant to assume large expenditures to purchase solar energy systems, causing a retraction in the sector. And in the third scenario, “optimistic”, all the key components were activated to benefit the development of solar photovoltaic energy, which presented strong growth potential.

All the scenarios developed from the FCMs were valid, including extreme scenarios such as the “optimistic” case. The scenarios were validated by using the criteria established by Wilson (1978): plausibility; consistency and coherence; creativity and innovation; and relevance and pertinence. Therefore, the application of scenarios based on the FCMs proved to be a useful tool for strategic planning (Georgantzas & Acar, 1995, Brown, 1968), decision making (Wright & Spers, 2006, Wilson, 1978) and organizational learning (Bezold, 2010).

In relation to photovoltaic solar energy, chapter 4 described this sector in Brazil, showing that it has the potential to become one of the main sources of electricity in the country. In recent years, the technology has shown strong and steady growth, even in times of political and/or economic crisis. However, for the sector to continue growing robustly, the companies must be prepared for possible future events.

6.2. Contributions

This work supported previous studies related to the multidisciplinary nature of FCMs and identified new areas where they can be explored. Finally, new variations of the tool were consolidated and their contributions were presented. The main contribution of the research is to present the benefits and limitations of FCM-based scenario planning. For that, a new scenario planning method was created and the empirical evidence of its effectiveness was presented in the context of the Brazilian photovoltaic solar energy sector. Furthermore, this study contributes to future research by presenting the consolidated state of the literature and the main trends in the field. The identification of the main stakeholders is another important contribution of the study, since they are the main players in FCM based scenario planning.

6.3. Limitations and recommendations for future research

Some limitations of this study should be mentioned. The concepts used to develop the FCMs were obtained from the knowledge of the survey participants. Although they have long experience in the sector of strong knowledge in the area, relevant variables might have been left out in building the FCMs.

Another intrinsic limitation of intuitive methods is bias. Although the FCMs were obtained from different sources to mitigate this bias, it is not possible to claim that the consolidated FCM is free of any negative influence. Also, a consolidated method was not used to choose the specialists and stakeholders, all of whom reside in the same country and are influenced by the same phenomena.

A suggestion for future research would be to test the method in other sectors. Another recommendation is to create a new approach to FCM-based scenario planning, using only historical data and then comparing the results. A final suggestion in light of the results and limitations of this study is the application of the method with support of a procedure to select the participants, which would contribute to the construction of better maps.

FURTHER REFERENCES

- Ab Kadir, M. Z. A., Rafeeu, Y., & Adam, N. M. (2010). Prospective scenarios for the full solar energy development in Malaysia. *Renewable and Sustainable Energy Reviews*, 14 (1), 3023–3031. DOI: 10.1016/j.rser.2010.07.062
- Amer, M., Jetter, A., & Daim, T. (2011). Development of fuzzy cognitive map (FCMs)-based scenarios for wind energy. *International Journal of Energy Sector Management*, 5 (4), 564 – 584. DOI 10.1108/17506221111186378.
- Amer, M. (2013). *Extending Technology Roadmap through Fuzzy Cognitive Map-based Scenarios: The Case of the Wind Energy Sector of Pakistan*. Tese de doutorado, Portland State University, Portland, USA.
- Associação Brasileira de Energia Solar Fotovoltaica (ABSOLAR) – de <http://www.absolar.org.br/quem-somos.html>, acessado em 2016.
- Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*, Princeton University Press, Princeton.
- Bezold, C. (2010). Lessons from using scenarios for strategic foresight. *Technological Forecasting and Social Change*, 77, 1513-1518. DOI: 10.1016/j.techfore.2010.06.012
- Bishop, P., Hines, A., & Collins, T. (2007). The current state of scenario development: an overview of techniques. *Foresight*, 9(1), 5-25. DOI: 10.1108/14636680710727516
- Bradfield, R., Wright, G., Burt, G., Cairns, G., & Heijden, K. V. D. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures*, 37(8), 795–812. DOI: 10.1016/j.futures.2005.01.003
- Brown, S. (1968). Scenarios in systems analysis. In: E.S. Quade, W.I. Boucher (Eds.), *Systems analysis and policy planning: applications in defence*. New York: American Elsevier Publishing Co.
- WWF – Brasil. (2015). *Desafios e Oportunidades para a energia solar fotovoltaica no Brasil: recomendações para políticas públicas*. Brasília: WWF Brasil.
- Di Souza, R. (2016). *Sistema de energia solar fotovoltaica: livro digital de introdução aos sistemas solares*. Ribeirão Preto: Blue-Sol.
- Empresa de Pesquisa Energética. (2012). *Inserção da geração fotovoltaica distribuída no Brasil – condicionantes e impactos*. Rio de Janeiro: EPE.
- Empresa de Pesquisa Energética. (2016). Website da empresa, acessado em maio de 2016.
- European Photovoltaic Industry Association (2012). *Global market outlook for photovoltaics until 2016*. Report, 11.

- Georgantzas, N.C., & Acar, W. (1995) *Scenario-driven planning: learning to manage strategic uncertainty*. Westport, Connecticut: Quorum Books.
- Godet, M. (1993) From anticipation to action. Paris: Unesco.
- Goldemberg, J., & Moreira, J. R. (2005). Política energética no Brasil. *Estudos avançados*, 19 (55), 215-228.
- Hammond, G. P. (2000). Energy, environment and sustainable development: a UK perspective. *Transactions of IChemE Part B: Process Safety and Environmental Protection*, 78 (4), 304–323.
- Heinecke, A. & Schwager, M. (1995). Die Szenario-Technik als Instrument der strategischen Planung. Braunschweig.
- Huss, W. R. (1988). A move toward scenario analysis. *International Journal of Forecasting*, 4(3), 377-388. DOI: 10.1016/0169-2070(88)90105-7
- Instituto Brasileiro de Geografia e Estatística (IBGE). (2017). Área Territorial Brasileira. Available in: <http://www.ibge.gov.br/home/geociencias/areaterritorial/principal.shtm>.
- International Energy Agency (2014). Technology Roadmap: Solar Photovoltaic Energy.
- Intergovernmental Panel on Climate Change (IPCC) (2007). Climate Change – The Physical Science Basis. Cambridge University Press, Cambridge, UK.
- Jetter, A. J. & Schweinfort, W. (2011). Building scenarios with Fuzzy Cognitive Maps: An exploratory study of solar energy. *Futures*, 43 (1), 52 – 66. DOI: 10.1016/j.futures.2010.05.002
- Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. *Global Environmental Change*, 19(1) , 122–133. DOI: 10.1016/j.gloenvcha.2008.08.003
- Kok, K. & van Delden, H. (2009). Combining two approaches of integrated scenario development to combat desertification in the Guadalentin watershed, Spain. *Environment and Planning B: Planning and Design*, 36 (1), 49-66. DOI: doi: 10.1068/b32137
- Kosko, B. (1986). *Fuzzy Cognitive Maps*. *International Journal of Man-Machine Studies*, 24(1), 65-75. DOI: 10.1016/S0020-7373(86)80040-2
- Martins, F. R., Pereira, E. B., & Abreu, S. L. (2007). Satellite-derived solar resource maps for Brazil under SWERA Project. *Solar Energy*, 81 (4), 517–528. DOI: 10.1016/j.solener.2006.07.009.
- Mietzner D., & Reger G. (2004). Scenario-Approaches: History, Differences, Advantages and Disadvantages. Proceedings of the EU-US Scientific Seminar: New Technology Foresight, Forecasting & Assessment Methods in Seville, Spain, 3–14.

- Ministério de Minas e Energia. (2009). Programa de incentivo às fontes alternativas de energia elétrica (PROINFA). De www.mme.gov.br, acessado em maio de 2016.
- Ministério de Minas e Energia. (2015a). Energia solar no Brasil e no mundo. Núcleo de Estudos Estratégicos de Energia. De www.mme.gov.br, acessado em maio de 2016.
- Ministério de Minas e Energia. (2015b). Programa de Desenvolvimento da Geração Distribuída de Energia Elétrica: Ações de estímulo à geração distribuída, com base em fontes renováveis. De www.mme.gov.br, acessado em maio de 2016.
- Ministério de Minas e Energia. (2015c). Plano decenal de expansão de energia 2024. Secretaria de Planejamento e Desenvolvimento Energético. De www.mme.gov.br, acessado em maio de 2016.
- Miranda, M.M. (2012). Fator de emissão de gases de efeito estufa na geração de energia elétrica no Brasil: Implicações da aplicação da avaliação do ciclo de vida. Dissertação de mestrado. USP, engenharia Ambiental de São Carlos.
- Nakabayashi, R.K. (2014). Microgeração fotovoltaica no brasil: condições atuais e perspectivas futuras. Dissertação de mestrado, Universidade de São Paulo, São Paulo, SP, Brasil.
- Ozesmi, U., & Ozesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling* 176, 43-64.
- Papageorgiou, E. I. (2011a). Review study on fuzzy cognitive maps and their applications during the last decade, *IEEE International Conference on Fuzzy Systems*, 828 – 835. DOI: 10.1109/FUZZY.2011.6007670.
- Pearce, J. (2002). Photovoltaics - A Path to Sustainable Futures. *Futures*, 34(7), 663-674. DOI: 10.1016/S0016-3287(02)00008-3
- Renewable Energy Country Attractiveness Index (2015). Issue 45. ey.com/recai. Acessado em 08/05/2016.
- Schoemaker, P. J. H., Cornelius A. J. M., & van der Heijden. (1992). Integrating Scenarios into Strategic Planning at Royal Dutch/Shell. *Planning Review*, 20 (3), 41-46.
- Silva, A. T. B., Spers R. G., Wriqth, J. T. C., & Costa. P. R. (2013). Cenários prospectivos para o comércio internacional de etanol em 2020. *Revista de Administração da Universidade de São Paulo*, 48(4), 727-748. DOI: 10.5700/rausp1117
- Stach. W., Kurgan, L.A., & Pedrycz, W. (2010). Expert-based and Computational Methods for Developing Fuzzy Cognitive Maps, In: Glykas, M., *Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications*, Springer (ISBN-10: 36-42032- 19-2), 2010. DOI: 10.1007/978-3-642-03220-2_2
- Varella, F.K.O.M., Cavaliero, C.K.N., & Silva, E.P.S. (2008). Energia solar fotovoltaica no brasil: incentivos regulatórios. *Revista Brasileira de Energia*, 15 (1), 9-22.

- Van Vliet, M., Kok, K. & Veldkamp, T. (2010). Linking stakeholders and modellers in scenario studies: the use of fuzzy cognitive maps as a communication and learning tool. *Futures*, 42(1), 1-14. DOI:10.1016/j.futures.2009.08.005
- Wilson, I. (1978). Scenarios, In: J. Fowles (Ed.), *Handbook for Futures Research*, Connecticut Greenwood Press.
- Wright, J. T. C. & Spers, R. G. (2006). O país no futuro: aspectos metodológicos e cenários. *Estudos Avançados*, 20(56), 13-28.

APPENDIX

Appendix A

Instrumento de construção dos FCMs

Prezado Sr.(a),

Esta pesquisa é parte do trabalho acadêmico de Mestrado em Administração que apresentarei à Faculdade de Economia, Administração e Contabilidade da Universidade de São Paulo – FEA/USP, e tem como objetivo investigar quais as vantagens e limitações do planejamento de cenários baseados nos *Fuzzy Cognitive Maps*.

Solicito vossa contribuição e participação nesta pesquisa. Os participantes receberão um relatório síntese dos resultados, que poderá auxiliar em suas tomadas de decisões. Os dados coletados dos respondentes não serão apresentados de forma isolada, mas apenas os dados integrados e consolidados.

Em caso de eventuais dúvidas, coloco-me à disposição para esclarecimentos adicionais através do e-mail gustavocarvalho@usp.br e do telefone (61) 999376080.

Muito obrigado por sua atenção e colaboração,

Gustavo Macedo de Carvalho

Mestrando em administração – FEA/USP.

Appendix B

Esclarecimento Inicial

Este questionário está estruturado em três etapas que abordam os seguintes aspectos: identificação das variáveis que impactam no crescimento do setor elétrico fotovoltaico brasileiro, definição da relação causal e definição dos pesos.

ETAPA 1 - Identificação das variáveis que impactam no crescimento do setor elétrico fotovoltaico brasileiro

Quais variáveis impactam no crescimento do setor elétrico fotovoltaico brasileiro?

[illegible]

Appendix C

ETAPA 3 – Relação entre as variáveis

Quais variáveis estão relacionadas?

Exemplo: “Crescimento econômico” impacta na “Demanda por energia”

Exemplo: “Demanda por energia” impacta no “Crescimento do setor fotovoltaico brasileiro”

Appendix D

Qual o impacto da variável X na variável Y?

Exemplo:

Variáveis	“Crescimento econômico” → “Demanda por energia”
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Variáveis	→
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Variáveis	→
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Variáveis	→
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