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Solar Energy Growth in Brazil: Essential Dimensions for the Technological Transition

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ABSTRACT

Solar energy is a clean, affordable and inexhaustible alternative that has evolved from a niche market to become a major source of electricity in world terms. We used qualitative research method of document analysis in 73 sources of data to understand the solar energy technology. The main contribution of this paper is to presents essential dimensions of solar energy technological transition process in Brazil. We discussed the growth of solar energy sector in Brazil on five dimensions: Domestic solar panel industry development, new markets formation, government initiatives for the dissemination of solar energy, stakeholder commitment to R&D and technologies for innovations. The results showed the absence information exchange, learning process and cooperation between stakeholders. Brazil is currently in the emerging technological innovation system and the integration of the actors would enable the co-evolution of the system, leading to the emergence and consolidation of this technology nationwide.

Keywords: Technological Change, Energy Policy, Innovation Incentives
JEL Classifications: O33, Q48, O31

1. INTRODUCTION

Transition theory can be seen as a challenge to existing assumptions in a number of research paradigms, in what Kuhn (1970) referred to as "scientific revolutions," in which pre-existing theories are gradually replaced by new theories or models according to the development of science. Transition studies are interpretative, predominantly qualitative and show a continuum of interaction between fundamental and applied research. They combine and integrate different scientific disciplines, they are multi and interdisciplinary as well as transdisciplinary (integrating tacit, lay knowledge with scientific knowledge) (Loorbach, 2007).

An innovation system is composed by economic, sociopolitical, institutional and organizational dimensions with are responsible for an innovation trajectory since its generation, diffusion and adaptation. Innovation Systems can be classified as national, regional or local according to their geographic scope. Additionally, technological systems involve specific systems within the more general concept of Innovation Systems, for sectors, industries or specific technologies. Moreover, Perez (2004) stresses that the implementation of each technology system involves several interconnected change and adaptation processes, such as the development of surrounding services (necessary infrastructure, specialized suppliers, distributors, maintenance services, etc.).

The modern concept of a National Innovation System highlights the role of the institutions of the System in the technological advances of a country. In this sense, Nelson (2004) points out the need for reorientations to be applied in countries needing to catch up in certain technologies, as is the case in Brazil. The author also highlights that an innovation system can be constituted considering the policies necessary to catch up more effectively in the new context.

The search for renewable energy sources to generate electricity has increased worldwide and, in Brazil, there is particular interest in technologies that generate photovoltaic solar electricity. Solar energy is so far at the technological niche level in the country. The possibility of applying this source of energy in remote places not connected to the electricity network, the huge potential of this energy source due to high solar irradiation level and the environmental impact reduction has increased interest in this energy source in the country.

The goal of this paper is to identify fundamental dimensions for the use and dissemination of solar energy in Brazil. The main contribution of this paper is a panorama of the technology trajectory in the country from three different approaches: Socio-technical innovation, governance for new technology and solar energy domestic trajectory.

Regarding the methodology, the present study consists of a qualitative documental analysis whose purpose was not to reach definitive and conclusive results, but to propose a way of integrating these different theoretical approaches, highlighting the structural and institutional aspects and the factors that influence the innovation of the solar energy system in Brazil. We identified some challenges to the solar energy sector growth in Brazil from a qualitative document analysis of 73 sources of data and discussed these challenges into 5 dimensions: (1) Domestic solar panel industry development, (2) new market formation, (3) government initiatives for the use and dissemination of solar energy in the country, (4) stakeholder commitment to research and development and (5) technologies and innovations applied development inside this segment.

The results showed that this source of energy is in niche phase in the country and there's still a long way to go in order to encourage and disseminate this technology nationwide, as will be shown in next sections.

2. LITERATURE REVIEW

2.1. Socio-technical and Innovation System Approach

The origins of innovation system theory lie in the classical theory of List (1856), which describes the national systems of political economy and conducts a comparative analysis of different countries, including the themes of industrial systems and public policies. Later, Schumpeter (1912) presented the figure of the entrepreneur and emphasized the diffusion of innovations in different regions and industries. However, it was from the seminal work of Nelson (1993) that the link between innovation and economic development was proposed by establishing the conceptual bases of national innovation systems.

Contemporaneously, authors of modern evolutionary theory explored aspects such as the role of the actors in systems, the mobilization of resources and the production and diffusion of knowledge. This resulted in the constitution of the current study of National Innovation Systems through a historical and socio-technical analysis of growth and technological change through different innovation systems (Nelson, 2008; Lundvall, 2010; Saviotti, 2010; Malerba, 1999; Perez, 2009).

Innovation system can be outlined based on different criteria, which can be spatial/geographical, sectorial or even in accordance with the activities involved. In geographical terms, Johnson et al. (2003) highlight that a system can be local, regional, national and supranational, assuming that the area in question has a reasonable degree of "coherence" or "interior orientation" regarding innovation processes.

Lundvall (2010) defines a national innovation system as elements and the relationship between these elements, which interact in the production, diffusion and use of new knowledge that is economically useful, viewing the national innovation system as a social system whose main activity is learning. It is also characterized as a dynamic system composed of positive feedback and reproduction. Complementarily, causation and virtuous and vicious circles are part of innovation systems and subsystems.

In this sense, a national innovation system can be constituted by a diversity of actors, ranging from factories and suppliers to research institutes, universities and government agencies that are related through communication, cooperation, competition and command. These interactions are shaped by the institutions through rules and regulations, making the system change over time (Malerba, 1999).

Unlike the definition of a sector, a sectorial system focuses on knowledge and its structure as a central element. In this sense, the key aspects of firms are considered, such as learning processes, competences, behavior and organization, as well as connections and complementarities, including interdependencies between vertically or horizontally related sectors. This means that these interdependencies define the real limits of a sectorial system (Malerba, 1999).

The basic hypothesis for the transition approaches to be tested in studies lies in verifying whether the multiple-level and multiple-phase concepts constitute a sufficient and adequate structure to describe and explain the complex and dynamic transition processes (Loorbach, 2007; Geels, 2002). In this sense, transition theory seeks to analyze processes of change that occur over time, stemming from different actors in the system in a flexible way. This could be considered a metatheory to integrate existing theories and constitute fertile soil for scientific debate by proposing to integrate different scientific approaches.

In studies of socio-technical theory, the word "transition" is defined by Geels et al. (2004. p. 2) as a "passage from one state, stage, subject or place to another or a movement, development or evolution from one form, stage or style to another." The states or forms have certain internal characteristics that give them coherence and stability. The notion of transition also has the connotation of rapid change, a "jump" from one state to another.

Complementary, the term technological paradigm is often used to describe the notion of technological revolutions in a neo-Schumpeterian effort to understand innovation and identify the regularities, continuities and discontinuities in the innovation process. In this sense, Perez (2009) resorts to Schumpeter's concept of innovation and invention, highlighting that the space of the technologically possible is much greater than that of the economically profitable and socially acceptable. The author highlights that the meaningful space where technical change needs to be studied is that of innovation, at the convergence of technology, the economy and the socio-institutional context, which is essentially dynamic and represents the rhythm and direction of change in a given technology.

Regarding the concept of technological trajectory, Corazza and Fracalanza (2004. p. 135) claim it is "determined by a paradigm and may be defined as a normal problem-solving activity." In this sense, a technological trajectory may be represented by a movement based on the solution of trade-offs between variables defined as relevant by the paradigm.

Dietz and O'Neil (2013) are in favor of an economic plan that can help humanity with a better future in which the factors of sustainability and the equilibrium of human beings are the goals, rather than simply striving for economic growth. This proposal is based on three basic assumptions. The first is total recognition that our planet is finite, which requires changing how we see our relationship with nature, especially within economic institutions. This is followed by practices and policies to achieve a stable course for the economy. Finally, willingness to act is required, as the necessary changes will not occur of their own accord.

Studies that involve analyzing technology and its transition view concepts such as national, regional or sectorial innovation systems, technological innovation systems (TIS) and the multi-level perspective (MLP) as central to understanding the trajectory of a technology over time.

National innovation systems are complex systems, composed of complex structures of different connected actors that evolve dynamically, propelled by the variety of structures and the heterogeneity of the actors that make up these macroeconomic systems (Loorbach, 2007; Kastelle et al., 2009). Innovative actors, like entrepreneurs and consumers of novelties, and innovation systems co-evolve, as the actors can modify their innovation systems. They can also be modified by the aspects of macroeconomic systems (Kastelle et al., 2009).

Due to the cumulative nature of technical learning combined with aspects of interdependence between institutions and technologies, Lundvall (2010) highlights that it is probably impossible to find an institutional system that will permanently guarantee an innovative economy, as institutions that encourage innovation for a given time may eventually slow them down later. In this sense, a system of institutions may vary quite differently, depending on the particular nature of the technology and the development stage of the technological trajectory in question.

Innovative actors tend to be similar between and within different systems and can include companies, research institutes, financial institutions, universities, NGOs, facilitating agents and agents who stimulate innovation.

The TIS changes according to how the technology evolves and develops. Transition processes do not only involve the growth of new technologies, but different stages of maturity in these technologies, also considering their eventual decline, although the perspective of TIS is not ready for these tasks (Markard et al., 2015). To demonstrate these different stages, Markard (2016) presents the life cycle of a TIS in four phases of development: Nascent, Emerging, Mature and Declining, as shown in Table 1.

The life cycle of a TIS can include the emergence of a new technology, followed by the institutionalization process and strong growth, maturity and eventual decline and elimination. For the first two stages, in which the system emerges and stabilizes, Markard (2016) points out a strong dependence on the context, as the development of the system depends on the mobilization of resources, the entry of actors and the legitimacy of the technology. Its incorporation into already existing structures is essential in this phase.

At the end of these phases, a TIS accumulates in terms of structure and grows in size, expanding in a self-sustaining way, as shown in Figure 1. This development shapes certain structures in the context. Although initially ignored, new technologies can later compete and even replace existing technology when the technologies in question have similar uses. Complementarity is also possible, especially when the existing and emerging technologies can be combined, mutually benefiting each other (Markard and Hoffmann, 2016).

Innovation systems are better analyzed as populations. Different types of innovation system interact at the level of the most innovative actors, and an aspect that one actor dominates in a particular situation varies from one system to another. The innovation system and innovative actors in the system co-evolve. "Rather than thinking that agents must conform to the constraints of the system they work within, it is important to realize that they can also shape these systems through innovative action" (Kastelle et al., 2009. p. 2).

The structuration of the systems is one of the central themes of the MLP. When addressing the different types of structuration activities in local practices, Geels et al. (2004) differentiates the degree of formalization according to the micro, meso and macro levels. According to the author, in technological niches, structuration is vague and loose, increasing the degree of formalization at the regime level, where the rules are stable and generate effects on the activities of the actors. This structuration of activities is even stronger at the landscape level, where widely shared cultural beliefs, values and symbols form gradients for action. The relationship between the three levels can be understood as a nested hierarchy. In other words, regimes are embedded within landscapes and niches within regimes, as shown in Figure 2.

The relationship between the three levels of the MLP is conceptualized as follows: Socio-technical landscape, the macro level, forms the external environment and, through its influence on the socio-technical regime, it makes some technological developments easier than others. In incremental technological developments, the socio-technical regime can be constituted in the trajectory of the technology; and the niche level is where radical innovations are incubated and multiplied.

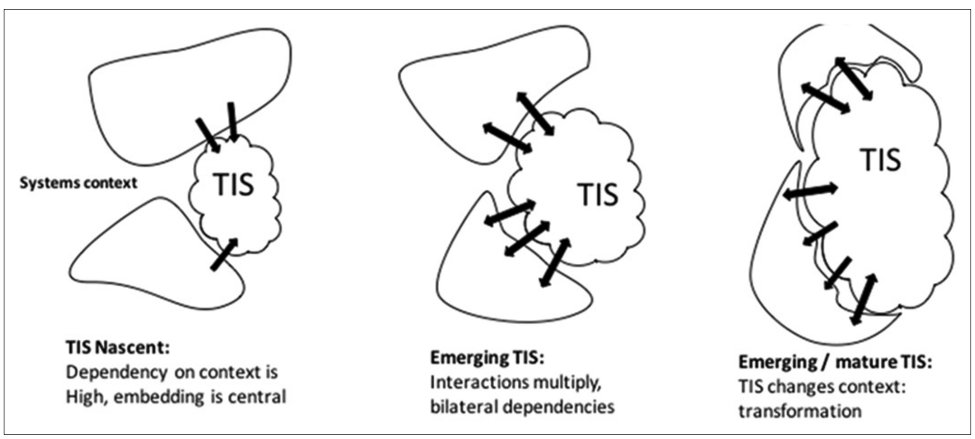
A socio-technical regime is composed of three interrelated elements: A network of actors and social groups, a formal, cognitive network with normative rules that guide actors'

Table 1: Four types of tis at different stages of maturity

Column 1	Nascent TIS	Emerging TIS	Mature TIS	Declining TIS
1. Size (Market, Elements)	Market (s) inexistent, sales close to zero, small number of actors	Market (s) forming, sales low or moderate; medium to large number of actors	Market (s) well established; sales are high; medium number of actors, few large actors may be dominant	Sales declining; medium to small number of actors
2. Activities	Knowledge generation, creation of legitimacy, formation of expectations	Knowledge generation, market formation, system building, institutional change in context	Production and system maintenance	Defensive action, reconfiguration
3. Structure (Important institutions)	Scattered relationships; rather few, mostly cognitive institutions (ideas, concepts)	Dense collaboration networks; technology-specific institutions; emerging standards, increasing formalization	Established value chains; established standards, dominant design, rigid formal institutions	Relationships breaking apart, institutional structures destabilize
Degree of structuration	Low	Medium	High	Medium to low
4. Diversity technology	High	Medium	Low	TBD
Actors	Low; vertically integrated; universities and private R&D labs dominant	Medium; different kinds of actors in different roles; intermediary actors emerging	High; specialized service providers and associations, medium to low vertical integration, few large firms dominate the market	TBD
Dynamic	Moderate growth low entries	Strong growth; high entry and exit rates	Stable/moderate growth; low entry/exit	Decline; frequent exits

Source: Adapted from Markard (2016)

Figure 1: Emergence and maturation of a technological innovation system



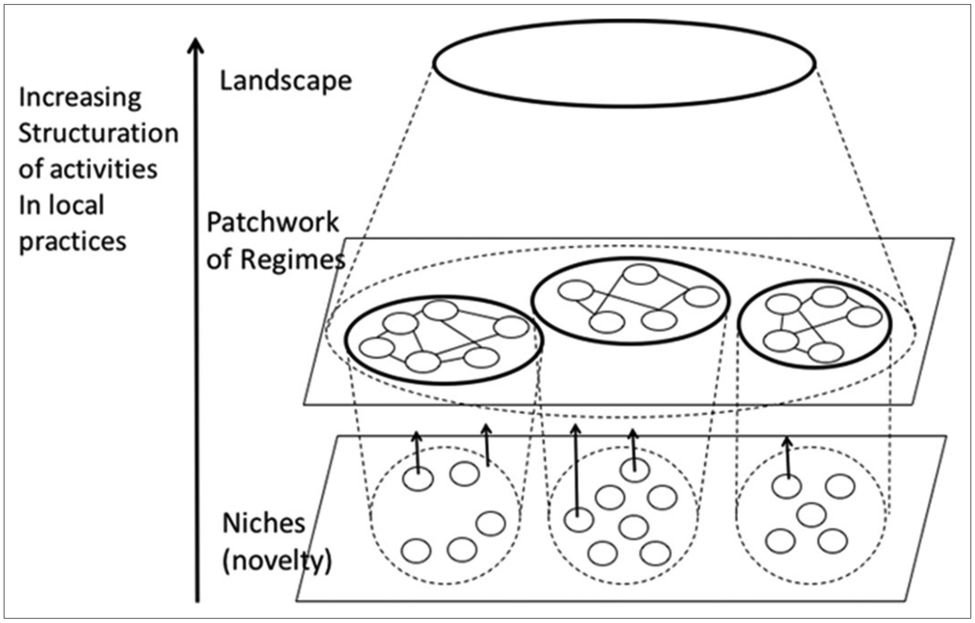
Source: Adapted from Markard (2016)

activities, and the material and technical elements, such as artifacts and infrastructures. The response of the regime to aspects of destabilization may occur to respond to landscape pressures and absorb innovations developed in niches level. Under certain conditions, it may cause a transition to a new regime, where the dynamic and pace of transition are shaped by the environment in which the system is embedded.

Landscape pressures and the regime dynamic can modulate niche development, creating windows of opportunity and eventually contributing to the success or failure of the niche. A qualitative evaluation will determine whether a niche is sufficiently developed to become a candidate for an alternative to the existing regime. Finally, a transition ends when a new socio-technical regime emerges, meaning that the social and technical aspects of the innovation and its use are incorporated into the institutional sphere in the production and subsystems of the use of the socio-technical system Papachristos (2010).

Despite presenting a pertinent theoretical scope for the object of study, offering an integrated view of a co-evolutionary process, "transition management is not yet firmly grounded within the field of policy and governance sciences and has only been limited and tested on a limited scale" (Loorbach, 2007. p. 27).

Figure 2: Multi-level perspective as a nested hierarchy



Source: Adapted from Geels (2002. p. 1261)

As changes occur in the regime, new kinds of formal policy are required to aid the institutionalization process of the rules, highlighting the need to break down barriers and unsustainable practices systemically (Wittmayer and Loorbach, 2016). This process of policy-making and governance is fundamental to the technology transitions and we will discuss them in the next section.

2.2. Governance for New Technologies

Loorbach (2010) highlights that governance models need to consider three fundamental aspects: (1) All the social actors influence and drive changes in society, which are shaped through interaction networks; (2) Top-down planning and market dynamics only take part of social change into account, and should also include network dynamics and reflexive behavior; (3) The steering of change involves a reflexive process of researching, learning and experimenting.

There is a wide variety of concepts, analytical models and theories involving governance. In this sense, complexity theory is presented as a complementary contribution to socio-technical transition theory and the MLP, as these transitions of the social system can be considered particular cases of so-called "complex dynamic systems" (Grin et al., 2009; Loorbach, 2010; Geels, 2004).

Diversity, uncertainty and heterogeneity of society are aspects that directly affect governance. This concept is described by the authors in many different ways and related to institutions and some form of political interventions, strengthened by government initiatives. It should be said that government institutions are important, but not the only means of achieving governance or coordination among actors (Ulli-Beer, 2013).

Research traditions address governance, such as ecology, political studies, technology and innovation. Despite the diverse origins, these different approaches share elements that emphasize participation, experimentation and collective learning as key elements in governance, under the collective heading of "reflexive governance." This impacts dimensions of policy in terms of problems and solutions, rules and structures, and interactions and processes at the micro, meso and macro level, as shown in Table 2 (Voß and Bornemann, 2011).

In their study on governance in energy, Florini and Sovacool (2009. p. 5240) define the governance process as "any of the myriad processes through which a group of people set and enforce the rules needed to enable that group to achieve desired outcomes." The authors debate so-called governance for sustainable development by touching on aspects of socio-political governance, which involves the relationship between public and private actors to solve society's problems.

Ulli-Beer (2013) highlight the role of circular causalities in the process of controlling power groups with similar beliefs, stating that eventual discrepancies between desired and effective system states create pressure for corrective actions within the socio-technical system. Such purposeful responses may be overruled by historically established steering mechanisms and actor groups. This creates systemic resistance to change and results in undesired path dependencies (self-reinforcing processes that accelerate the direction of development within a system) and lock-in (state of a historically evolved system that can only be modified with a great effort).

Based on the diverse complexities, Loorbach (2007) proposes that a long-term governance model should take into account the fundamental aspects of complexity theory from the basic idea of understanding society as a miscellaneous collection of complex adaptive system and views transition management as a central element of this process. Governance process should observe the conflicts between long-term goals and short-term dynamics,

Table 2: Relevant aspects of the policy in different dimensions and levels

Levels	Policies (problems and solutions)	Policies (rules and structure)	Policies (interactions and processes)
Micro (focal interaction)	Problems and goals of a specific governance process	Rules of procedure for a specific governance process	Struggle for domination between participants in a governance process
Meso (political domain)	Definition of political approaches and problems dominant within the political domain	Institutional arrangements within a political domain	Struggle of organized political actors for dominant positions within a policy domain
Macro (political system)	Discourse of fundamental political values and beliefs	Constitutional rules and political culture	Struggle for domain between large social groups, sectors, classes or regions

Source: Voß and Bornemann (2011)

aspects of economic, social and environmental development and a balance between present and future interests.

By combining the complex systems perspective, new forms of governance and the notion of sustainable development, it is assumed that social change will be influenced in an organized and structured way. In this sense, the transition management approach offers a framework for structured governance, which can integrate the theoretical governance models and the transition management models. These prescriptive models involve multiple actors, drafting policies, adaptability and flexibility of political processes, social learning and effective long-term planning (Loorbach, 2007).

The author proposes linking the central elements in policy and governance mentioned in the literature, such as drafting multi-actor policies, establishing and anticipating collective long-term goals, setting a common agenda, a process of experimentation, innovation, evaluation, adaptation and reflexivity, as well as the diffusion of knowledge and learning to construct a sustainable governance model. In order to identify the fundamental elements for proposing a new governance model for solar energy in Brazil, it is necessary to review the solar energy system, detailed in the next section.

2.3. Solar Energy in Brazil

Electrical energy has become a basic need that has an important role in economic and social development in the modern society. The energy economy of the industrial world is highly dependent on fossil fuels, implying that even if a rapid growth of renewable energies occurs it would take at least two decades for significant changes occurs. In the world scenario, renewable energy sources in 2012 accounted for about 13% of primary energy production, most of which consisted of traditional biomass use in developed countries, followed by hydroelectric power. Global energy use continues to grow, driven by population growth and economic development, especially in large developing countries such as China, India and Brazil, associated with increased industrialization (Twidwell and Wier, 2015; Ayres, 2012; Saepudin, 2018).

An important aspect of electricity production and consumption is that unlike other network systems, such as sanitation and gas, electricity cannot be stored in an economically feasible way. This implies a need for a constant balance between supply and demand. According to the Brazilian Association of Electricity Distributors (ABRADEE), all the energy produced must be consumed instantly and, when there is an imbalance, even for fractions of a minute, the system runs the risk of a blackout (ABRADEE, 2018).

Brazilian electricity sector can be classified according to technical or regulation aspect. Technicical involves government agents, responsible for the energy policy of the sector and its regulation and operation and the sale of energy. In this segment, the agents directly linked to the production and transport of electricity are those that generate, transmit and distribute it. The second aspect involves regulation and inspection. These are the responsibility of the National Council for Energy Policy, ministry of mines and energy (MME), electricity sector monitoring committee, energy research company (EPE) and the Brazilian Electricity Regulatory Agency (ANEEL) (ABRADEE, 2018).

The energy sector is highly regulated in Brazil, being controlled by governmental institutions, with little scope for privatization or private free-trade activities in the sector. A study carried out by Sadik-Zada et al. (2018) on the impact of privatization on the energy sector in Latin America shows that Privatization has a positive and significant impact on the level of access to electricity services in each model specification.

The literature on evolutionary theory identifies the heterogeneity of actors as one of the key elements for the development of a sectorial innovation system by including in this aspect a variety of beliefs and expectations that lead to a degree of differentiation on a series of factors. These include the knowledge base, technologies, market demand, historical aspects and formal and informal learning and cooperation processes and relationships between different types of actors, such as universities, research centers and government agencies (Malerba, 1999; Lundvall, 2010; Nelson, 1993). For solar energy, this process is in the niche phase, as the technology has not been diffused in the country and the institutions involved are beginning the consolidation process of a sector system. Solar energy technology knowledge is in its early stages in Brazil, where it is considered an incipient technology.

One of the elements that retard the dissemination of solar electric power is its cost. Despite a significant drop since its emergence in the 1950s, its price remains high compared with other sources of electricity. Hinrichs et al. (2015) highlight the advances of this technology in terms of efficiency and falling costs and claim that despite the costs remaining high, the solar market continues to grow. The authors highlight that the advantages of solar energy include its autonomous application in remote areas, the fact that it does not cause pollution, the rapid implementation of the system and its abundant principal raw material, the silicon in the environment. Furthermore, a cultural change in consumers concerning "clean energy" propels the growth of photovoltaic installations.

Another challenge for solar energy development in Brazil is related to the professionalization of the sector. The Brazilian market does not have qualified professionals to work specifically in the solar energy systems market and brings professionals from other areas, mainly from the electric and civil construction sectors. The country also does not have preparatory courses and formal education aimed at this market segment at all levels (technical, undergraduate and postgraduate).

Photovoltaic energy has advanced greatly on a worldwide scale, especially in developing countries. It is estimated that there are 1.5 billion people with no access to electricity, including 190,000 families in Brazil, according to data from the MME (2015), most of whom are in rural zones. This shows the huge potential for this energy source in Brazil.

Next section will discuss the qualitative methodology we used to identify challenges and opportunities for the emergence of solar energy in Brazil.

3. METHODOLOGY

We used a qualitative research method of document analysis, which is a procedure to identify relevant documents, analyze them and interpret the data from the document examination. Document analysis is a qualitative research method that refers to procedures for analyzing and interpreting data (Schwandt, 2007).

We analyzed a total of 73 documents from Brazil. These sources of data included government documents, regulations, resolutions, reports from Ministry and news media (interviews and photographs), as shown in Table 3.

We adopted three criteria for the selection of the documents to be analyzed: (1) Importance of the document for solar energy policies and regulation; (2) legitimacy of the organization that disseminated the information; and (3) impact of the information on the path of solar energy in the country. The schema of interpretation and analysis emerged from the data itself, which were interpreted, understood and later categorized according to the shared meaning of observations of the documents of Brazil. The main findings will be described in next sections.

Table 3: Number and origin of documents analyzed

Origin of the document	Total documents
Regulations and resolutions	18
News media (including interviews and photographs)	17
Associations and NGO's reports	9
Solarimetric atlas and other technical materials	7
Reports and ordinance from Ministry	7
Notices and reports from ANEEL	6
Courses on solar energy	3
International reports	3
Notices from BNDES	2
Projects for new law	1
Total	73

4. DATA ANALYSIS OF SOLAR ENERGY IN BRAZIL

We identified the analytical categories into a coding scheme in order to answer the research questions and consolidated the results from the 73 documents into five main dimensions: (1) Domestic solar panel industry development, (2) new market formation, (3) government initiatives for the use and dissemination of solar energy in the country, (4) stakeholder commitment to research and development and (5) technologies and innovations applied development inside this segment. From the analysis of each of the documents, we performed a codification of the subjects that most appeared and classified according to the similarity and meaning and we achieve the result in the 5 dimensions presented below.

4.1. Domestic Solar Panel Industry Development

There's a need for a structural change in the system to make the technology transition feasible. Although there is optimism regarding the development of the domestic solar panel industry throughout the chain, there is a need for a medium to long term plan with the involvement of different stakeholders and the legitimization of technology as a market opportunity to be explored.

4.2. New Market Formation

The market demand for solar panels is a fundamental factor for the consolidation of this technology in the country, because the high demand brings scale of production and security to the investor.

Many studies have pointed to economic growth through access to energy services and the relationship between growing energy demand and GDP in the same region, showing that access to energy services is a necessary element for sustainable development. This is because it aids not only the economic growth of a country but also access to essential elements to improve quality of life, such as education and healthcare (Matheson and Giroux, 2010; IEA, 2004). Some authors classify the relation between renewable energy consumption and economic growth in terms of their conservation and growth and compares the energy consumption with economic growth (Khobai and Roux, 2018).

Data from the MME show that the national electricity supply shows the same trends in a reduced share of petroleum and hydraulics and an increase in other sources compared with the rest of the world as is the case of countries in the Organization for Economic Cooperation and Development (OECD) and other countries (MME, 2015).

Governance based on transition management was developed in different sectors and regions. However, only the future will show whether transition management is a symptom of the emergence of a new policy and a paradigm of governance or a fad to cover up the fact that it is just politics as usual. These governance processes are focused on short-term innovation and long-term sustainability, linked to desired social transitions, and include a network with diverse businesses, government, science and civil society. Brazilian Energy Balance data for 2016 show that the electricity matrix is predominantly renewable, highlighting hydraulic generation, which accounted for approximately 64% of the country's internal supply in 2015.

The generation of electricity in Brazil in service centers and self-production reached a level of 590.5 TWh in 2014, which was 3.4% higher than 2013. Public utility power stations, with 84.1% of total generation, remain the main contributors. The main source of electricity generation in 2015 remained hydraulic in origin, although it was reduced by 3.7% in comparison with 2014 (BEN, 2016).

4.3. Government Initiatives for the Use and Dissemination of Solar Energy

Government initiatives for the use and dissemination of solar energy in the country also emerged from the data analyzed as an essential factor for solar energy technology, since financial and financial incentives encourage investors in the sector.

Regulative, legislative and legal aspects play a fundamental role in the establishment of energy policies. Furthermore, Matheson and Giroux (2010), based on a work of the OECD, point out the environmental functions required for each level of the sectorial ministries in a country. These functions range from formulating environmental policies for energy development to managing human resources, and monitoring and demonstrating performance, showing the requirements for governance in the energy sector.

4.4. Stakeholder Commitment to Research and Development

Stakeholder commitment to research and development is one of the fundamental factors for solar energy since the integration between the different actors allowed the production and diffusion of knowledge, as well as professionalization of the sector, with an exchange of information between the productive sector, academia and government institutions.

4.5. Technologies and Innovations

Technologies and innovations is considered one of the most important dimensions for solar energy since the innovations contribute to the strengthening of the technology, bringing good perspectives in economic terms. Development of new technologies is a dimension that complements the others, since the development of a national industry, market formation, government initiatives and integration among stakeholders will not be enough to consolidate the market without the development of technologies and innovations. The national strategic contribution to innovation in the energy sector can not be transparently demonstrated due to the absence of an institutional apparatus that favors the visibility of results (Silveira et al., 2016).

The political challenges facing the energy sector in developing countries are diverse and complex, ranging from access to modern low-carbon energy to the environmental degradation associated with traditional biomass fuels to the lack of a stable and reliable internal supply of electricity, safe supply and the costs of importing energy (Matheson and Giroux, 2010).

The technological issue significantly affects the way the population uses energy and steers the technological paradigm of this activity. According to Corazza and Francalanza (2004), the technological paradigm is a model or pattern for solving selected technological problems, formulated based on principles derived from the natural sciences through the employment of selected material technologies. On the specific point of generating electricity, new technologies can greatly help to reduce CO^2 emissions, with greater efficiency and reduced costs. Thus, technological development was one of the determiners in the choice of the sources that will compose the national energy matrix to make it more diversified on the horizon of the 2030 National Energy Plan (EPE, 2007).

In terms of the structure of the sector, the current stage of solar energy technology in the country is at the niche level, according to the multi-level proposal of Geels (2002), which shows that the country still has a long way to go so that the use and dissemination of solar energy occurs widely in the country.

The technology for generating photovoltaic energy remains incipient in Brazil and its advance so far has depended on government institutions and their initiatives to promote it. This development was shaped by the government institutions of the sector that play a very important role in diffusing this technology in the country. In terms of innovation, the National Innovation System is currently in the Emerging TIS phase, according to the four different stages of maturity proposed by Markard (2016) (Table 3), with the CTI policy (Science, Technology and Innovation) a relevant but not exhaustive initiative to develop new technologies for the energy sector as a whole, as will be discussed in the next section, where we will discuss the conclusions and recommendations.

5. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to analyze the solar energy sector in Brazil from three different approaches: Socio-technical innovation, governance for new technology and solar energy domestic trajectory. We identified some challenges to the solar energy sector growth in Brazil from a qualitative document analysis of 73 sources of data.

The results were consolidated in five important dimensions: (1) Domestic solar panel industry development, (2) new markets formation, (3) government initiatives for the use and dissemination of solar energy in the country, (4) stakeholder commitment to research and development and (5) technologies and innovations applied development inside this segment as discussed before.

Brazil is currently in the emerging TIS, going through a moment of evolution within the innovation system. Government initiatives to promote this technology have not yet taken off, there is no transfer of technology from other countries and the few research and development projects has been developed in the country. The transformation and evolution of the sectoral innovation system involves the relationships between actors of different natures and the process of learning and exchange that develops through these relationships. The entry of new players in the domestic solar energy sector may introduce new skills and exchanges and enable learning and the consequent development of new technologies for Brazilian solar energy.

Furthermore, the relationship between actors already established in the Sector Innovation System develops a process of co-evolution of the system. This makes the central elements of the system, such as technology, knowledge and market demand, develop jointly and more dynamically, with greater interconnection. The technological transition process benefits from this and may leads to the emergence of this technology in the electricity sector in Brazil.

The ability to create and maintain an environment suitable for the development of all sustainable energy sources in Brazil involves political, regulatory, financial and planning elements focusing on energy efficiency and optimized and efficient resource management. It is imperative that the Brazilian government creates specific incentive mechanisms for the promotion and dissemination of solar energy in order to universalize the population's access to this technology as well as promote the development of the domestic industry and the consequent job generation and positive movement of the economy in this sector.

These investments in specific policies for the solar energy can be justified by the reduction of the emission of CO^2, inserting the country in the low carbon economy, besides the diversification of the current national energy matrix, highly dependent on hydropower.

The practical contribution of this study lies in the fact that it provides the actors in the electricity sector's Innovation System with a better understanding of the social context in which they are involved. A further contribution is the fact that managing the transition to a sustainable energy system is considered essential by many authors.

Among the limitations of this study is the fact that it observes only one source of renewable energy and it would be suggested that in-deep interview should be taken with relevant actor of the national innovation system to complement the analysis. A suggestion for future research would be to broaden the scope of the study, with an approach that involves all kind of renewable energy and their trajectory within the National Innovation System of the electricity sector.

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