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Challenges and opportunities for the growth of solar photovoltaic energy in Brazil

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ABSTRACT

This study investigates from a socio-technical perspective the emergence of Solar Photovoltaic electricity (PV) in Brazil and identifies challenges and opportunities of PV energy in the country. The research is based mainly on primary data from 2015 to 2016 including 15 in-depth interviews with representing relevant actors from the system. Additional written data involved resolutions, regulations and reports from the official government organizations. Multilevel perspective and the functions of innovation systems perspective were used for data analysis. The need for the dissemination of PV energy includes the establishment of long-term clear goals, fiscal and financial incentives, more attractive opportunities for investors as well as professional training courses. The paper includes a critical review of the applicability of the multilevel perspective and functions of innovation system with recommendations for adapting them to better fit this case. What is especially interesting to derive from the analysis is the impact of the niche developments on the regime and the landscape, especially in the establishment of a domestic PV energy industry, national economic growth, local and regional development, which would result from the dissemination of PV energy.

1. Introduction

Since environmental issue was first presented with intensity in the 1980s, the concerns and studies on environmental problems are growing worldwide, national and global proposals aimed at limiting and reducing environmental damage, which involves fossil source of energy replacement and the increase of renewable energy sources usage. The GEI (Global Electricity Initiative) report for 2014 demonstrates that the demand for electricity tends to grow strongly worldwide, and it is expected that in the coming decades more than 90% of this demand growth is coming from developing countries.

In the scenario for 2030, there will be a tripled energy demand in Brazil and a higher energy demand per person, due to several aspects: growth of the population over 30 million, increase in national GDP and an aging population; all factors contribute to higher energy demand per capita (EPE, Empresa de Pesquisa Energética, 2015; Jannuzzi and Melo, 2013).

This study investigates the socio-technical transition process in the electricity sector in Brazil, specifically for PV energy and identifies challenges and opportunities from a multilevel perspective (MLP) and functions of innovation system (FIS) approach. In this study, the socio-technical transition is constituted as a process that takes place in multiple phases, which permeates the composing aspects of the landscape, the regime and the niche and it is consolidated as a response of the multiple actors involved in the environment for sustainable development of the PV energy activity on the national scene.

Regarding the national and global goal in achieving the growing demand of electricity at the lowest possible environmental impact, it is relevant to analyse how and why the renewable energy sources emerge within the electricity activity, and how it impacts on the transition to a more sustainable national energy system. Despite an insignificant representation in the national scenario, PV energy in Brazil showed a substantial increase from 2013 to 2017, according to the Ministry of Mines and Energy. The main question raised by this paper is: "What are the main challenges and opportunities for the growth of PV energy in Brazil?".

Among the main issues identified is the need for the establishment of specific policies for PV energy technologies, including long-term clear goals, fiscal and financial incentives. The lack of new technologies development, the low knowledge transfer, the shortage of skilled professional and the small-scale domestic market complete the main challenges for the growth of PV energy in the country, as we will describe in the following sections.

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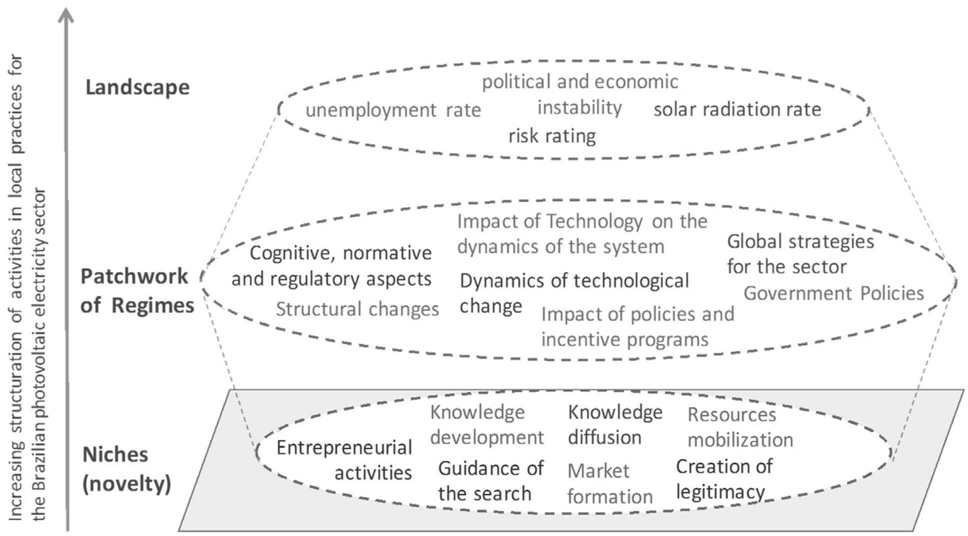


Fig. 1. MLP Levels and indicators for Brazilian PV energy sector.

2. Research method

The socio-technical perspective has its roots on two main theories: institutional and evolutionary economic and it argue that the innovation process is a socially-embedded process that need to be understood under its co-evolutionary relations within the system. We chose to use the socio-technical perspective as a method because this approach can cover the analytical categories of the solar energy system, both technically and socially. Socio-technical theoretical basis means that the system under study is interlinked by both technical and social elements (Kamp and Forn, 2016).

PV energy sector of Brazil is analyzed in this paper based under two socio-technical approaches theories: MLP (Multi-Level Perspective) and FIS (Functions of Innovation System), as discussed below.

The transition as a multilevel process arose from the need to establish a bridge between the STS (science and technology studies) perspective and evolutionary economics (Rip and Kemp, 1998; Schot, 1998; Geels 2002, 2004, 2005). According to Geels (2004), the multilevel perspective (MLP) is composed of three analytical levels for understanding the complex dynamics of socio-technical change: the socio-technical landscape, the socio-technical regime and the technological niches. The Socio-technical landscape refers to material infrastructure, political culture, social values, paradigms, macro economy, demographics and the natural environment, whose transition processes change slowly and autonomously. The socio-technical regime are dominant practices, rules and shared assumptions that guide private action and public policies in a given field, structuring the behaviour of the actors. The technological niches are local domains in which new or non-standard technologies are used (Kemp and Rotmans, 2010). Niches are important learning arenas which provide "protection" for the novelties because they act as incubators (Geels, 2004).

The dynamic of the network actors is essentially initiated by the emergence of new technologies, but their later development is jointly determined by the technologies and institutions (Saviotti, 2010). Multi-Level Perspective emerges and can be understood as a structure for studying technological change and the diffusion of innovations. This perspective emphasizes the role of the social group or network interconnections and the dynamic of change in the system. The alignment of activities influences the stability of the regime and can be reduced as new groups associated with the new regime become more active, pressing the existing regime (Papachristos, 2011).

Technological transition processes can be understood from the dynamic between the levels of niches, regimes and socio-technical landscapes, in a co-evolution of the system. For a regime change to occur, it should be recognized as necessary, feasible and advantageous for a wide range of actors and institutions. In general, the analysis of stablished regimes tends to emphasize the stability and continuity. Therefore, a number of explanations for these technological converge process, such as “path dependence” (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 from a great effort) have been proposed in order to describe this scenario and “lock out” (that occurs within the system for the replacement of certain technology) have been proposed by several authors of the socio-technical theory (Geels, 2004; Nelson, 1996; Perez, 2009).

The literature on technological change for established systems emphasizes the persistence of incremental changes, which requires actors to combine physical artefacts, natural resources, scientific elements and legislative artefacts. There are technical and institutional obstacles to change from one system to the other (Berkhout, 2010; Geels and Schot, 2010).

The socio-technical analysis of the technological transition usually involves a long-term time horizon. In this type of approach historical aspects are essential, since they enrich a view of multi-causality, co-evolution and the use of different time scales. Summarizing, we analyse the three levels of multilevel perspective by evaluating the indicators for Brazilian PV energy sector, shown in Fig. 1

PV energy in Brazil is currently into a technology development, typical from niche phase. In its development and maturation process, a new technology is immersed in a technological niche, which depends on the recognition of its value in order to evolve and to start competing with other technologies already established in the system (Kamp and Vanheule, 2015). In order to analyse the activities and the dynamics that takes place inside the Brazilian PV energy innovation system we used the literature of Functions of Innovation System (FIS) literature, as follow.

An innovation system is a network of institutions whose activities contribute to the learning and the transmission of new technologies favouring an innovative performance of companies to acquire new skills and competences through the network information sharing (Nelson, 1996; Freeman, 1987; Malerba, 2002; Mendonça and Cunha, 2014). The goal of an Innovation System can be described as the transfer, implementation and diffusion of technology, which are composed by key process for a well-functioning Innovation System, named in literature as Functions of Innovation System (FIS) (Alphen et al., 2008). Hekkert et al. (2007) divide FIS in seven key activities, based on empirical studies at Utrecht University: (1) Entrepreneurial activities; (2) knowledge development; (3) knowledge diffusion through networks,

Table 1
Indicators of FIS for PV energy system in Brazil.
Source: own elaboration from Alphen et al. (2008).

Function of innovation system	Indicators
1. Entrepreneurial activities	Niche initiatives for new technologies Number of organization entering PV business Export activities
2. Knowledge development	Learning by doing and learning by using R&D projects
3. Knowledge diffusion	Interacting and exchange of information National and international Knowledge exchange
4. Guidance of search	Expectation on PV energy growth Government Policies and goals to promote the PV energy
5. Market formation	Scale demand expectations (market size, import share) Regulation / Financial incentives
6. Resources mobilization	Access to financial and human resources Foreign investments in PV energy in Brazil
7. Creation of legitimacy	Lobby activities pros and against technology

(4) guidance of the search, (5) market formation, (6) resources mobilization and (7) creation of legitimacy / counteract resistance to change (Hekkert et al., 2007; Alphen et al., 2008).

Hekkert et al. (2007) described the example of the diffusion of solar cells, which depends on technological progress made in universities' research centre worldwide. The global spread of solar cell strongly depends on national investment incentives and subsidies policies. Moreover, other sectors such as microelectronics, silicon production and housing are also influencers for the dissemination of this technology. (Hekkert et al., 2007). We apply the FIS model to analyse the Solar PV innovation system in Brazil by fulfilling the set of functions, as shows Table 1.

This study describes the trajectory of the PV energy system in Brazil by identifying the activities and historical aspects from a longitudinal methodology largely applied to analyse sociotechnical transition in the multilevel perspective and analysis of the structure, named "process analysis". The case study data of this paper was collected by two different sources of information: (1) 20 In-depth interviews with 15 key organizations from the PV energy system (see Tables 3), (2) written data reviews from 69 documents, including governmental resolutions and polices, as well as documents and reports from niches initiatives projects to promote PV energy in Brazil (see Table 2).

The interviews were focused on understanding the challenges and opportunities of PV energy in Brazil and followed a semi structured format, which permitted the interviewees to freely point out their thinking about economics, cultural and social factors that affects the innovations trajectory of this technology.

We coded the interviews, identifying each organization of the primary data, according to Table 3. We used each organization's codes (E1, E2, etc) to identify the data in Section 4 below.

Table 2
Number and origin of written data.

Origin of the document	Total documents
Regulations and resolutions	17
News media (including interviews and photographs)	16
Associations and NGO's reports	9
Solarimetric atlas and other technical materials	7
Reports from Ministry of energy	6
Notices and reports from ANEEL	6
Courses on solar energy	3
International reports	2
Notices from BNDES	2
Projects for new laws	1
Total	69

Table 3
Interview coding.

Organization	Number of respondents in the organization	Interview code
3BEnergy	01	E1
ABRAGEL	01	E2
CompactCia	01	E3
COPEL	01	E4
CPFL Renovaveis	01	E5
BNDES – National Bank for Economic and Social Development.	01	E6
ELCO	03	E7
ELEJOR	01	E8
EPE – Energy Research Company	01	E9
Hübke Consulting	01	E10
MME - Ministry of Mines and Energy	02	E11
Paraná Metrologia	01	E12
Renova Energia	03	E13
Sistechne	01	E14
UTFPR – Federal Technological University	01	E15

The document analysis aimed to identify main drivers published by important stakeholders for PV energy technology and describe the path followed by these determinations and how it had indeed promoted the development and dissemination of solar PV energy in Brazil. We developed a complete picture about the major activities that somehow influences the trajectory of this technology, based on historical description, narrative of relevant activities and sector milestones, such as incentive resolutions and structural changes in the system.

Research in the multilevel perspective allows us to identify the current stage of a technology but does not reveal the obstacles and opportunities for the development process of this technology. In a complementary way, the analysis of the functions of the innovation system contributes to indicate ways to face obstacles and seize the opportunities, subsidizing the definition of strategies and public policies.

As the main results of this analysis, we have identified that the growth of PV solar energy in Brazil depends on interdependent initiatives. These initiatives include the definition of a long-term plan to increase this technology with clear and objective goals, which provides security for this sector, especially for investors. In addition, it is necessary to promote fiscal and financial incentives, which favor the development of economic activities in the sector, as well as the consolidation of an educational plan that adequately enables professionals at all levels to work with solar PV energy. These activities are interdependent because the development of one of them also promotes the structuring of the others, that is, there is a direct interdependence between the elements that promote the growth of this technology, as will be detailed below.

3. Analysis

This section describes the results of the technological innovation system for PV energy in Brazil. As a starting point, we described the technology development and its historical aspects, followed by an application of MLP and FIS perspectives to the sector. This section ends with the explanation of challenges and opportunities for PV energy in Brazil.

3.1. The electricity sector in Brazil

The electricity sector in Brazil is characterized by strong and direct state presence, historically playing a driver and controller role and segregate the energy activities in generation, transmission and distribution (see Table 4). Despite the co-existence of public and private

Table 4
Historical aspects of the Brazilian electricity sector.
Source: Adapted from Magalhães and Tomiyoshi (2011a,2011b)

Phase	Description of regime	Regime aspects
Phase 1 - Experience and pioneering developments (1879–1896)	Imperial government carries out experiments and public works, including electric trams and the first hydroelectric plant in the city of Diamantina (MG).	• Monopoly • Private Companies • Deregulated market
Phase 2 - Foreign capital and domestic private groups (1898–1929)	Predominance of foreign capital and private groups in the sector, especially American & Foreign Power Company (Amforp) - mainly in municipal concessions.	• Self-financing little competition • No planning
Phase 3 - Regulatory and increased installed capacity (1931–1945)	Water Code (1934): a milestone for the sector that establishes rules for concessions. Creation of institutions to act in the regulation and supervision of electric power companies in the country, especially in hydroelectric and thermoelectric plants.	• Strong state presence • Nationalization • Market regulated by the government • Financing by public resource
Phase 4 - government policies and public companies (1948–1963)	National Bank for Economic and Social Development (BNDES) Foundation in 1952. Creation of several state companies of electricity, mostly hydroelectric subsidiaries of the Eletrobras system.	• Non-existent competition • Regulated rates in all segments • Determinative planning
Phase 5 - Consolidation and crisis of the state model (1964–1990)	Federal government planning to ensure the operationalization of the interconnected systems, due to the large generation expected for the Itaipu dam, the largest energy production in the world. National Privatization Program (PND) creation, which aimed to reorganize the state's strategic position in the economy and bring investments to the sector.	
Phase 6 - Privatization and reforms (1992–2009)	Privatization of several electricity companies. The energy crisis of 2002 required the implementation of emergency planning to match the demand and supply of electricity. Energy rationing and hiring of emergency thermal energy, named Thermoelectric Priority Program (PPT). Incentive Program for Alternative Energy Sources (Proinfa), hiring 3.300 MW of electricity by wind, biomass and small hydroelectric plants.	• Free market competition • Privatization • Public and private financing resources • Competition in the generation and commercialization of energy • Tariffs freely negotiated for energy generation and commercialization and regulated for energy distribution and transmission
Stage 7 - regulatory state and standby power planning (2006–2016)	State takes over the role of expansion planning coordinator with long-term contracts in electricity auctions, which now also includes other renewable energy sources such as photovoltaic solar energy.	• Hybrid model • Private and public companies • Market both free and regulated • Funding using both public and private resources • Competition in the generation and commercialization • For free market: free prices for generation and trading. • For regulated environment: auctions for lower supply • Planning by EPE

companies in the sector, planning and operation are centralized by government institutions, which regulate and control the auctions for supply energy demand (Camilo et al., 2017).

Government institutions have a historic central role in the dynamics of the relationships between the system levels, which directly or indirectly impact the trajectory of PV technology and determine the actions that will be taken into consideration for the future of this technology, both the federal and regional levels.

3.2. The solar photovoltaic electricity development in Brazil

The stakeholder map for the Brazilian PV energy sector can be divided into 7 main groups of actors:

1) PV Industry: consisting PV Panel Industries, company and workers union, small business entrepreneurs, start up's and niche innovations.
2) Governmental Institutions: consisting of Ministry of Mines and Energy, EPE _ Energy Research Company, ANEEL - National Electric Energy Agency as main actors, once they're responsible for the public policy development and for defining the nature of the national energy system planning;
3) Associations and NGO's: consisting mainly of Photovoltaics associations, cooperation agencies and non-governmental organizations of technological and environmental nature. The main organizations of this group are: ISES (International Solar Energy Society) and ABSOLAR (Brazilian Association of Solar Photovoltaic Energy).
4) Funding, which includes international and national banks, credit unions in regional and local levels and others financial companies.
5) Education and professional training, consisting mainly of universities and educational institutes.
6) PV Centralized Generation, with large energy organization and large PV energy plants. For this group, the most important actors are the multinational energy organization, which usually wins the auctions in the country.
7) PV Distributed Generation, involving the micro generators, especially residential and rural cooperatives.

We have developed a Stakeholder map for PV energy in Brazil (see Table 5) and classified their scope of action according to three levels (local, regional or international) and each of the 7 main groups of actors. This map is not exhaustive and the criterion of selection of the actors was its importance for the innovation system.

Brazil began the process of analysis and development of PV energy in its energy system in 2011 with the Call for R&D number 13 of the National Electric Energy Agency (ANEEL), which had as main objective propose technical and commercial arrangements for electricity generation through PV energy, creating conditions for infrastructure and technology development for integration of solar photovoltaic generation in the national energy system. This call included the installation of a solar plant with an installed capacity between 0.5 MWp and 3.0 MWp, plus a Solarimetric station able to provide data to evaluate the technical and economic project performance. The government initiatives and resolutions for PV energy in Brazil had two main goals: to develop a national solar panel industry and also to increase the generation capacity of this source of energy in the country.

The project Call 13 was a milestone in the history of PV energy in Brazil, since it enabled an analysis of current technologies for electricity generation, potential impacts on the grid and exchange with experts from countries with outstanding knowledge in this area. In addition,

Table 5
Stakeholder map for PV energy in Brazil.

	Local	Regional and national	International
1. PV industry	Start up's - niche Small business entrepreneurs	PV panel industry Company union Workers union	Multinational PV panel industry R&D innovation institutions
2. Government institutions	Municipality	Power distribution company MME – ministry of mines and energy ANEEL – National electrical energy agency EPE – Energy Research company Eletrobras Inmetro	
3. Funding organizations	Credit union Local credit	BNDES – national bank for economic and social development National banks Regional banks Financing networks	International funding International investors
4. PV distributed generation	Smart grids Small generators	Cooperatives for microgeneration Energy consulting	
5. PV centralized generation		PV energy farms and plants Power transmission and distribution companies	Multinational Energy organizations
6. Education and professional training	Education and training consulting Technical courses Research groups	Universities Technical education institutes	Universities Research centers
7. Associations and NGO'S	NGO's	NGO's Cooperation agencies ABSOLAR - Brazilian association of photovoltaic solar Energy ABENS - Brazilian association of solar energy	ISES – International solar energy society NGO's

this project also included a description of the most suitable places for the installation of plants, considering the solar radiation in Brazil. Despite the low representation of solar energy in the national energy system, the expectation of growth of this technology is favourable for the coming years. The auctions that took place in November 2015 signed a total of 33 solar photovoltaic generation projects, with 1115 MW-peak capacity and should come into operation from November 2018, with contractual period of 20 years of energy supply. These factors move PV in Brazil and makes the country more attractive to equipment vendors (Faria et al., 2017).

Estimates from ANEEL for the distributed generation market show that the number of residential and commercial solar PV systems installed by the year 2024 will be approximately 886,000 units, which represents a huge increase as shown in Graph 1 (ANEEL, Agência Nacional de Energia Elétrica, 2017).

The summit of power consumption for PV energy in the summer period takes place between 12 and 17 h because of the increasing use of refrigeration systems, which coincides with peak generation of PV systems. In this scenario, it's an advantage the usage of PV systems because they may act as a load gear in the power utility network and may reduce the demand for the use of thermal power plants (TPPs), powered by fuel oil, coal and / or natural gas, since Brazil has systematically used such source of energy, generating additional costs to the Brazilian consumers (Lacchini and Dos Santos, 2013).

The federal government, in order to increase the representation of PV energy in the national energy system, made important changes in the Normative Resolution No. 482/2012, which establishing the Electricity Compensation System, allowing the consumer to install photovoltaic solar panels on your property and change energy with the local energy company in order to reduce the value of your electricity bill. These changes came into effect on March of 2016 and shall encourage the installation of new systems in homes and in commercial and industrial establishments (Gomes et al., 2018).

The transition from the current energy system of Brazil relies heavily on government incentives and initiatives. This transition to renewable energy should consider the potential not only technological, but also social. According to Dolata (2013) the transformative capacity of technology is related to the potential impact that new opportunities this technology should have on the sector, which involves not only the innovative potential of the new technology itself, but also the degree of organizational restructuring, socioeconomic and institutional that it is necessary to fully realize this potential. In the case of PV energy, promoting incentives for the adoption of new technology the government is not only contributing to the environment, but especially in social and economic terms, since the development of this technology creates new opportunities for employment, income and economic development for the country. In the next section, we analyse these impacts and how the transition of this technology occurs from a multilevel perspective and the innovation system functions.

3.3. MLP perspective applied to PV energy in Brazil

The elements that influence the transition to the change of technological paradigm are not originated unilaterally, but in a multi-level dimension and it is inevitable changes in the social dimension for example, in user practices, regulation and networks in order to make technological change sustainable (Geels, 2002). To validate this proposal, this study seeks to analyse all the influencers dimensions of this relationship considering its multi-level nature, multi-actors, multiphase and multi-causes and multi-domains and proposes that the new technological paradigm for electricity activity in Brazil is the result of innovative initiatives from this relationship.

The analysis of the electricity regime for Brazil shows stability and continuity for the predominance of hydropower energy in the energy system, which had its beginning together with the system history and leads to a lock in and a path dependence once the stablished infrastructure for power transmission and distribution are mostly established around the hydropower dams.

At the landscape level, main barriers for PV energy for growth are related to political and economic instability, which raises the risk of investment in the country and discourage large investors, especially foreigners. In 2016, three of the major global credit rating agencies (Fitch, Moody's and Standard & Poor's) lowered the rating risk of the country, from low investment grade category to speculation category, with negative expectative, which means that there is still the possibility of further lowering the rating. The risk rating decrease was mainly influenced by economic factors, since the country is in low growth and the expectation is that government debt exceeds 80% of gross domestic product (GDP) in the coming years, beyond the challenging political moment by which Brazil is going through, which leads to concern about the resumption of economic growth. The current political instability in which the country is experiencing tends to aggravate the economic scenario.

Among the consequences highlighted by the high-risk investments are effects on the dollar, the country's companies financing and the level of foreign investment in the country, which can affect all economic sectors. Historically, countries take between 5 and 10 years to recover a risk score, reinforcing the negative scenario for foreign capital investments in the country for next years. This economic scenario reflects the worst recession the country in 25 years, which led to an even worse picture in formal employment, income and quality of life to Brazilians. The unemployment rate in the country in 2018 grew to 13% and it's the largest reading since May 2017 (Reuters, 2018).

On the other hand, at landscape level there is one important drive that motivate the PV energy development, which is the solar radiation rate in Brazil, one of the highest in the world (Holdermann et al., 2014). Among the efforts in the country to assess the availability of solar radiation, we highlight the Atlas solarimetric conducted by the Federal University of Pernambuco and the Atlas of solar irradiation in Brazil, held by the Federal University of Santa Catarina, both point out that even in regions with lower radiation levels, Brazil has a huge potential for PV energy generation.

At the regime level the country's energy sector has not experienced any major structural change since the creation of most state utilities and Eletrobrás System (see Table 4). There is a strong state presence in the sector, with government policies of regulative character and rates fixed by the government. The actual hybrid model (composed of public and private companies) enables market competitiveness, although not fully, since it is regulated in various ways by government resolutions. PV energy transition is a long-term process and it's going to take some years to grow and become representative into the energy system, but the first initiative in this direction have been made by the government and as this new technology begins to be seen as an opportunity and not a threat, it spread within the sector, gaining legitimacy and changing the current mental model.

The analysis of the innovation system is not enough to understand the determinants of change, but a map of the relevant activities that takes place inside the system may provide insights in the interaction of forces that determine the slow and difficulties of change (Hekkert et al., 2007). A relevant activity is the one that influence (both positive and negative) the development, application and diffusion of a new technological knowledge – goal of an innovation system.

On the niche level, we used the FIS analysis as descried in the next section

3.4. Perspective applied to solar photovoltaic energy in Brazil

The PV innovation system is in an initial phase, pre-development. It's necessary to focus the analysis in the niche development and its coevolutionary relations with the regime.

Function 1: Entrepreneurial activities. There are about 1.200 companies working with PV energy in Brazil in segments of projects, installation or supply of photovoltaic solar generation equipment (ENF, Directory of solar companies and products, 2018). Only few companies operate in the manufacture of photovoltaic panels in the country. Entrepreneurial activity for PV energy in Brazil develops especially in niche initiatives, but there isn't a common agenda stablished and also there's no exportation of equipment or knowledge transfer to other countries. The entrepreneurial activities for PV energy face huge barriers to new technologies promotion and the establishment of new businesses model, since the electricity market in Brazil is composed of large organizations already established and with power within the system (E8; E3).

Function 2: Knowledge development. Today the country has a shortage of skilled professionals to work in the photovoltaics sector, requiring the creation of programs for the professional specialized training at all levels (technical, undergraduate and graduate) to act in all segments of the production chain. Regarding organizational capacity, most of the regional energy companies are not prepared to install a huge amount of consumers into distributed generation and connect them to the network. (E8; E4).

Function 3: Knowledge diffusion through networks. There is no technology transfer from other countries and the few research and development projects conducted in the country are made in isolation and timely manner, without the involvement of representatives of all the production chain of the sector. Although there is a search for information by government agencies, universities and research areas and development of electric power companies on new national and international technologies, today there is a recognition of the need to strengthen ties between the various network actors at all levels, ranging from government institutions, education, media companies, consumers and industry associations in order to exchange information, experiences and the establishment of a common agenda among stakeholders to exchange and information flow (E1; E13; E5; E7).

Function 4: Guidance of Search. By launching specific auctions to promote photovoltaics in the country, the Ministry of energy has two main goals: to increase the installed capacity of photovoltaic power generation and also generate demand on a sufficient scale to develop a national industry of photovoltaic panels. In April 2012 ANEEL published the Resolution number 482, that established rules for net-metering from which the consumer is able to generate its own energy in buildings and inject the surplus generated in the distribution network, which is already quite used in the rest of the world in terms of PV energy. Since Resolution 482 in 2012, and its regulations in beginning of 2013, the number of PV systems that were installed in Brazil increased significantly. Although there is already a move towards promoting micro generation, adapted to local needs, it would still require a plan to expand the number of facilities through tax incentives such as the deduction of income tax of individuals or the deduction of annual property tax (named IPTU) where the PV system is installed (E15, E3).

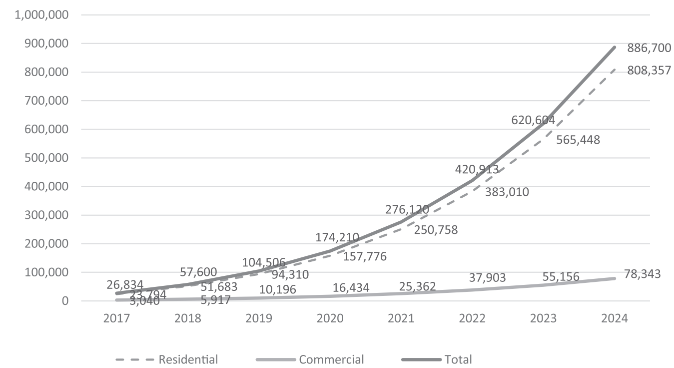
Function 5: Market formation. The market for photovoltaics in the country is very small and does not have enough scale to attract large investments today, but when we observe the future prospects, the market has a very promising and optimistic scenario, due among other factors, to expansion of government incentives for renewable sources in the national energy system, such as 80% discount on rate for use of electric transmission systems (TUST) and the usage rate of the electrical distribution systems (TUSD) for PV energy systems up to 30 MW. This incentive is valid for 10 years for plants that come into operation by December 2017. The plants that come into operation after this period will have 50% discount. New markets emerge in this sector especially in rural and isolated areas where local power generation tends to be more financially advantageous when compared with the extension of the power grid, bringing benefits such as reducing the environmental impact and the generation of employment and income. The so-called isolated systems are pointed out by ANEEL as a possible solution for universal access to electricity, considering the immense territorial extent of Brazil. The Ministry of Mines and Energy has a central role in the market development, once it's policies establishes conditions and needs for a local production of equipment to meet the generation of PV energy, once the auctions were created to give support for the establishment of a national industry and some more specific PV energy auctions are been planned in next years in order to keep an industrial scale that allow the industry development in Brazil (E11, E9; E6).

Function 6: Resources mobilization. Many foreign investors, such as multinational PV energy panels manufacturers decide not investing in the equipment opening factories in Brazil due to high risk, mainly attributed to political and regulatory instability and, by consequence, market uncertainty. Today already exists in Brazil several incentives for manufacturing, such as PADIS - Support Program for the Development of the semi-conductor industry, but there's still a lack of PV energy dedicated support policy and development of the national industry solar photovoltaic power systems (E13, E2, E10). In terms of human resource today there's a lack of formal education in all levels. The PV project companies search professionals from other areas, such as electronic and electrician and teach them of how to work with PV system (E7; E1, E12, E14).

Function 7: Creation of legitimacy / counteract resistance to change. The use of PV energy systems is considered relevant by a significant number of actors inside the national innovation system. For this new technology, be fully legitimized within the electricity sector and deemed appropriate by relevant actors in the field lobbying and outreach activities are necessary at all levels, especially for end users (distributed generation) in two very important ways: information of this source of energy and industry mobilization network at all levels for legitimation (E15; E12, E3).

3.5. Challenges and opportunities for solar PV energy in Brazil

Based on the seven functions of the innovation system for PV energy in Brazil we assessed the main challenges and opportunities (Fig. 2) to



Graph 1. Cumulative number of consumer units with photovoltaic systems in Brazil.
Source: Adapted from ANEEL, Agência Nacional de Energia Elétrica (2017)

the growth of this energy source in the country and put some thoughts on aspects necessary for the transition to happen.

The present status of this energy source shows a lack of information, infrastructure, financial resources to promote, as well as dissemination of information about the technology, which slows the process of

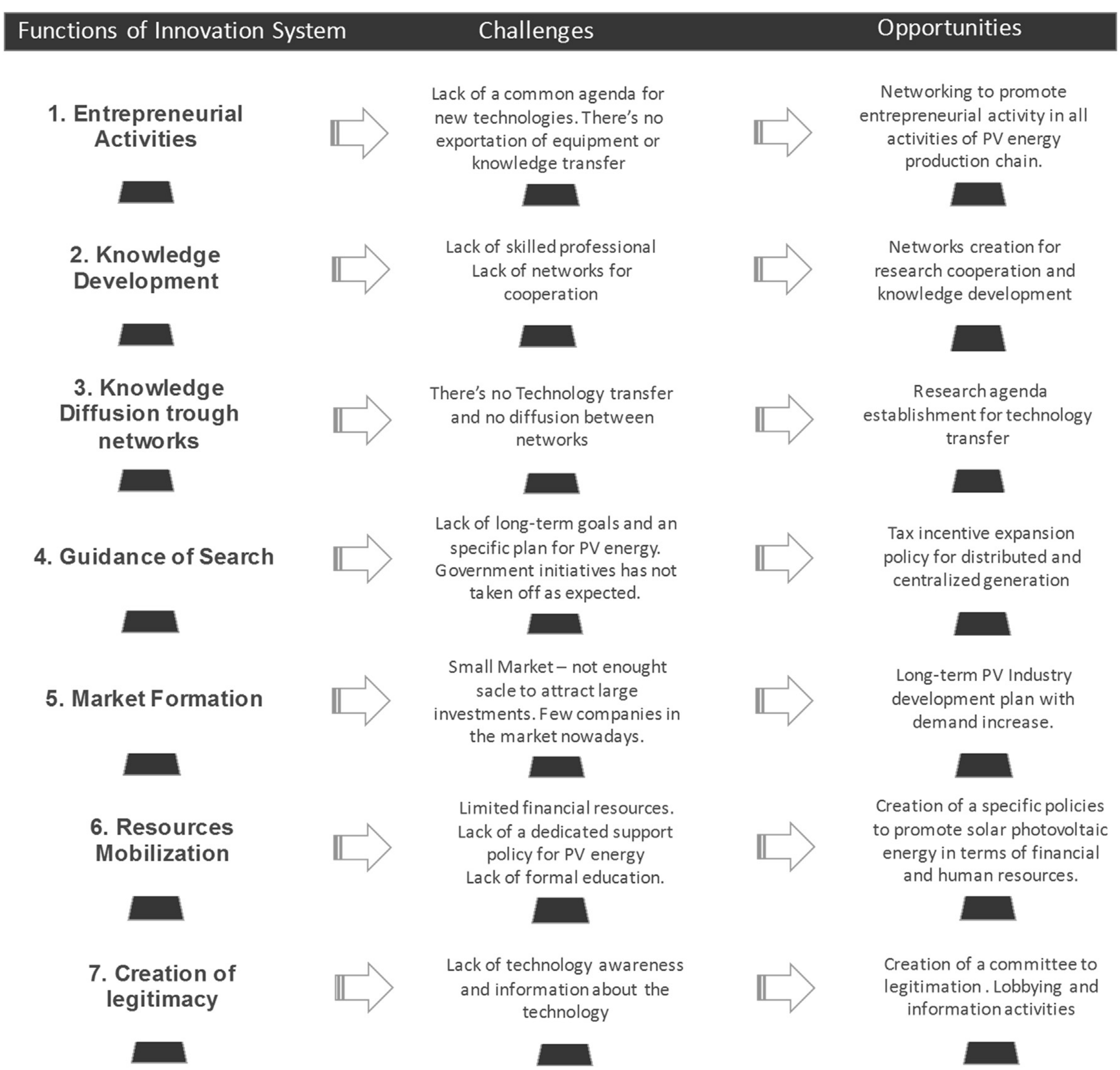


Fig. 2. Challenges and opportunities for Solar PV energy in Brazil.
Source: own elaboration from Geels (2002) and Hekkert et al. (2007)

transition for this source of energy in the national energy system. The opportunities to be developed involves the creation of a committee for information exchange between all production chain stakeholders, activities aimed at increasing installed capacity and to promote the development of the national industry, with technology transfer and formal professional training. These are some of the keys opportunities to develop an open and competitive market for PV energy sector in Brazil.

The FIS framework applied to developing countries has some implications, as described by Tigabu et al. (2015) such as that the support for innovation involves not only technological and economic factors, but also organizational, institutional and social elements that block the transition of technology as a function of a unfavourable environment. By identifying the challenges to the growth of PV energy in Brazil this paper also indicates opportunities and ways that can be trodden in order to achieve a spread of this technology in the country.

When analysing the transition from a technology in a developing country, it is essential to observe the social and economic impact that this technology can bring to the country. In this sense, it is suggested to include this dimension of analysis within the multilevel perspective to better fit the case. Data from the Brazilian Association of solar energy show that for each installed megawatt solar energy are created between 20 and 30 jobs (direct and indirect), and is expected an installation of 3.3 GW of solar power plants contracted via auctions. It is estimated that the total jobs created in the country for this type of energy to be around 60–90 thousand new jobs by 2018. Taking into account the fact that electricity in Brazil is highly controlled by state, the development of technology is extremely dependent on governmental initiatives. When asked about the essential aspects for the development of photovoltaics, most respondents mentioned the issue of public incentives and policies for the sector, which reinforces the prevailing culture in the country that the government should be the initiator of these technological transition.

4. Conclusions and recommendations

This paper reviews the emergence process of the PV electricity in Brazil from a combined perspective of two main approaches: Multilevel Perspective (MLP) and the Functions of Innovation System (FIS). The aim of this paper was to describe the actual status of this source of energy and identify opportunities for growth.

PV energy meets the basic principles of Brazilian energy decennial plans, published by Ministry of Energy involving sustainability, reduced energy costs, as well as the diversification of the energy system. Importantly, the country has large reserves of silicon, indispensable material for the production of solar energy, as well as large land area and incidence of sun, which reinforces the positive perspective.

Considering the vast territory and the high solar irradiance, Brazil has the potential to substantially increase the power generation using PV energy, capable of generating tens of thousands of GWh only with this energy source.

Brazil has the opportunity to promote the use and dissemination of PV energy as an important source in the national energy system, and to develop the entire production chain, which, as described in this paper includes the manufacture of raw materials, components, equipment and skilled labour to operate in this sector. The growth of this source of energy demands some action and governmental policies that involve the private sector, the development of and regulatory agencies, banking institutions and various government agencies.

PV energy growth in Brazil not only depends on techno-economic initiatives. We can conclude that the sector's growth depends also of a learning process that includes formal education, population knowledge about this source of energy, an opening and competitive market activity and the national industry development with technology adaptation to meet national conditions.

We identified the challenges and opportunities for the growth of PV energy in Brazil from an analysis based on both MLP and FIS approaches and identified the complementary and circular interrelation between them. This means that by improving one dimension there is an impact on the others as well. For example, the creation of policies to promote PV energy has a direct impact on the mobilization of resources, but also results in the promotion of entrepreneurial activities in the sector and, additionally, boosts jobs generation. The dissemination of knowledge among the actors in the cooperation system promotes the creation of cooperation networks for the development of new technologies which, on the other hand, stimulate the structuring of the market and the expansion of the panel domestic industry.

We recommend the establishment of some priorities and some drivers set up, addressing the functions that are fundamental on this system, such as entrepreneur activities and legitimacy, as well as market formation. Despite the theory dealing with institutions and organizations, it is important to highlight the central role that individuals exercise, since the decision-making on R&D projects and investments in niche initiatives depends on the approval of such persons, which has the power to direct where the resources of the companies will be implemented and what will be the niche projects contemplated.

The analysis showed that all the functions from the PV energy system face obstacles and some of them are strength. The expanded use of solar technology relies heavily on government incentives, whether tax origin or the provision of credit for financing. The market barriers related to high production costs of PV energy can be overturned through public policy drivers for the sector, both for the establishment of a domestic industry equipment and for tax cuts and incentives for micro generation. But not all opportunities depend exclusively on financial issues. The lack of skilled and qualified professionals in the domestic market is an important barrier that needs to be overcome.

With the production increase of photovoltaic panels in the country coupled with the expansion of centralized generation and development of new alternative technologies for photovoltaic solar systems, it is expected a scale gain in the industry and the consequent reduction of production costs, which is a key factor for the sustainable development of this source of energy. This growth of scale and investment for the development of a domestic industry requires to break the barrier of economic instability in the country, which are from the landscape level. The perceived risk in the landscape level generates a negative impact on the development of niche for PV energy. We also observed that the development of the productive chain of solar energy in the niche has positive impacts on education indicators, employment rates and economy performance, which are all indicators from landscape level.

We observed a direct relation between a landscape level indicator impacting the niche level elements and vice versa. Our proposal in terms of theoretical contribution to the multi-level perspective is not only isolated analysis inside each level, but also the analysis of the linkages and the impacts that can be observed between landscape and the niche levels, especially in terms of social development, which makes the theory best fits this case. We identified a complementarity between the FIS analysis and the MLP perspective because the elements of the niche pressure the regime for system changes, which change over time and bring new elements to the niche in a recursive and continuous process. This complementarity occurs from the multilevel analysis, which allows us to observe how the relationships between the different levels (niche, regime and environment) occur and how the trajectory developed by the niche transforms the established regime.

Additionally, we observed that the functions of the niches extrapolate the internal relations of this level, acting as a form of pressure on the existing system. The networks formed at the level of the niches also have the transforming function of the regime, through market creation, mobilization of resources that enable the diffusion of technology. In the case study of this research this pressure on the regime involves public authorities and private organizations to legitimize the new technology. We extrapolate the Alphen et al. (2008) assumption of FIS application at the niche level. In the case analyzed we have identified a pressure of functions also on transformations in the regime. We suggest, therefore, an extension of the application of FIS at all levels of the system.

This article is the first step in the analysis of the technological transition process for PV energy in Brazil and proposes the inclusion of economic and social elements in MLP perspective to analyse the social impact that new technology can bring to a developing country. For future research, we suggest expanding the scope of the study to other renewable energy sources at an early stage of development, such as biogas, geothermal or wave power with an MLP perspective and FIS.

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