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ORIGINAL PAPER

Transformative innovation policy for solar energy: particularities of a developing country

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Abstract

The study of transformative policies and how they can promote the spread of a technology connects interests among different actors such as government, industry, and academia, who seek solutions for the use of renewable energy, among them solar energy. This study investigates transformative innovation policy for the solar PV energy in Brazil from a sociotechnical perspective of innovation and suggests ways to better promote this technology in Brazil. This study was based on data from two different information sources: (1) in-depth interviews with actors in the Brazilian national innovation system; and (2) secondary data from energy sector in Brazil. With an analysis that is unprecedented for Brazil, the study presents a proposal for transformative innovation policies for the sociotechnical transition process of solar energy in Brazil. The results indicate the need for incentive policies to develop the Brazilian domestic solar panel industry across the whole value chain, as well as for the definition of policies to encourage technological innovation and the formation of cooperation networks among the actors of the system as key elements to promote and disseminate this technology in Brazil.

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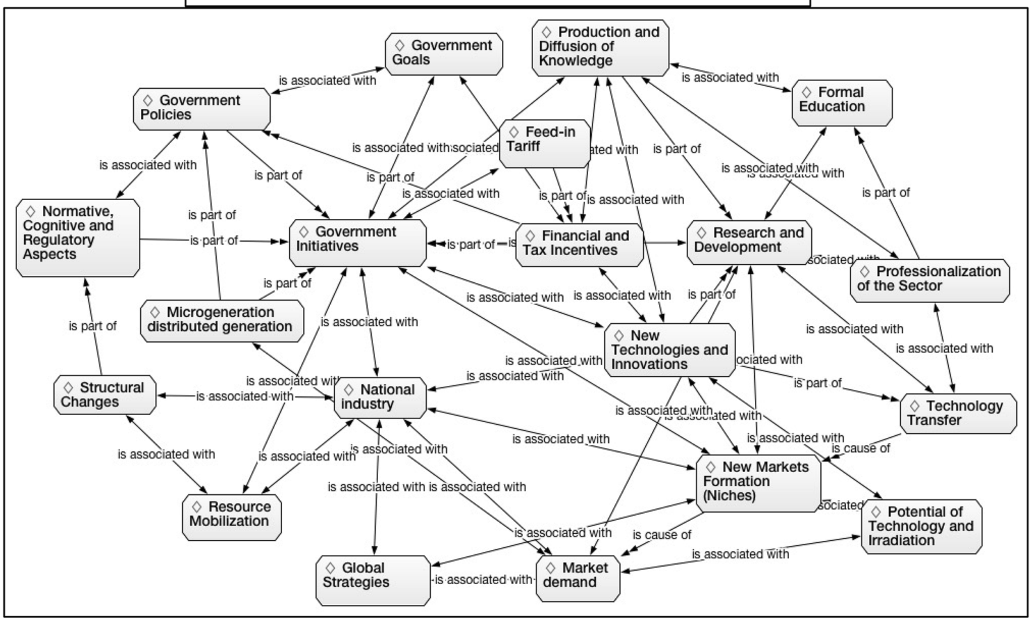
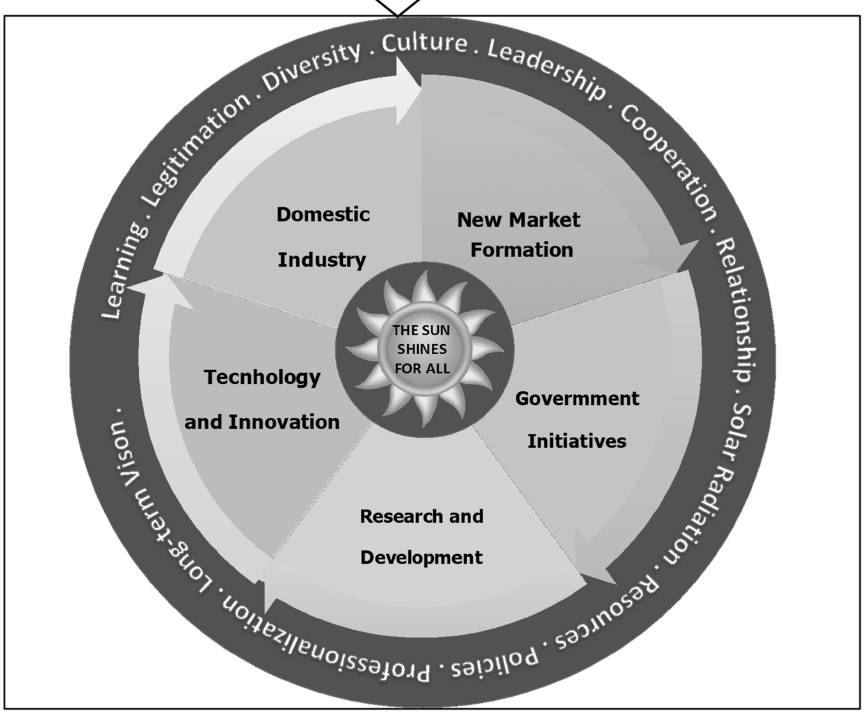
Graphic abstract

PV Energy NIS analytical categories



Transformative Policy Dimensions



Keywords Solar energy · Transformative innovation policy · Innovation policy

Introduction

Some initiatives have been undertaken to encourage the use and dissemination of renewable energy in Brazil. Historically, all domestic energy policies have been highly centralized and government-controlled. By identifying emerging policies to promote solar energy at the various levels and scopes of the sociotechnical system, this article maps the fundamental elements for a transformative innovation policy framework for solar energy in Brazil that tie together the needs of the *stakeholders*, while being cognizant of the particular needs of a developing country.

This study addressed the following question: What are the fundamental elements for a transformative innovation policy that promotes solar PV energy in Brazil?

We describe how the transition process in the solar energy innovation system depends on transformative innovation policy that favor the use and dissemination of this technology at all levels and suggest pathways for innovation policy based on an analysis of the Brazilian trajectory. This study provides a vision of how multi-level perspective in transition studies and transformative innovation policy (TIP) frame can be combined in order to contribute for solar energy transition and how this transition involves the different dimensions of governance and innovation policies.

The article is structured into five sections: "Transformative innovation policy as a new frame in sociotechnical innovation theory" section presents the theoretical framework based on transformative innovation policy as a new way of interpreting innovation policy to renewable energy, which seeks to identify the essential elements for the development of transformative policies from a theoretical perspective. "Methodological approach" section describes the methodology for applying our research to Brazil's socio-technical PV energy system. "PV energy transformative innovation policy framework" section presents the analysis of primary and secondary data and, lastly, "The sun shines on all: PV energy transformative innovation policy framework in Brazil" section presents the model of transformative innovation policy for the use and dissemination of solar energy in Brazil.

Transformative innovation policy as a new frame in sociotechnical innovation theory

This study is based on transformative innovation policy—TIP as a new way of understanding the potential for innovation policy making for renewable energy transition. The analysis performed in this study allows for identification of the essential elements for the development of a proposal for innovation policies for solar energy in Brazil.

The multi-level approach of Geels (2002) as well as Loorbach's (2017) transition management research is quite relevant for transition studies. These studies identify the trajectory of an innovation and the fundamental elements for them to consolidate in an already existing socio-technical regime. In a complementary way, Schot and Steinmueller (2018) point out the need to develop a new framing for innovation policy, named "transformative change." This framing seeks to answer the question of "what needs to be transformed."

Within the transition approaches to sustainability from the perspective of the socio-technical theory of innovation emerged a new frame for innovation policymakers that look at the transformative potential of innovation. This new frame is named TIP—transformative innovation policy. In this sense, Schot et al. (2017) present a theoretical essay that summarizes a common understanding of the researchers of the transformative innovation policy consortium (TIPC) on the elements of this policy, divided in five topics: research and development, innovation, economic growth, environmental and societal challenges, and public welfare/clean environment (see Fig. 1).

Fagerberg (2018) argues that policy advice needs to be based on field research on innovation studies and that sustainability transitions and climate change policies should consider the existing theorizing and knowledge in innovation.

Chataway et al. (2017) propose three non-static, non-impermeable frameworks for technology systems and innovation policy: research and development (R&D), innovation systems, and transformative innovation policies. Transformative innovation policies are not only focused on ensuring that the innovation process takes place, but also on the direction that innovation will take. This approach argues that any profound change in terms of innovation revolves around "bottom-up" sociotechnical transitions that can be achieved through processes of experimentation, learning, networking, and participation (Chataway et al. 2017).

The seminar paper from Schot and Steinmueller (2018) points out that innovation policies have been historically presented in three distinct phases: The first, which starts after the war, consists of state support policies in structuring R&D to support the productive sector, reduce market failures and stimulate economic growth. The second one, which began in the 1980s, aims to structure national innovation systems geared toward the knowledge economy. This policy focuses on developing networks and clustering of knowledge and stimulus to entrepreneurship. The third phase consists of the transformative change, inspired by the UN Millennium Development Goals, to develop policies that seek to address the complex process of socio-technical transition to sustainability, based on arrangements that stimulate the

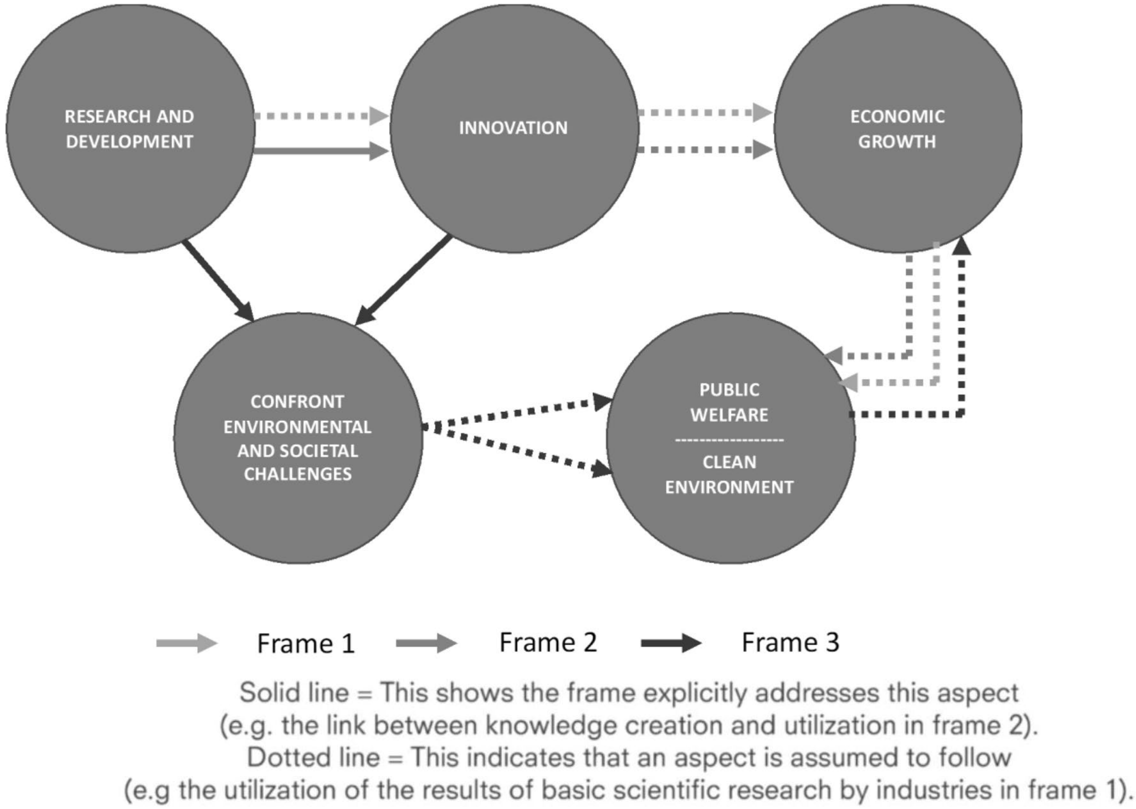


Fig. 1 Shared understanding of transformative innovation policy *Source*: Schot et al. (2017)

reduction in inequality and facing the problems caused by climate change.

Adopting renewable energy sources requires a commitment of money, time, and effort. Twidell and Weir (2015) note that while some of the choices that need to be made are financial, others are ethical, personal, and based on business and political criteria. The authors also point out that the choices of individuals and society are based on varied criteria, which may involve the discussion of values, but also economic and mathematical criteria to quantify decision making.

Regarding the theory of managing the transition to sustainability, Loorbach (2007, p. 12) presents this approach as a "new governance model that provides a framework for generic (scientific) governance research and for policy models to influence change in society in the long run." In a world in constant change, the challenge in terms of governance and policy is to deal intelligently with all the short-term processes of change in order to accelerate and lead them in a certain direction (Loorbach 2007). This author emphasizes that our current institutions, as well as our policies, are focused on solving problems in short- and medium-term horizons, and that the development of long-term goals aimed at governance requires disruption of existing routines and ways of thinking. However, it is the only option, and it must be based on a sense of urgency as well as on strong and inspiring visions of long-term sustainability and on strategies of social innovation.

The sociotechnical theory of innovation has its origins in Neo-Schumpeterian thought, which sought to understand the process of innovation, by analyzing regularities, continuities, and discontinuities. This perspective also focuses on the analysis of the technological pathway, its structure, and the role that these technologies play in rejuvenating the economy through the application of the technical-economic paradigm that accompanies them (Perez 2009; Nelson 2008; Soete et al. 2009). These authors use the socio-technical perspective as a basis for their study of transitions by arguing that research in this area involves understanding the context in which a certain technology is installed. This, in turn, comprises not only the development of knowledge and prototypes, but also the mobilization of resources, the creation of social networks, the formation of new markets, and the regulatory frameworks.

In this sense, technological development involves the creation of links between several heterogeneous elements (Geels 2004; Geels and Schot 2010). Such technological changes require actors to combine physical artefacts, organizations, natural resources, and scientific and legislative elements. Innovations in the system can be described as large-scale transformations of how social functions, such as energy, transportation, communication, housing, and food, are offered. Artefacts alone have no power, and it is only in association with human agents, social structures, and institutional organizations that artefacts perform functions within socio-technical systems (Geels 2004).

When describing the multi-level perspective (MLP) for innovation systems, Geels (2004) points out some aspects of the dynamics of transitions, including the following concepts: novelties emerge from technological niches; the diffusion and breakdown of new technologies occur as the result of the connection in development at multiple levels; once innovations can disseminate and enter mass markets, they begin to compete with the existing regime and may eventually replace it; and the innovations of the system are rarely driven by the advance of radical technology, but by the union and combination of multiple technologies. The MLP perspective is a well-known theoretical approach to inform transformative innovation policy and this has been applied in this paper to look at the solar energy transition in Brazil.

According to the socio-technical transition approach proposed by Geels (2002), the path for a sustainable transition starts at the niche level, with the emergence of innovations. At this stage, there may occur hybridization among novelties and symbioses among system actors. In the solar energy socio-technical system, it was possible to identify small networks of entrepreneurs, which create innovations and strive for their technologies to develop, who are gaining legitimacy and market scale. Gradually, elements essential to the establishment of the system align, such as professionalization of the sector, norms for standardization of photovoltaic systems and their components, as well as research and development processes for solar energy, as such classifying the current situation of the socio-technical system for PV solar technology in Brazil.

In this second phase, Geels (2002) highlights processes of socialization and institutionalization among niche actors, reinforcing the legitimacy of the new technology, and creating a technological path with its own rules. From this stage, there is a widespread diffusion of the technology, which is the third phase, and the consequent competition with the regime that is already established. In the case of solar energy, this process of use and dissemination of PV energy would provide more visibility to this technology in Brazil, putting pressure on the socio-technical regime. Finally, there is a final phase with the gradual replacement of the established socio-technical regime, replacing old technologies for new ones. The solar energy socio-technical system in Brazil could be considered as being in Phase 2, with initiation of alignment and consolidation of activities within the regime, as shown in Fig. 2.

Berkhout (2010) asserts that a change in the technological regime encompasses innovation in the system as a whole and is usually affected on a large scale. Almost by definition, these innovation processes are not likely to emerge from existing market conditions and relationships, and the establishment of innovation policies is critical if regime change is to occur. The author characterizes innovation in technological regimes as a result of the dynamics of the interaction and identifies four types of innovation: abatement (*end of pipe*) innovation; process innovation; product innovation; and infrastructure changes. For each of these forms, there are distinct components in terms of socio-technical systems, as well as differentiated environmental outcomes and impacts.

The transition process involves decentralization from an initial state, centralized in government institutions, to developing policies distributed among the levels and actors of the socio-technical system, with less clearly defined roles, mechanisms, and accountability (Smith 2007). Transition is a process of structural social change from one relatively stable system to another, through the coevolution of markets, networks, institutions, technologies, policies, individual behavior, and autonomous trends. The complexity of a transition implies a diversity of driving and impact factors. Single events can accelerate transition but cannot be the sole cause. Transitions are, therefore, multi-process, multi-level, multi-domain, multi-actor, and multi-phase processes. Despite being characterized by nonlinear behavior, transition processes are gradual and can be described in terms of innovation or even in terms of creative destruction. The central assumption is that social structures go through long periods of relative stability and optimization, followed by relatively short periods of structural change (Loorbach 2007).

Transitions are considered as interactive processes that coevolve and develop over decades from new practices and combinations of emerging technologies, initiated by change agents. The processes are embedded in the system and, throughout a process of experimentation, acceleration, institutionalization, and stabilization, begin to dominate the new regime (Loorbach et al. 2017), as depicted in Fig. 3.

Analytically, transition processes can be differentiated with respect to how actors can influence these processes in terms of the transition dynamics and transition governance. This understanding of the transition process involves nonlinearity, multi-level dynamics (Fig. 3), coevolution, emergence, and variation and selection as a process of experimentation and learning-by-doing (Loorbach 2017). In the following section, we detail the methodological approach to the analysis of the transformative innovation policy for solar energy transition Brazil.

The use of technology is fundamental to the development of a socio-technical system, as technology expands the range of resources that humans can access. Technology penetrates deeply and broadly into society, structuring and regulating it. New technologies not only play an important role in the restructuring of existing markets or in the creation of new

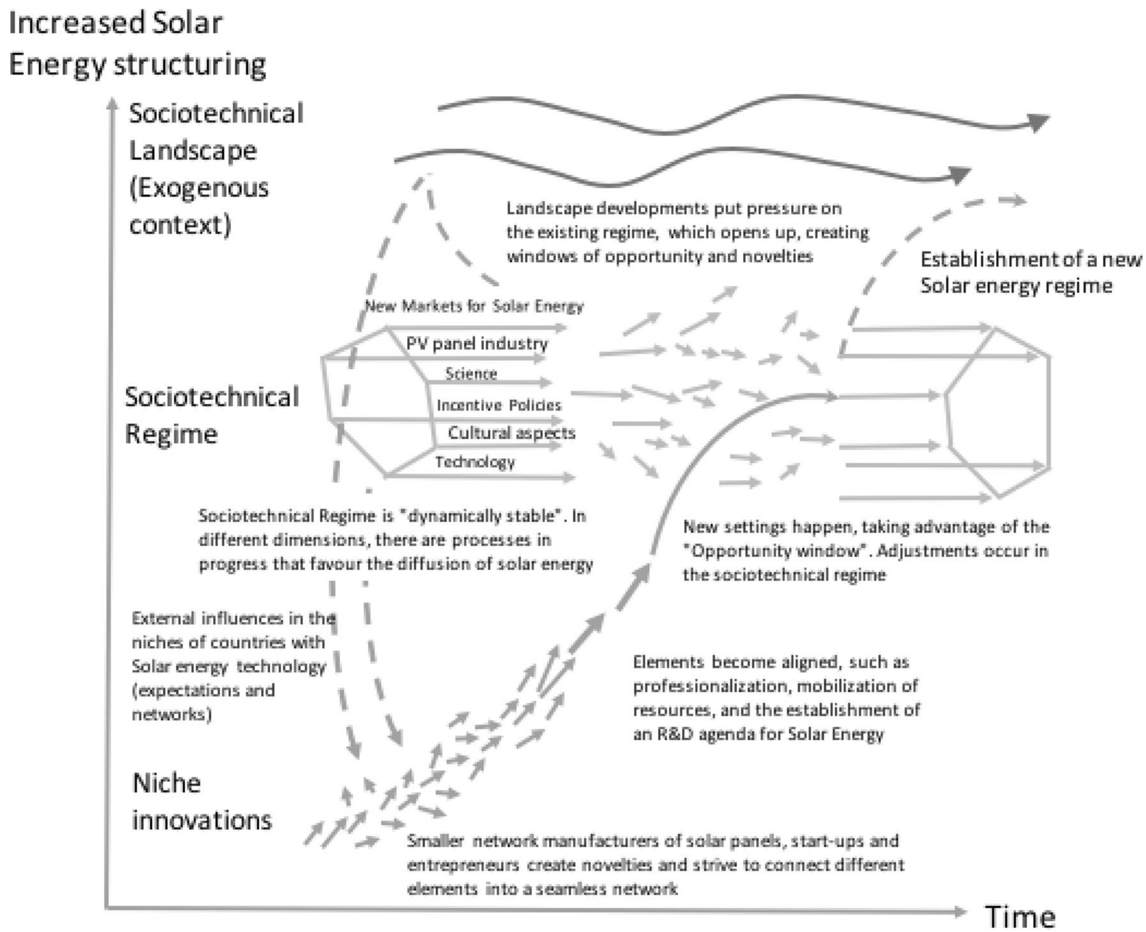


Fig. 2 Multiphases perspective for the solar energy in Brazil *Source*: Modified by the authors from Geels (2002)

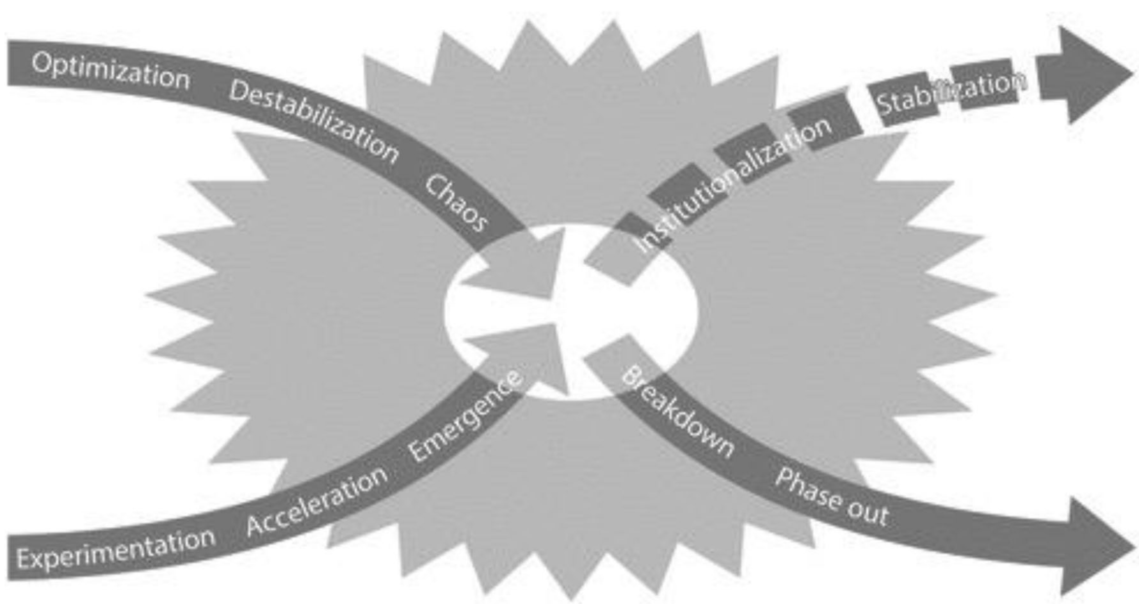


Fig. 3 Multi-level dynamics of the transition process to a new regime *Source*: Loorbach et al. (2017, p. 607)

markets; they also form the basis for major structural and organizational changes in the processes of production, service delivery, and in entire sectors (Dolata 2013; Saviotti 2010). These movements for socio-technical changing, as well as their ramifications, are influenced by transformative innovation policies, which will be addressed in the next section.

This paper aims to identify key elements for a transformative innovation policy in solar energy in Brazil from an exploratory qualitative approach, whose methodological assumptions are described in next section.

Methodological approach

The present study seeks, through an approach unprecedented in the Brazilian context, to observe the impact of actors' initiatives on the management of the socio-technical transition of innovation in electric energy activities directed at the use and dissemination of solar energy. The approach employs multi-level perspectives (technological niche, socio-technical regime, and socio-technical landscape) that were used to describe the transformative innovation policy to solar energy transition in Brazil and identifies key elements for solar energy TIP framework in a developing country. The exploratory phase occurred between 2015 and 2016 and involved primary data from 20 in-depth interviews with strategic actors of the socio-technical system, such as Ministry of mines and energy, universities and final users (see Table 1).

The participants of the interviews were selected according to criteria of their importance for the innovation system and their willingness and interest in participating in the study. Additionally, 69 secondary data were analyzed, such as documents, resolutions, regulations, rules, incentive policies, financing policies, and official reports from relevant institutions in the national solar energy socio-technical system (see Table 2).

The descriptive phase involved document and content analysis of all collected data, to study socio-technical dimensions at the levels of socio-technical landscape (Macro), socio-technical regime (Meso), and technological niches (Micro), based mainly on Geels' (2004) approach.

Table 2 Number and origin of documents analyzed

Origin of the document	Number of documents
Regulations and resolutions	18
News media	13
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	69

Table 1 In-depth interviewees of the Brazilian PV Energy socio-technical system *Source*: Primary data

Actor's role within the system	Position of the interviewee	Number of respondents
Ministry of mines and energy (MME)	Secretary of energy planning and development	2
Energy research company (EPE)	Director of energy research	1
Brazilian Assoc. Clean energy generators—ABRAGEL	CEO	1
National Bank for economic social develop. (BNDES)	Manager of sectorial studies—renewable energy	1
Renova energy S/A	Management of regulatory affairs	2
CPFL renewable	Director of institutional relations	1
COPEL (State Energy Company)	Implementation coordination	1
ELEJOR (Power Plants Jordão River S.A)	Infrastructure engineering	1
Paraná Metrologia	Management advice	1
UTFPR (Federal Technological University of Paraná)	Full professor PV energy expert	1
UP (Positivo University)	Full professor PV energy expert	1
3B Energy (PV Project Company)	CEO	1
Elco (PV Project Company)	PV specialist engineer	2
SISTECHNE (PV Project Company)	Commercial management	1
CompactCia (PV Project Company)	CEO	1
Lubke (PV Consulting Company)	CEO	1
Residential system	House owner	1

In order to provide a complete understanding of how policies have been developed in Brazil and how they promote solar energy in the country, as well as to identify key elements for a proposal of innovation policies applied to this country, actors were selected from different levels and roles within the system for interviews. Selection criteria for the organizations interviewed were legitimacy within the social context in which they function and importance to the development of policies with transformative potential within the system. For data treatment, we adopted the assumptions of the content analysis technique, applied with the aid of the "ATLAS.ti 7," software for treatment of qualitative data. The analysis included 69 documents, plus the complete transcription of the 20 audio recordings of the in-depth interviews.

PV energy transformative innovation policy framework

This section describes the results and describes key elements for a PV energy TIP framework in Brazil. We start by describing socio-technical aspects in the Brazilian context, and then explore our framework of transformative innovation policy, based on this data analysis.

We used the ATLAS.ti 7 software to analyze the research data, both with regard to interviews and documents. As a result, 1066 codes were assigned in 20 analytical categories, which emerged from the data according to the criterion of number of repetitions in the documents evaluated and number of mentions during the interviews (see Table 3).

The analysis of relationships between the analytical categories enabled identification of the five most centrally connected dimensions: (1) government initiatives, (2) research and development, (3) new technologies and innovations, (4) formation of new markets (Niches) and (5) societal welfare and clean environment (see Fig. 4).

Table 4 presents the description and some statements regarding each dimension that emerged from the data collection, either through interviews or through documentary analysis. It is important to note that the connection between categories and the density of relationships is quite intense. The fact that an analytical category is analyzed in one of the five divisions therefore does not mean that it cannot fully or partially integrate into another or all other categories.

The policies implemented in Brazil since the 1980s proved to be efficient for structuring the National Electric Power System in Brazil. The national energy system was structured from a hydropower generation, with the participation of relevant actors such as: National Electricity Agency—ANEL, Ministry of Energy, financing agencies, hydroelectric power plants, distribution companies energy, among others (Mendonça et al. 2018).

Table 3 Analytical category for Brazilian PV energy TIP framework *Source*: Authors

Analytical category	Total
Financial and tax incentives	145
Government initiatives	88
Government policies	86
National industry	83
New technologies	74
Potential of technology and irradiation	71
New markets formation	69
Microgeneration—distributed generation	63
Research and development	63
Technology transfer	53
Global strategies	43
Structural changes	39
Normative, cognitive, and regulatory aspects	32
Market demand	30
Production and diffusion of knowledge	28
Government goals	27
Feed-in	23
Innovation system professionalization	18
Formal education	16
Resource mobilization	15

These data illustrate some of the challenges to the dissemination of solar energy in Brazil, such as the need for cooperation among actors to disseminate knowledge, the lack of technology transfer, the lack of clear and objective long-term goals that can assure investors, the lack of market scale, the fiscal incentive policies, and the poor technology dissemination in the country. The analysis was based on the five categories in Table 4; however, most of the analytical categories are connected to each other, which reinforces their character as multi-causation, multi-level, multi-domain, multi-actor, and multi-phases of transitions as proposed by Loorbach (2007), who describes such transitions as characterized by nonlinear behavior.

Some common elements were identified by several respondents from different levels as essential for the development of this technology in the country and were summarized here in twelve factors: (1) learning among actors; (2) legitimization in the socio-technical system; (3) diversity among actors; (4) culture, which needs to change; (5) leadership; (6) cooperation; (7) relationships among key actors; (8) solar radiation; (9) mobilization of resources in socio-technical system; (10) policies to encourage technology; (11) professionalization of the sector; and (12) long-term vision. These elements are in agreement with both theoretical bases used in this research. The socio-technical approach presents the learning processes, the diversity, and the cooperation among the actors of the socio-technical

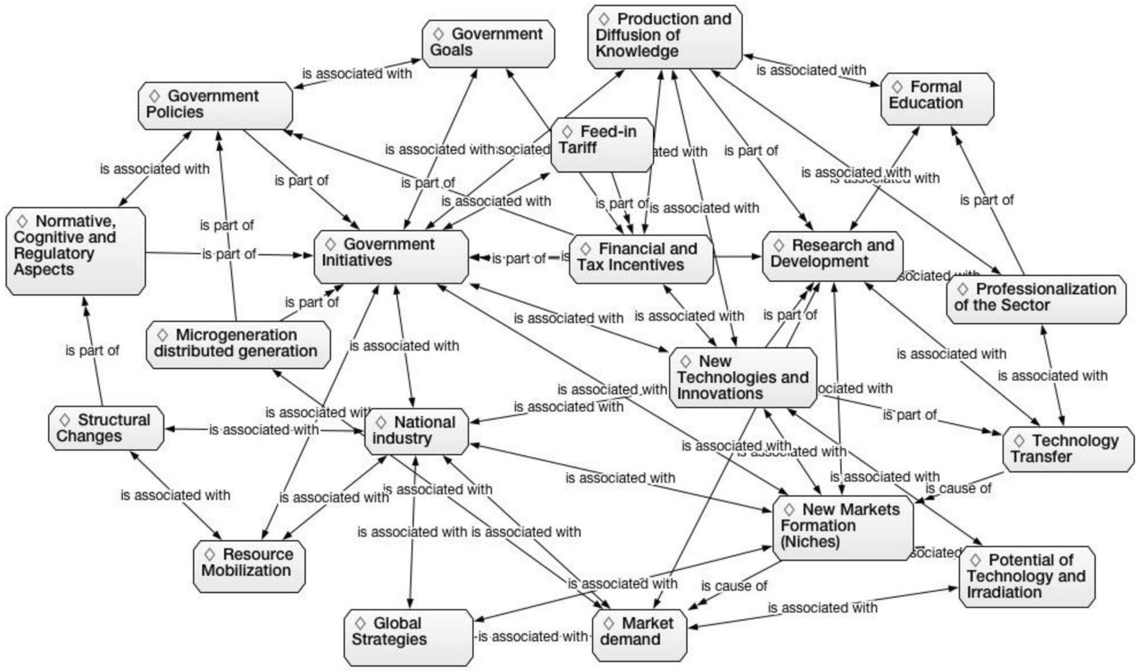


Fig. 4 Structure of the relationships between the analytical categories for PV energy in Brazil

system as fundamental elements for the transition process to take place. "In order to stimulate the innovation process by shaping and creating technologies, sectors and markets, dynamic relationships must be developed which create trust between actors" (Mazzucato 2017 p. 14)

In the next section, we will show how the findings of this research contributed to the development of a framework for transformative innovation policy for solar energy in Brazil.

The sun shines on all: PV energy transformative innovation policy framework in Brazil

The PV energy transformative innovation policy framework presented in this section merges theory–practice and results from a combination of the theoretical principles of the socio-technical theory based on MLP perspective, transformative innovation policy approach, Brazilian PV energy system, and empirical results from the energy sector in Brazil. This framework took into account central elements from socio-technical transition theory, which highlights four characteristics, presented below:

- The non-prescriptive nature, always paying attention to a process of revision and reformulation. Transition processes are dynamic and present aspects of complexity that make it impossible to draw prescriptive and long-term results.
- The interdisciplinarity, which is an essential element in the formulation of such a framework, as the socio-technical transition process involves actors from a wide range of backgrounds and interests.
- The historical aspects related to the socio-technical system under study, involving issues of centralization and control by the government, a hydropower-based trajectory, and the strengthening of government institutions. These historical aspects strengthen the trajectory of the technology, in a process of systemic resistance to change from so-called 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 to be modified from a great effort).
- The incentive policies which affect the use and dissemination of technology among the actors of the system, and involves environmental policies, incentives to use PV solar energy, fiscal incentives, and rules that regulate and define the next steps for the development of this technology in Brazil.

The purpose of this policy proposal for the use and dissemination of solar energy is to provide a theoretical contribution to the management perspective of the transition to sustainability, as well as an empirical application-based study of the PV energy in Brazil. This process is an effort to consolidate elements of theory and practice, resulting in an integrated and applied proposal for the MLP and TIP approaches under study. This proposal takes into

Table 4 Key elements for PV energy in Brazil *Source*: Authors

Description	Testimonials of participants (verbatim extracts from interviews)
1. *Government initiatives*	
Government initiatives were grouped into six different analytical categories: "Regulatory, Cognitive, and Regulatory Aspects," "Microgeneration—Distributed Generation," "Government Policies," "Financial and Financial Incentives," "*Feed-in*" and "Government Targets." Regulatory aspects have a strong impact on the speed and intensity of the transition of a technology, and this process is no different for solar energy. Norms and regulations contribute to the standardization of the activities of the sector, as well as to the professionalization and development of this technology in Brazil.	Government incentives are essential as, historically, other countries have developed such technologies through incentives. Thus, it was after the US incentive that the solar boom happened. After the German incentive, the solar boom happened. Then the incentive of China which resulted in the solar "boom." Thus, the incentives end up being essential in the process. (Interview with the CEO—3BEnergy) For the 2024 horizon, the expectation is of an installed capacity of 8.3 gigawatts of photovoltaic […] There is also a plan to encourage mounting solar panels on the roofs of federal schools, hospitals, supermarkets, residences, and allow these consumers to sell this surplus of energy in the free market (Interview with the Planning Secretary of the Ministry of Mines and Energy)
2. *Research and development*	
The Research and Development category was divided into three dimensions: "Production and diffusion of knowledge," " Professionalization of the Sector," and "Formal Education." Integration among the various actors in knowledge production and diffusion is one of the key aspects for technology transition, but it faces some significant barriers. Academia wants to divulge findings and research, but companies want to keep their technologies and new projects confidential to avoid the risk of offering information and subsidies to their competitors. This results in a conflict of interests between the actors, related to the different roles and expectations that each actor has within the system	There is little integration. Few researchers in this area. Thus, as the researchers multiply, this will become natural and increase (Interview with UTFPR Professor) You take any engineer, graduated from a good university in electrical engineering, what he learned throughout the course was how to work with hydropower. Then, you go to an expensive area, you do not have a qualified workforce […] Engineering school lacks an undergraduate class on solar energy. Now Prof Jair has created a specialization course, which is elective, that I took, in the renewable energies field. It is a matter of time (Interview with Elco engineer)
3. *New technologies and innovation*	
When mentioning the barriers to the transfer of PV energy technology, the cultural issue comes first. This is because few people know a photovoltaic electric system and many mistakes it for a water heating system, as this is an application of the technology that is historically and culturally more widespread in the country Cultural change is a process that can take time and requires a certain effort from the actors of the system in terms of dissemination and awareness of new technologies. Although transitions are characterized by nonlinear behavior, the system innovation process itself is gradual	There is a cultural barrier, […] there are days when I come home with no voice, no voice, because all day long, "Oh, this does not heat water, it generates electricity," and its always this talk, you know, to change the culture. Today, my job is not to sell photovoltaic, to sell renewable, but to raise awareness, and thats the macro function here of the company, you know? So, the difficulty is also cultural (Interview with CEO of Compactcia)
4. *Development of new markets (Niches)*	
Development of New Markets (niches) was divided into three elements for the purpose of analysis: "Global Strategies," "Market Demand," and "Technology Potential and Irradiation." The establishment of a domestic industry focused on the production of photovoltaic systems depends on market demand that, in turn, must be guaranteed on a large scale in order to reduce risks and make the market attractive to an investor Large-scale demand depends mainly on alternative power source auctions with a focus on photovoltaic electric energy. It is necessary to set targets for technology expansion in these auctions that, despite having been a success in 2010 and 2011, lack medium and long-term commitment on the part of the Ministry of Mines and Energy to the continuity in the growth of this source	Scale is the name of the game […] in solar energy there is only one technology, only one way in which the panel is made in the world… one does not have a dilemma of several technologies, then, the competitiveness variable is the production variable, it is quantity. Then you are going to have a big industry… (Interview with the Director of Institutional Relations CPFL Renováveis)

Table 4 (continued)

Description	Testimonials of participants (verbatim extracts from interviews)
5. *Societal welfare and clean environment*	
The societal welfare and clean environment analysis category was divided into two dimensions of analysis: "Structural Changes," which is particularly concerned with the need for changes in the system to make the technology transition feasible, and "Resource Mobilization," which identifies the various ways in which the NIS actors use their resources. Given this scenario, the environment is considered favorable to the demand for sources of renewable energy other than hydroelectric, bringing an optimistic perspective regarding the future of this technology. A structural change involves a long-term transition process and requires the involvement of strategic actors in the system, as well as legitimization of the technology among the different levels of the innovation system, which starts with identification of solar energy as an opportunity to explore. Financing for promotion of the domestic solar panel industry is related to local content requirements that, for this technology, comprise a minimum of 60% in order to access the most attractive financing conditions, such as those offered by BNDES (the Brazilian National Bank for Economic and Social Development) As most panels used in Brazil are of foreign origin, mainly from China and Europe, access to such financing faces a barrier	Nowadays, the hydropower plants and small hydropower plants are almost saturated; the environmental requirements have become very rigid, which ended up making it more expensive to set up a small hydropower plant. Today, for you to build a hydropower plant, you have to support, for I do not know how many years, the people that live around it, promote reforestation, not that this is wrong, but the environmental question has been much more rigid, compared to what it used to be, and more difficult to deal with (Interview with engineer—ELCO) Ministry policy sets the conditions and requirement for local production of the equipment required for photovoltaic energy generation. So even the funding lines establish levels of local content to be able to do the financing. This is important because those who want to obtain financing for set up must have a certain level of locally produced content in the equipment (Interview with Planning Secretary of the Ministry of Mines and Energy)

consideration the fact that the transition process is unpredictable and proposes some elements to facilitate the long-term direction of the PV energy through the emerging field of transformative innovation policy. Thus, "The sun shines on all" is an interpretation of what transformative innovation policy for PV energy in a developing country might look like.

Due to its socio-technical character, this model also considered the impacts that this technology may have on the country in terms of social change—such as vocational training, research and knowledge development, employment, and income generation at all educational levels—as well as on the national industry and, in the future, on the country's economy. Confirming what Loorbach (2007) and Loorbach et al. (2017) propose regarding transitions and sustainable development, this proposal is based on the integrated analysis of actors and their roles and is made in an effort to normatively redirect the technological development, as unpredictability and randomness are factors in complex social networks.

Government initiatives are one of the strategic elements of the proposed framework because of the historical trajectory of the Brazilian electricity sector that is highly regulated by the state and determined by government institutions that carry out research, planning, and management of the energy sources that will comprise the national energy matrix. The impact of socio-technical landscape level indicators on niche level technology must be highlighted to reinforce the suitability of the multi-level perspective as a methodology for the object under study. This dimension also includes the normative, cognitive, and regulatory aspects of the system, as well as public policies for the incentive and development of solar energy generation technology. Government policies such as programs to encourage the use and dissemination of renewable energies bring, like any innovation, their impacts on the innovation system to which they belong. Perez (2009) comments that the impact of a new socio-technical system stems from the "broad adaptability" of the contributing innovations in its many facets. Each technology system brings together technological innovations in inputs, outputs and processes that result in organizational innovations and may lead to important changes in the social, institutional and even politics. In the case of the Procel programs (National Energy Conservation—promotes the efficient use of electric energy) and the Reluz (National Program for Efficient Public Lighting—promotes efficiency energy in public lighting), it can be said that the impacts were economic, behavioral, and cultural, since most of the actors involved in the socio-technical system, including final consumers, became aware of the innovation and many made their purchasing decisions based on following the guidelines of the programs.

Research & development is the second strategic element and involves the production and diffusion of knowledge, professionalization of the sector, and formal education. It is considered as one of the barriers to the use and dissemination of PV energy in Brazil. One of the goals of transition management is spreading new knowledge. Therefore, the process of exchanges among the actors must be intensive, in order to provide learning among the participants, generate new ideas, solutions, and technologies, and thus contribute to the consolidation of an environment with exchange of knowledge and of experiences on the production, diffusion, and integration of knowledge within the socio-technical system (Loorbach 2007; Schot and Steinmueller 2018). Formal education is a necessity for the development of new technologies that, in addition to improving the conditions for the process of technological diffusion, also contribute to the professionalization and standardization of the activity of professionals working with solar energy in the country.

New technologies and innovations constitute the third strategic element of the framework, among other aspects, the technology transfer to the actors that are part of the system. Such innovations bring about changes and transformations in the structural, organizational, and even cultural aspects of the sector.

New technologies and innovation should connect with social and environmental objectives. Transformative innovation policies from Schot and Steinmueller (2018) differ from policies aimed at structuring the national innovation system, since it involves debate with society, managing conflicting agendas, changing culture and values, new rules, new sources of funding. The process of socio-technical transition involves innovation policies, but goes beyond composing with the Millennium Development Goals, taking into account the social and environmental agenda. This strategic element requires the formation of networks and coalitions involving economic actors, representatives of civil society, producers of equipment, consumers, representatives of civil society (trade unions, associations, industry federations), representatives of regulatory agency (ANEL, and Energy), financing institutions, among others.

The fourth fundamental element is the creation of new markets and economic growth (niches). The market for this technology depends on a scale of demand sufficient to cause interest, and to impart a perception of security to domestic and foreign investors that may invest in this technology. The policies for the development of this technology should contemplate the current national demand, as well as the potential use of this technology, as the consolidation of an industry in this sector depends fundamentally on market formation.

The fifth and final key element is societal welfare and clean environment, considered essential for the study of the socio-technical transition of innovation in the country, due to the potential positive social impact, by generating job opportunities and income, thus seeking sustainable economic and social development. The social dimensions involved in the technology transition process are central elements of an approach through sociotechnical transition theory. In the case of solar energy in Brazil, this resulted in two important perspectives. The generation of employment and income, in a country such as Brazil, is a factor of extreme importance that occurs in all links of the value chain of the analyzed case, including the workforce for the solar panel and component factories, the development and design professionals of the projects, and the installers and professionals who perform maintenance and technical assistance. The second factor is the cost of technology, which tends to decrease with the development of a domestic industry and with production scale gains. This would makes it possible to install solar panels in distant regions of Brazil, outside the reach of the power grid and brings the prospect of improving the quality of life of the families residing in these places, resulting in relevant social impact for the region.

The PV energy framework resulting from this study, called "The sun shines on all" also places twelve factors, called transversal factors, as essential to the development of this system. These factors are elements that have transversal application in all five dimensions detailed in "PV energy transformative innovation policy framework" section and that influence the development and consolidation of each of them, as illustrated by Fig. 5.

The multi-level perspective was applied to this model, especially as solar energy technology is in an early stage of development in Brazil. However, factors including government policies, development of new markets, and new technologies are at the level of regime, and should be differentiated from this regime's established institutional structure in order for the transition to this technology to occur. The multi-level perspective in this governance model can also be recognized from the socio-technical landscape indicators, such as professional development, employability, and the direction of the country's economy that are directly impacted by indicators located in the technological niche.

The landscape pressures that accompany the proposed guidelines to meet the UN Millennium Development Goals require changes geared toward the production of other renewable energy sources, such as photovoltaic, wind, biogas. It is time to implement bottom-up transformative innovation policies with the involvement of relevant players in the energy system. This requires incorporating into the policy agenda the needs of actors such as energy producers (including small local producers, entrepreneurs), distributors energy, consumers, civil society organizations, universities and research laboratories, equipment suppliers, etc.

The proposed "The sun shines on all" framework is our interpretation of what transformative innovation policy could look like, as a result from MLP perspective and TIP analysis in solar energy in Brazil. This framework could be applied as a tool to define a long-term vision and as an incentive for the technological transition process and the transformative policy formulation for the dissemination of technology at all levels of the socio-technical system. Adaptations will be necessary to enable its analysis in other contexts, as each transition process presupposes different

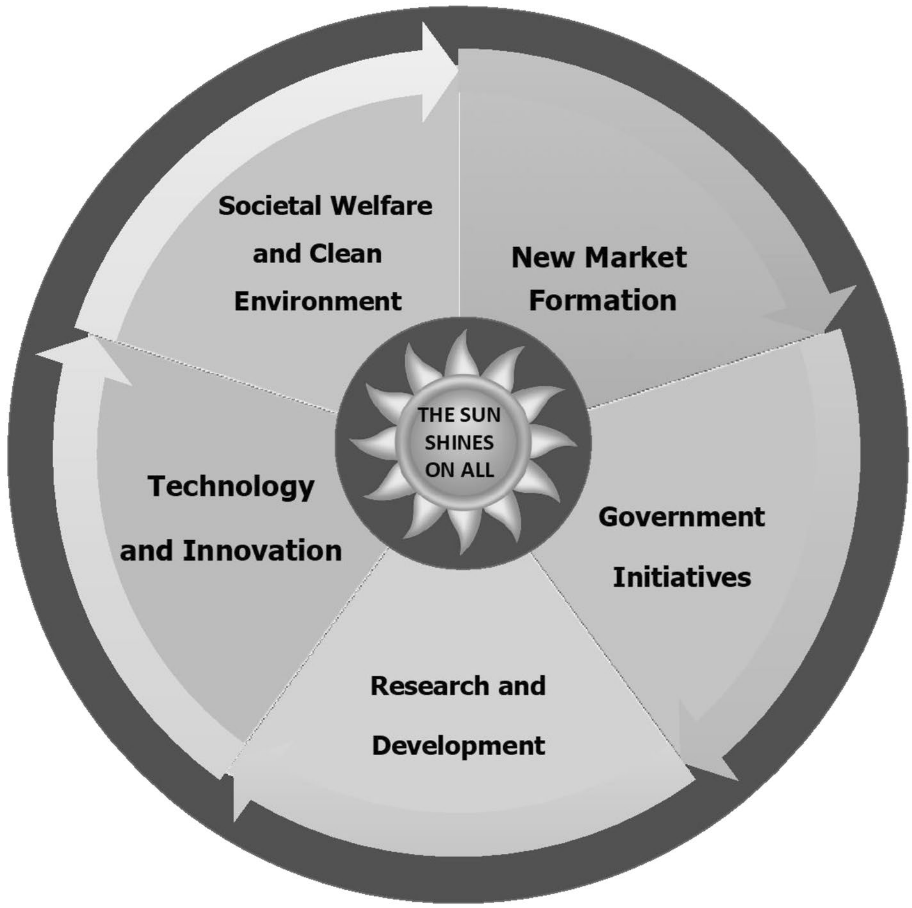


Fig. 5 Solar energy transformative innovation policy framework *Source*: Authors

challenges, as well as involvement of different actors and relationships.

The transformative innovation policies (TIP) differ from the policies aimed at structuring the SNI, since it involves the debate with society, the management of conflicting agendas, the change of culture and values, new rules, new sources of financing. The process of socio-technical transition involves technological innovations, but goes beyond composing with the agendas, desires, values and culture of the whole society. In this sense, TIPs, different from the policies aimed at the structuring of the innovation system, should, besides searching for economic growth, increase the well-being of the population avoiding environmental degradation, thus meeting the Millennium Development Goals.

Conclusions and recommendations

Brazil has the opportunity to foster and disseminate the use of photovoltaic solar energy as a relevant source in the national energy matrix, as well as to develop the entire production chain of the sector, which includes the manufacture of inputs, components, equipment, and specialized labor. The promotion of this energy source requires some actions and governance policies that involve the private sector, development and regulatory agencies, banking institutions, and various government departments. Decentralizing the distribution of electric energy is one of few possibilities to offer electricity to millions of people living in the furthest reaches of this continental country.

The results presented in this paper do not offer definitive conclusions about the subject analyzed, but rather present key aspects and notes on emerging themes for transition management research, offering a theoretical and practical framework to contribute to the future research agenda in the field and in the industry, mainly regarding MLP perspective as a theoretical approach to inform how transformative innovation policy can be applied.

The analysis of the electricity regime in Brazil showed a trend toward stability and continuity of hydroelectric energy in the national energy matrix. It developed along with the history of the system, leading to a process of lock-in and path dependence, as the infrastructure for the transmission and distribution of energy are mostly built around hydropower dams. At the socio-technical regime level, the technological transition to photovoltaic energy in Brazil is a long-term process, which can take many years to develop and consolidate within the industry. Still, some initial steps were taken by the government, albeit timidly.

The main findings of this research were identified from the MLP analysis, applied in this study as a theoretical framework for looking at solar energy in a developing country. The "sun shines for all" is an interpretation of how to think about innovation policy for solar energy in Brazil. They present five dimensions as essential for creating new policies for this technology: new market formation, government initiatives, R&D, technology and innovation, societal welfare, and clean environment. The technology under study is now seen as an opportunity for the industry, and no longer as a threat, and is beginning to gain legitimacy with important actors in the system, leading to a process of change in the currently consolidated mental model. As this technology gains more legitimacy with the other actors at the regime level, it begins to gather momentum, and the technological transition process tends to consolidate.

While applied to the solar energy system in Brazil, the framework that is presented here in a non-exhaustive way can be combined and refined for application to other contexts and sectors. However, its use alone cannot guarantee the greater use and dissemination of technology, nor is it a necessary condition for the technological transition process to actually take place. Its application can facilitate the process of understanding and diffusion of this technology, as well as directing the trajectory of the transition to paths desired and specified by the policies established among the actors of this socio-technical system.

Among the limitations of this study are that it does not include all the elements and actors of the socio-technical system. The multi-stage, multi-level, multi-phase, and multidisciplinary characteristics of the sociotechnical systems show the high complexity of this system; researchers have the responsibility of identifying and selecting the most relevant elements of the analyzed context. It is suggested as future research the application of this same methodology in other contexts and technologies, or to make the comparison between the policies of incentives to adopt renewable energies in other countries.

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