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Wind energy in Brazil: an alternative source in the diversification of the energy matrix and its technological innovation stimuli[1]

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This work aims at studying the technology for energy produced from wind in Brazil. The wind power has been stimulated as an alternative source of energy in this country since the early 21^{st} century. (Bennett 2010; Pereita et al 2012; Saywer 2012). The Brazilian government started giving support to the wind industry since its implementation. The market and conditionalities to operate in Brazil seem to be attractive.

Renewable energy has received attention and was stimulated more intensively worldwide since the oil crises, 1973. The need for a sustainable energy transition emerged due to the belief that the fuel resources would run out in two decades. In the 80s and the 90s the fear of global warming stimulated countries to remain adopting alternative sources of energy, diversifying their matrixes. In addition, renewable energy provides security of supply, help the balance of trade and balance of payments, and give energy price stability (Shift-Hook 2012:147-150).

Energy supply crises took place in 2000 and 2002 due to droughts that had affected hydropower generation (IRENA 2012:26). There had also been an energy demand increase and lack of investment in the sector in the previous decade (Bardelin 2004:26).

Reforms in the energy sector have been reinforced and accelerated from the moment Brazil faced such energy supply crises. As a consequence, the diversification of the energy matrix was put in a higher position in the political agenda.

In 2002, Brazil created a Programme of Incentives for Alternative Electricity Sources, PROINFA. The program was introduced to foster the expansion of renewable sources. As a result, from 2002 to 2012 the Wind Power capacity installed in Brazil grew from nearly zero to 1600 MW (ANAEEL[3] 2012).

3 *Agência Nacional de Energia Elétrica:* National Electric Energy Agency.

The 2009 report from UNEP[4] pointed out Brazil as the country with the most worldwide potential for renewable energy. According to the Global Wind Council, the "progressive regulatory action and public-private sector co-operation are jointly responsible for the country's leadership in the wind sector" (Bennett 2010:13).

Despite the lack of liquidity globally during the economic crisis of 2008 and 2009, the Brazilian Development Bank (BNDES) continued giving support through investments locally, which allowed the wind industry to expand and develop in Brazil, and also attracted foreign companies.

Due to the mentioned above, the strategies to promote diversification of energy sources had followed the sustainability agenda[5], as well as the pursuit for additional green sources of energy. Nevertheless, these strategies translate the pursuit for maintenance of growing rates of Brazil, and its insertion in the global arena as an emerging power.

The governmental loans provided by BNDES also come with condicionalities. In this sense, Brazil is promoting the national manufacturing of Wind turbines and also attracting OMEs[6]. The local content requirement demands 60% of the installed wind turbines to be produced in the country.

The adaptation and introduction of this new technologies in Brazil for over the past decade with governmental support is what triggers our study. Even though we acknowledge that the energy sector is broader and more complex in the big picture, we aim at focusing on the development, challenges and leverage of the technology concerning energy production from wind in order to be able to grasp its characteristics, domain and specificities in Brazil.

This background reveals the importance for an analysis and greater understanding of the

4 United Nations Environment Program.

5 United Nations conference for the environment and development (1992) which motivated the signature of the Kyoto protocol (1997) and set the targets for Rio+10 in 2002. In June 2012 the Rio+20 reconfirmed the commitment to sustainable development. (Brazil 2012).

6 OEMs: Original Equipment Manufacturer. Accorging to Sawyer, 2012, "no fewer than seven other OEMs entered to the market in the past two years, including Vestas, Gamesa, GE, Alstom, Siemens, Acciona, and LM Windpower; Sinovel is considering a factory, and Brazilian electrical manufacturer WEG decided to enter the market in 2011."

technological trajectory and motivations of the incipient wind industry within Brazil. For reasons mentioned above, the overall goal of this paper is to explore the technology as regards to energy production from wind in this country.

In extension, several questions have been raised to help analyze this problematic: Is the wind industry in Brazil a business with potential to breakthrough on its own or is it being able to survive and grow only because of the governmental support? Is the technology being introduced and incorporated along with the creation of capabilities (industrial, technical and social)?

2. Methodology

This work is divided into two main sections. Firstly, a theoretical framework will be presented, followed by an analytical section. It is an exploratory work and preliminary engagement in a new field of study to the writer. Thus, it is an initial research that intends to be complemented with further researches in the field of energy in Brazil and its role concerning the Brazilian foreign affairs in a later stage. Therefore we recognize and acknowledge the limitations to this project due to time, space constraints and the above mentioned.

The purpose of this study is to understand how and why the diversification of the energetic matrix is demanded and has been taking place. As well, this research will examine the reasons why wind power has been chosen as an alternative, and to which extent innovation stimuli could derive from such activities. Therefore, the present work is divided as follows.

Section three will deal with the chosen theoretical framework and section four will entail the analysis of the wind industry in Brazil. The last section will comprise of the conclusions.

In order to have a better understanding of the evolution of the wind industry in Brazil and accomplish the goals of this study, the project aims at addressing the discussions around innovation as the theoretical framework. The theoretical section will be divided in three subsections. Firstly, it will be presented the reasons for choosing the selected approach.

Subsection 3.1 reveals the debate on Sustainable Innovations and Innovation Studies to justify the change of perspective in regards to understanding technology and environmental challenges.

Following this justification, the two approaches selected are outlined. These are, the technological innovation system (TIS) (subsection 3.2), and the Socio-technical systems (subsection 3.3). The TIS will be defined and most importantly, the functions, as they will be measured and applied in the analysis. The socio-technical system framework is presented along with its sub-levels, characteristics and dynamics and is the narrative guide for our analytical section.

The last subsection of the theoretical part (3.4) will expose shortly the need for both frameworks chosen, their connectedness and set up for the following analytical section.

We aim to present theoretically the categories and interactions of the actors, agents and structure within both frameworks. The frameworks provide a reliable set-up to analyze the energy sector. The functions provided by one of the frameworks are identified thorough the analysis. Two of them, most relevant to our study, are explored in a more detailed sense. Both approaches chosen to be applied indicate the trajectories of a new technology being introduced in an environment in which a common practice is already institutionalized.

The discussion of these two frameworks mentioned above will be presented in order to have them as a guide for the collection of data and orientation of our analytical section. Nevertheless, as from a critical data collection, we also aim at verifying the conditions of an energy matrix diversification transition.

Subsequently, the analytical section is divided in three parts. Section 4 will highlight and analyze the results of the energy production and installation of wind turbines since its implementation in comparison to other sources. Then, (subsection 4.1) the history and evolution of the new technology will be presented. The relevance of such technology and social urges for the wind energy production to have been introduced. In addition, the regulatory framework will be examined, once the current framework suggests technological inducement. Considerations on the wind energy market will also be drawn.

The final subsection in this analysis (4.2), is entailed with a deeper exploration of the technological innovation system (TIS) studied. The relevant institutions and functions of the TIS will be assessed in order to help us draw conclusions in regards to the development, challenges and leverage of the Wind industry in Brazil.

2.1. Methods

We will combine a qualitative and qualitative analysis when conducting our analytical section. We have chosen to rely on both of these to provide a comprehensive and complete picture of the issues and both styles of analysis allow for unique perspectives on the problem issue. These methods will be conducted through several ways. Firstly, a variety of data will be compiled and analyzed (quantitative). Secondly, some of the functions presented by the framework to be studied demand qualitative analysis and for that we will critically access the current contributions on the topic.

2.2. Sources

The sources in this project vary from primary and secondary sources. This ranges from official documents provided by different ministries and agencies from the Brazilian government (mostly MME, EPE, Finep and BNDES[7]). The Brazilian Association for Wind Energy is also a primary source along two important international sources: the Global Wind Energy Council and the Renewable Energy Policy Network for the 21st Century, which is part of the United Nations Environment Programme (UNEP). These are the scopes where we intend to find the measurements for the functions to be observed.

3. Theoretical Framework

Energy production from wind has been recently introduced in Brazil. This technology has struggled among other existent technologies to succeed. This process is likely to reflect in the local institutions[8].

7 MME: Ministry of Mines and Energy; EPE: Enterprise for Energy Research; Finep: Brazilian Innovation Agency and BNDES: Brazilian Development Bank.

8 In innovation studies the concept of institutions tend to be related to three domains: regulatory, normative and

Technologies are embedded in a common practice. The usage of such technology is legitimized by the society and institutionalized. At the moment a new practice is introduced: an interaction takes place and a change might occur. Innovation becomes a breaking edge strategy for governments and societal actors.

Based on the dynamics mentioned above, two frameworks that deal with this problematic will be used for the development of the project and analysis. These frameworks are the Technological Innovation System – TIS and Socio-technical systems.

Firstly we have to point out that

> […] the term "innovation" should not be understood as being restricted to technological innovation, but should instead be interpreted in a broader sense as referring to new types of activity. It thus includes not only technology […], but also marketing and markets [...], new ways of structuring a company or an industry, and the development of new sources of raw materials. (Ocampo 2011:26)

Furthermore, in order to study the Energy sector in Brazil we intend to revise briefly the contributions around Energy innovation system research (Truffer et al 2012). The contributions of the TIS will be stressed and correlated to the Socio-technical System. Both frameworks address the process of having a new technology introduced in an environment in which there is an already dominant practice. They also provide insights on the possible transition to a new system.

The first deals with actual functions and measurements that enable the observer to state the level of evolution as regards to the TIS. The latter, the socio-technical system, provides an overall perspective to understand how a technology is permeated in a given sociological and historical perspective. Thus it will be used as an explorative narrative-guidance.

To reinforce the chosen approach, we have that,

> The TIS framework is well suited to study emerging industries that develop out of radically new technologies and the institutional and organizational changes that have to go hand in hand with technology development (Truffer et al 2012:7)

Notwithstanding, these frameworks were chosen due to the fact that we intend to give more emphasis to the role of innovation in the process of development. That is, including the capability

cognitive institutions (Truffer et al 2012: 13). At this point is important to bare in mind that positive postulates, societal behavior and moral patters are seen as institutions when it comes to the interaction of a new technology in the environment studied.

building as from the process of learning. Considering new demands and constrains such as the sustainability agenda, which is also at stake and such concern is part of the Socio-technical system approach. (Geels 2005)

3.1 Sustainable Innovations and Innovation Studies

In this section we will present a short revision on innovation system study contribution and it will be stressed the role of sustainable innovations.

In a broader sense, the system of innovation approach addresses the

> […] technical innovation, and argues that it emerges not just from individual firms, but from a wide network or system of actors (universities, research institutes, government programmes, R&D department in firms). […] The main focus in this approach is on the *functioning* of systems (Geels 2005:7).

There are several systems of innovations[9] in the literature that varies on the domain observed and unity of analysis used. One of the first concepts to emerge was that of national innovation system, coined by Ludvall (1992) Freeman (1987) and Nelson (1993). It aimed at providing a conceptual framework for policy makers in the national and international levels, "emphasizing the role of institutional framework conditions and the evolutionary nature of innovation processes" (Ludvall 2007).

Besides the national innovation system, there are other different sub-orientations, to name the most relevant: the regional innovation system (Cooke 1996; Maskell and Malmberg 1997) sectoral innovation system (Breschi and Malerba 1997) and the technological innovation system (Carlsson and Stankiewitz 1991).

These approaches have been evolving since the 1990s and have shown their societal relevance. Firstly innovation studies were thought as guideline for policy making and not as a theory. Even though the framework here used is not a theory, the frameworks provided by the innovation system approaches suggest a causality and reasoning that is the same purpose of the theories (Lundvall 2007)

9 The innovation system perspective was explicitly conceived as a counterpoint to policy advice stemming from the neo-classical economics tradition (Ludvall 2007). The framework was based on different contributions, such as Friedrich List, Karl Marx, Marshall, Shumpeter, Christopher Fredman.

As for societal relevance, we might point to the sustainability commitment and the challenges faced structurally by several sectors of the modern society. “In the energy sector there are problems related to oil dependency, reliability, and CO2 and Nox emissions. […] These problems are deeply rooted in social production and consumption patterns” (Geels 2005:8).

A range of issues from pressure to competition of existing technologies is faced by any given technological innovation entering a new market. There are two ways to overcome the pressure and the competition. One would be revealing superior qualities when compared to mainstream solutions. The second would be the capability of addressing the particular needs of users that are currently not satisfied with the established technologies (Bower and Christensen 1995; Christensen 1997).

3.2 Technological Innovation System (TIS)

The first framework that will be used in the analysis is the Technological Innovation System. The following section will define the framework, outline the main functions and provide the steps to be followed in the analysis.

According to Truffer and colleagues “the technical innovation system (TIS) tradition has been by far the most productive in the energy field” (Truffer et al 2012:6). Technological Innovation Systems (TIS) emerged within a major field of transition studies.

The concept grew from the technological system that was defined as “a technological system [that] may be described as a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology” (Carlsson; Stankiewicz 1991:94).

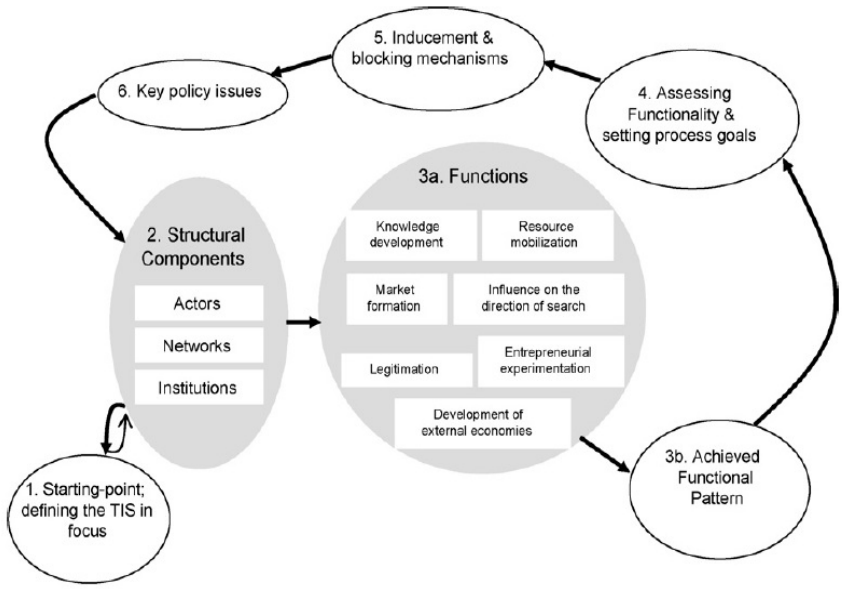
Several refinements have been established and *functions* proposed since then in an attempt to identify the key processes within the system and the correlations of its functions. Throughout such refinements the Technological Innovation System emerged (Bergek et al 2008). The refinements were developed to facilitate the intersection between specific technology issues and a more general industrial dynamics. (Jacobsson; Johnson 2000)

Accorging to Bergek and collegues, “technological innovation systems (TIS) [...] focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)” (Bergek et al 2008: 408).

The following part of this section present a scheme of analysis from TIS proposed by Bergek et al (2008). As well, a table that explores the functions themselves is outlined. The table will show the key processes in technological innovation system build-up compiled by Treffel et al (2012).

It is given a focus to the system outcomes and dynamics rather than to its structural components once the innovation is approached through functions. This is another benefit of the approach, the capability of separating structure from content (Bergek et al 2008:409).

Fig. 1. The scheme of analysis (adapted from Oltander and Perez Vico, 2005)



Source: Berget et al (2008:411)

The scheme of analysis is a description of several sub-analyses that could be followed as a step-by-step guide taken by the analyst. The steps are not necessarily linear as the numbers presented, and can be reassessed at any given time.

The scheme above (Fig. 1) shows six steps to be followed and their description. We intend to apply them in our analysis to better grasp the TIS in the Wind industry in Brazil. It will not be given priority to the order of the steps, though. According to Berget and collegues (2008) the six steps are:

I. Step: It involves setting the starting point for the analysis.
II. Step: Identification of the structural components of the TIS.
III. Step: The focus changes form structure to functions. The functions are analized. With it, it is attempted to to describe what is actually taking place in the TIS in terms of the seven key processes.

IV. Step: This step is normative. It is assessed how well the functions are fulfilled and set process goals in terms of a “desired” functional pattern.
V. Step: Identification of mechanisms that either induce (drive) or block a development towards the desirable functional pattern.
VI. Step: Specification of key policy issues related to these inducement and blocking mechanisms.

(Compiled from Berget et al 2008:411)

Steps IV, V and VI will help us draw conclusions after the analysis has been done but we will not address them separately.

When it comes to the functions, the following compiled contribution (Table 1) will be applied. The following Table has been used to outline the various functions of the TIS. The key processes, the definition and their indicators will enable us to observe the TIS studied, which will be done in the analytical section. Resource mobilization and Knowledge creation and diffusion will be given priority, but all functions will be linked throughout the analysis.

Table 1: Key processes in technological innovation system build-up

Key process	Definition	Indicators
Knowledge creation and diffusion	Activities that create new knowledge, e.g. learning by searching, learning by doing; activities that lead to exchange of information among actors, learning by interacting and learning by using in networks	R&D projects, no. of involved actors, no. of workshops and network size and intensity, activities of industry associations, websites, conferences, linkages among key stakeholders
Influence on the direction of the search	Activities that positively affect the visibility of requirements of actors (users) and that have an influence on further investments in the technology	Targets set by the government, changes in regulatory frameworks, no. of press articles that raise expectations, visions and beliefs in growth potential
Entrepreneurial experimentation	Emergence and decline of active entrepreneurs as a prime indication of the performance of an innovation system, concrete activities to appropriate basic knowledge, to generate and realize business opportunities	No. of new entrants, no. of diversification activities of incumbents, no. of experiments
Market formation	Activities that contribute to the creation of demand or the provision of protected space for the new technology, e.g. construction of market segments	No. of niche markets, specific tax regimes and regulations, environmental standards
Creation of legitimacy	Activities that counteract resistance to change or improve taken-for-grantedness of new technologies	Rise and growth of interest groups and their lobbying activities
Resource mobilization	Activities related to the mobilization and allocation of basic inputs such as financial, material or human capital	Availability of competence/human capital, financial capital complementary assets for key actors
Development of positive externalities	Outcomes of investments or of activities that cannot be fully appropriated by the investor, free resources that increase with number of entrants, emerge through firm co-location in TIS	Emergence of pooled labor markets, intermediate goods and service providers, information flows and knowledge spill-overs

Source: Truffel et al (2012:8) compiled from (Bergek et al 2008; Hekkert et al 2007; Musiolik; Markard 2011)

It will be considered as system functions the intermediate variables between structure and its performance. According to this assumption, the outcome of the interaction of these functions would mold the overall system. One main aspect could be "the development, diffusion and utilization of new technologies" (Jacobsson; Bergek 2011:46).

3.3 Socio-technical regimes and transitions

Socio-technical system can be defined as "a range of elements [that] are linked together to achieve functionality, for example, technology, regulation, users practices and markets, cultural meaning, infrastructure, maintenance network and production system" (Geels 2005:1).

This approach shows that it is relevant to develop a reasoning interlinking the "social" and the "technical" spheres. Furthermore, "sociological frames and socio-technical systems provide a structuring context for economic (trans)actions." (Geels 2005:28)

In this sense, Technological Transitions (TT) are exposed by Geels (2002) in terms of sociology of technology[10] as being important technological transformations in the way societal functions are executed. Nevertheless, "TT do not only involve technological changes, but also changes in elements such as user practices, regulation, industrial networks, infrastructure, and symbolic meaning" (Geels 2002:1257).

For the past three decades contributions to this topic have been produced and they have incorporated the necessity of sustainability for over the last decade. Roots could be identified in evolutionary economic theory (Dosi 1982; Nelson; Winter 1982), in the notion of large technological systems (Hughes 1987), in the social construction of technology (Bijker 1997) as well as in the long-wave theory on techno-economic paradigm shifts (Freeman; Perez 1988).

The discussions around Socio-technical regimes and Socio-technical transitions is presented to have it as a narrative guidance for our analytical section. The TIS would be seen as the object in transition to be observed.

The basic characteristics within the Socio-technical system are here presented to grasp the

10 It is important to highlight that such approach implies that technology itself does nothing if not in association/interaction with human agency. "Only in association with human agency, social structures and organizations does technology fulfill functions" (Geels 2002:1257)

extent of which a transition is stimulated or hindered. It is important to bare in mind the increasing role played by sustainability and the attempt of impelling sustainable innovations. This perspective is also reinforced, once

> […] over the years the analytical interest in TIS research shifted from general technological innovations contributing to the economic growth of countries to new (energy) technologies as nuclei for fundamental socio-technical transitions (Treffel et al 2012:9).

As well, at the moment we consider a technology as a socio-technical system. It is given a thought regarding the action and purpose of such technology, taking into account different dynamics. For instance,

> […] environmental goals such as dramatic reduction in carbon emissions cannot be achieved through individual cleaner technologies alone, e.g., renewable energy, but require structural changes to encompassing socio-technical systems, e.g., energy infrastructure (Smith; Stirling 2010:11).

Aiming at having this various dynamic embedded in a possible analytical perspective, Geels (2002) proposed the Multi-level perspective with a target to observe the technological transition on the micro, meso and macro levels. Doing it so, the technological niches, the technological regimes and socio-technical landscape would have their dynamics conceptualized and interactions exposed (Geels 2005:75).

Therefore it is necessary to understand these three key levels and thus the following sections will provide a definition and explanation of each based on Geels (2002, 2005).

3.3.1 Technological regimes

Technological regimes should be seen as a "semi-coherent set of rules"[11] that provide coordination for human action and (inter)action (Geels 2005:77-78) concerning the set of practices that might influence the direction of innovation.

Having Giddens' approach on rules, it is shown that the regimes can change during cycles of action and structuration (Giddens 1984). Regimes refers to the set of rules that "enable and constrain activities within a communities" (Geels 2005:78)

11 Geels (2002, 2005) proposes a discussion on a broader concept of rules as regards the expansion of cognitive routine idea that would explain the technical trajectories (Nelson; Winter 1982). Instead, he addresses the need to consider formal, normative and cognitive rules in establishing technologies and having a technical trajectory influenced. (Geels 2005:77)

3.3.2 Socio-technical landscape

The Socio-technical landcape is where the technological trajectories are located and consist of "a set of deep structural trends external to the regime. […] they form an external structure or context for interaction of actors" (Geels 2005:78). The idea of Landscape is used to illustrate that it is difficult to have them influenced.[12] In that sense, it would impel a technical trajectory to go in one determined way or another, depending on the given context.

3.3.3 Niches

Niches are defined as spaces in which technologies in early stages of development are protected and are enabled to establish themselves (after incubation).

> Niche developments occur in two (partly overlapping) forms: technological niches and market niches. In technological niches, protection is provided in the form of public subsidies or strategic investment by firms[...]. In market niches, the protection comes from special-purpose performance requirement for special applications, and regular market transactions provide the resources to sustain the niche (Geels 2005:79)

The stability of the niche could be compared to that one of the regime, once "socio-technical aspects make it more stable" (Geels 2005:85)

3.3.4 Sociological characteristics of the three levels and its interactions

The multilevel perspective is based on sociological concepts and can be understood as a "nested hierarchy" of the three levels. The broader and larger the level is, the more rigid it becomes and less permissive to transitions. For instance, the niche is characterized as loosen and having actors operating in different directions. (Geels 2005:81)

The second level is more structuralized with the technological regimes: there are interests that have been articulated and rules do not "determine action, but guide them". (Geels 2005:81)

Finally, the landscape is comprised of a more rigid and stronger structuration of local activities. That is, "shared cultural beliefs, symbols and values are hard to deviate from them" (Geels 2005:81)

Niches would be considered the "seeds for change" (Geels 2005:83). Niches generate a socio-

12 The author makes an analogy to the *longe durée* concept of Braudel's structures.

technical transition to the level of possibly forming a technical regime. It would be possible if they were able to take advantage of the "*circumstances* of diffusion, that is, window of opportunity" (Geels 2005:85).

3.4 Applicability of TIS and social-technical system

In this section we aim to explain shortly the need for both frameworks chosen, their connectedness and set up for the following analytical section.

The TIS provides us with functions to be observed and will help us form a picture of what is taking place concerning the technology studied. The socio-technical system framework supports our narrative as a guide to identify the micro, meso and macro level, in which the technological trajectory is being stimulated or hindered.

We need both approaches due to the fact that one (TIS) will help us assess the state of the wind industry and the other provides insights on how the functions are able to permeate the environment studied.

It could be said that the Wind energy production as a TIS is one facet of the multilevel perspective. Once it is in the early stages it might be configured as a niche (of local market and technology).

Thus, if the wind technology remains growing and establishes itself, it could be become a technological regime. This new regime would even threaten the current regime in place in Brazil or coexist with the current regime.

If the evolved actors take advantage of the "window of opportunity", and the institutionalization and legitimization process of the Wind energy break the technological path-dependency, it could consequently be able to reshape the landscape in the macro level.

That is the reasoning underlying our theoretical approach. We will now move on to the analytical part to understand to which extent such dynamics comes about.

4. Analytical Section: Wind energy in Brazil

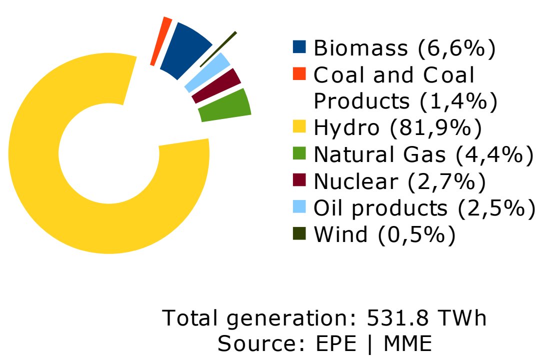
The content of renewable sources in the Brazilian energy matrix was amounted to 45,1% in 2010 and 44,1% in 2011 (EPE, 2012).Worldwide the amount of renewables in the energy matrix was comprised of 13,3% in 2009 and in OECD[13] countries it amounted to only 8% in the same year (Ren21, 2012).

As for the production of energy in Brazil, it is comprised predominantly of renewable sources. In 2011 it amounted to 88,9% (EPE, 2012). If compared to the number of the energy matrix worldwide it can be said that Brazil is one of the countries with the cleanest energy matrix. In 2009, Renewables worldwide, comprised 19,5% and 18,3% in OECD countries (Ren21, 2012).

Hydro-power in Brazil holds the largest share of clean energy production. The electricity supplied from this source corresponded to 81,9% of the total electricity matrix in 2011 with 435,5 Twh[14] produced.

Below (fig. 2) shows in perspective the percentage of each source regarding the domestic supply. The predominance of hydro in the energy matrix indicates a dependency of in this source. This characterizes a socio-technical landscape unlikely to be permeated. As well, the institutionalization of this practice is well-grounded.

Fig. 2. Brazilian Domestic Electricity Supply by Source (2011)



However, the energy supply in Brazil was hit by crises in 2000 and 2002. This was due to droughts that had affected hydropower generation. In addition, grid operators' preference to dispatch hydroelectric energy shrank the reservoirs even more. Another reason was the global

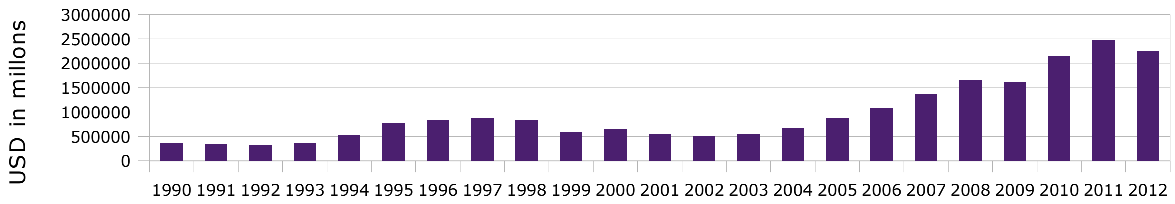
13 Organisation for Economic Co-operation and Development
14 Terawatt per hour: Unit of power generation capacity used for fossil plants as well as for wind-energy, hydro and other Resources

climate that affected the reliability of the hydro plant (IRENA 2012:26). in the previous decade , there had also been an increase in energy demand and lack of investment in the energy sector. According to Bardelin (Bardelin 2004:26), the lack of investment is associated to the privatization process, which started in 1993.

A possible technological regime transition starts to take place with the introduction of governmental incentives to diversify the energy matrix in Brazil. The environmental concerns and the global consensus on promoting a sustainable development have stimulated the engagement in research and technological development.

The increase of the Brazilian Gross Domestic Product (GDP) allowed the governmental engagement in financing the energy matrix development. The numbers below (graph. 1) suggest a boost from 2005 that had started as a constant rise since 2002.

Graph. 1. Normal and Real GDP (total per capita) from Brazil



Source: UNCTADSTAT

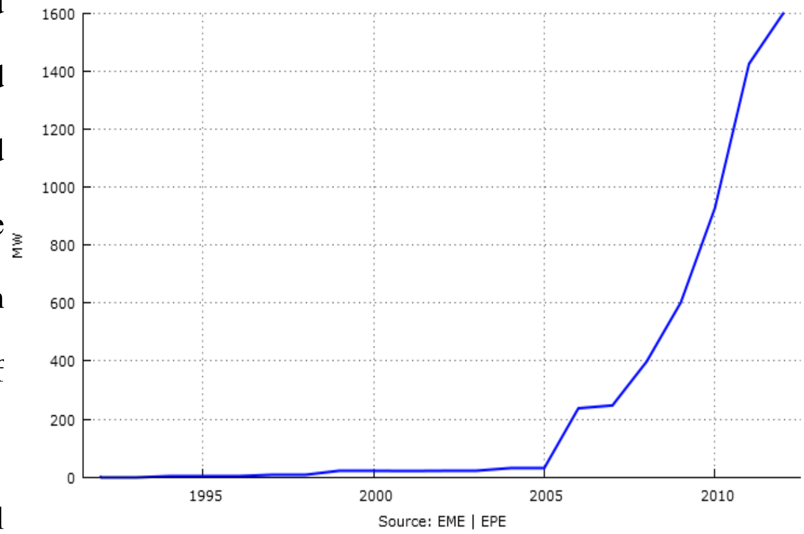
Embedded in this dynamics, PROINFA[15] played an important role in stimulating the wind industry. The Ministry of Mines and Energy (MME) was held responsible for setting guidelines, prepare the planning of the program and define the economic value of each source. The agent executor is Eletrobras S.A, which deals with contract purchases and sale of energy.

The aim of the program is to increase the participation of independent and autonomous producers of renewable energy into the National Electricity System. The entailed energy technology sources are wind, biomass and small hydro. The target is to respond to 10% of the electricity demand until 2020. (GWEC 2011; Chaves-Schinteck 2012).

15 Programme of Incentives for Alternative Electricity Sources. Instaured by Law 10,438 dated from April the 26th, 2002; amended by Laws 10,762/03, and Law 11,943 dated from March the 28th, 2009.

As an outcome, PROINFA stimulated technologies that did not exist in Brazil before, or were of very little relevance as regards to energy production and commercial presence. (Simas 2012:80)

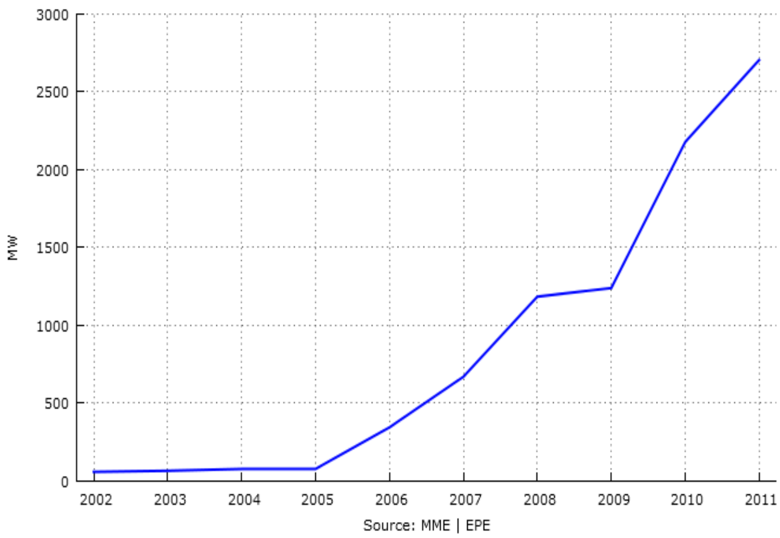
Graph. 2. Cumulative Wind Energy Installed in Brazil



As it can be observed (Graph.2), the cumulative wind energy installed increased considerably after the inauguration of the program. In 2012 it reached 1600 MW of capacity installed.

In regards to the total generation of energy from the Wind farms installed in the country (see Graph. 3), it evolved from 74 MW in 2005 to 2.705 MW in 2011.

Graph. 3. Energy generation from Wind in Brazil



Important to highlight is the fact that existent hydropower grids ease the integration of the wind energy in Brazil. Besides, the wind season coincide with the low rainfall seasons. Therefore, windpower becomes a natural complement of hydropower concerning resources and continuation of supply (ABEEólica 2012; IRENA 2012).

As mentioned before, the energy generated from wind in 2012 was enough to power four million households and accounts for 2% of national electricity consumption (GWEC 2012). Given the fact that the government set a target of 10% of national electricity consumption until 2020 for all sources under PROINFA, the wind industry shows a rapid growth. The target mentioned represents the TIS function concerning influences on the direction of the search. Once the forecast is to increase the demand for wind energy, the actors evolved also move towards investing further.

According to Abeeólica (2012) until 2016, the target is to add 8,4 GW of wind power in the Brazilian energy matrix. That amount would represent 5,5% of wind power participation in the national energy matrix. The forecast for 2020 is a share of 9%.

Hence, we address here how the governmental forecast triggered the private sector to set targets that surpass considerably the targets of PROINFA. On one hand the government poits to 10% for all renewables under the program and the private sector aims to reach 9% of wind power in the energy matrix in the same year, 2020. Thus, the picture is a puzzle regarding the influences on the direction of the search function.[16]

Nonetheless, in 2007 the target set by the government was to have 1,4 GW installed until 2015. In 2030 the wind power would correspond to 1% of the national energy production. As it can be seen in graph. 2. the target for 2015 was met already in 2011.

Additionally, a niche could be identified for the industry studied. The wind market (somewhat consolidated) and its technology (incipient) are two niches. This evidence relies on the incentives (special tariffs) and the local content set by the legal framework, which will be discussed in the following section.

At this point we would like to stress that the set up for the wind industry might provide the required contingencies for a catching-up strategy. That is, the incorporation of wind technology is taking place. It could also trigger the development of such technology locally in order to generate sustainable development, not only in production of energy but also technical and social development. This dynamics are likely to occur if the actors involved take advantage of the

16 Early studies of the Wind map in Brazil took for granted the technology available at that time, wind mills of 50 meters height. Nowadays, with the development of technology they can reach 100 to 150 meters. Thus, the Brazilian energy potential that was remeasured and grew considerably. It sums up to 350 GW at 100 meters. (Simas 2012:84)

"window of opportunity" that the diversification dynamics possibly provides.

According to Perez and Soete (1988:476)

> catching up involves being in a position to take advantage of the window of opportunity temporally created by a technological transition […] Development is not about individual product successes but about the capacity to establish interrelated technology systems in evolution, which generate synergies for self-sustained growth processes.

The more the industry consolidates itself and the more the wind technology remains at stake the more institutionalized it gets. The legitimization of such technology comes along with its consolidation process, issues that will be deepen while accessing the functions within the analyzed technological innovation system.

Therefore, we move to the analysis of the history and evolution of the wind technology, recently introduced in Brazil. Furthermore, this next section follows the insights provided by the technological innovation system.

4.1 History and evolution: technological inducement, legal framework and market

Brazil was the first Latin American country to install wind turbines in the early 90s. The introduction of the technology roots back to a partnership between the Brazilian center for wind energy and the Energy Company of Pernambuco. The finance was provided by the Danish research institute *Folkecenter* (Simas 2012:82).[17]

In the following decade little moved towards the consolidation of the wind industry as an alternative source. Two reasons are identified by Simas (2012): the lack of policies and the high cost of the technology.

As stated before PROINFA introduced the stimuli for the industry and a legal framework was established. The framework "states that Brazil will rely on wind generation as its main renewable alternative and it will be subsidizing the implementation of this technology into the public electrical grid" (Pottmaier et al 2013:682).

Notwithstanding, practical issues related to the implementation of the program undermined

17 As it can be seen in Graph.2 the capacity installed was not representative. Nonetheless, it estimulated experimental projects in the following years in the States of Ceará, Minas Gerais, Paraná, Pernambuco, Rio Grande do Norte and Santa Catarina (Aneel 2005)

the development of renewable sources in the early stage of the program. The problems identified are: 1. the bureaucratic and complex process of obtaining or renewing environmental licences; 2. the demanded Declaration of Public Utility[18] was problematic and there were delays to be obtained; 3. difficulties in the grid connection, primarily in the midwest region; 3. the local content requirements, fixed to 60% for equipment was calculated by weight[19] (IRENA 2012:38).

The legal framework runs price auctions (competitive bidding system) to contract companies. The winning companies would provide the wind turbines for the wind farms to be installed under the program. The agreement takes place as a bilateral contract between buyers (utility) and sellers (specific purpose companies). The auction pattern aimed at increasing energy security through efficiency and cost-benefit. However, wind and biomass technology compete with other sources occasionally (IRENA 2012; Chaves-Schwinteck 2012).

The investment directed to the wind industry in the auctions from 2004 to 2011 reached 25 billons (BRL). The forecast is 50 billons until 2020 (Abeeólica 2012). Below, table 2 demonstrates the wind energy capacity contracted in the energy auctions of 2009, 2010 and 2011.

Table 2: Installed Capacity contracted in the energy auctions of 2009, 2010 and 2011

Auction Classification	Year of Action	Contracted Wind Power Capacity [MW]	Number of Wind farms	Average price (BRL/MWh)	Type of contract*	Accomplishment date
ASE	2009	1805,7	71	148,39	A3 – 20 years of supply	July/2012
ASE	2010	2047,8	20	130,86	A3 – 20 years of supply	January/2013
ARE	2010	1067,7	50		A3 – 20 years of supply	September/2013
ANE	2011	1,519.6	44	99,58	A3 – 20 years of supply	September/2013
ASE	2011	861,1	34	99,54	A3 – 20 years of supply	June/2014
ANE	2011	976.5	39	105,12	A5 – 20 years of supply	January/2016

ASE	Auction of Storage Energy
ARE	Auction of Renewable Energy
ANE	Action of New Energy

* The auction legislation comprises two different types of contracts. A3 contracts must start commercial operation within 3 years. The A5 type has to start within 5 years after the selling date. Both are entitled to 20 years of supply.

Source: MTCI | EPE

The gap of relevant contracts from the moment of the announcement of the program until the auctions compiled above are related to the local content requirement. Companies were not being able to respond to the required (ABEEólica 2011). As a result, “the government has decided to

18 This classification enables easier negotiations to use the assets and rights affected by the projects. Above all the land, concerning disputes between owners and landholders. There are different terms of use and occupation, which obscure the identification of the property for the wind farm developer. For a better understanding of the concept, see http://www.jusbrasil.com.br/topicos/297711/utilidade-publica

19 It created an increasing demand for wind turbine towers produced locally, therefore an upward price pressure on Brazilian steel was created. In addition, the steel industry was dominated by one supplier, Usiminas. This led to higher costs when compared to the prices of imported steel (Azau et al 2011).

relieve this condition from the request to register wind farm projects willing to offer their production in the energy bids" (Chaves-Schwinteck 2012). Even though, the nationalization index is still a requirement for funding access provided by BNDES, which comes at a lower cost.[20]

We identify the development of positive externalities in the attractiveness of the Brazilian market. The second auction created more concurrence and reduced the average price/MWh in nearly 30%. This was also a result of the reduction in cost of projects from the first to the second action, according to the Brazilian Chamber of Electric Energy Commercialization.[21]

In regards to the timid recovery in the average price in the ANE/2011, the five years deadline for project developers before connecting to the grid and the high competition with hydroelectric and thermoelectric projects are to be mentioned.

Nevertheless, "the rigorousness of this system has given the industry confidence to move ahead, even with the very low prices of the winning bids" (IRENA 2012).

The TIS function regarding market formation is disclosed in the performance of the companies in interaction with the system set by the auctions presented. Therefore we are now going to look at the companies that participated in the auctions and won bids (graph. 4). It shows the diversification of companies according to the percentage contracted. The companies are turbine manufacturers that are to supply the wind farms presented in table 2.

As for the TIS function concerning entrepreneurial experimentation we link it to the manufacturers that have been doing business in Brazil and their establishment. There are four[22] manufacturers already established in the country and supplied the capacity in operation. Five[23] other manufacturers entered the market in the last two years. The first manufacturers to have production units in Brazil were Enercon and Impsa. This also reflects their bigger share in the last actions. Enercon contracted in the three auctions a total of 31% and Impsa 25%.

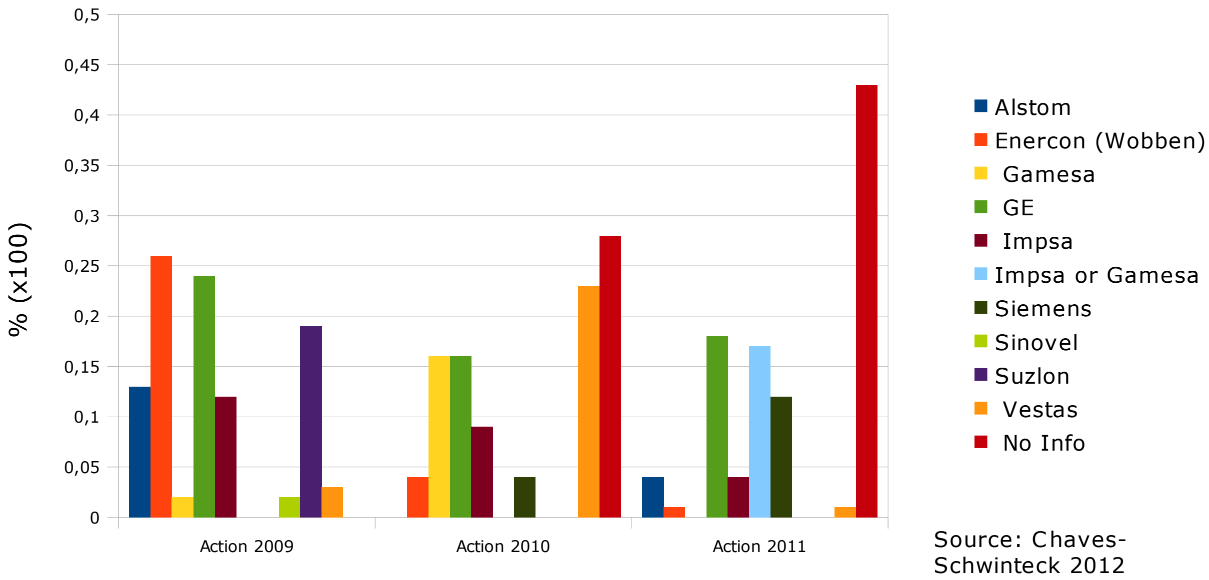
20 The BNDES funding is alligned with the types of contracts. It requires conditions to be fulfilled, such as meeting deadlines for implementation. The result is a rapid expansion of the local supply chain.

21 http://www.ccee.org.br/

22 Enercon, Impasa, Suzlon and Vestras. According to ABEEólica, The total installed capacity currently in operation has been manufactured mainly by Enercon (Wobben) (38,6%), Suzlon (25.9%), Impsa (21.8%) and Vestas (13.7%)

23 Alstom, GE, the Chinese Sinovel, Gamesa and Siemens.

Graph 4: Wind Turbine Manufacturers supplying Wind Farms concerning the Auctions



Despite the announcement of investments from GE, Siemens, the Chinese Guodian United Power and Sinovel, Enercon was still leading the supply of turbines to the wind farms in 2009.

The auctions evidenced a diversification of the supply in the last years. Enercon and Impsa lost their leadership positions to suppliers like Siemens, Alstom, Gamesa and GE in the last two actions (see Graph. 4).

The activities performed by the companies and their interaction with the legal framework tend to support the establishment of the wind technology. That could be due to the growing market and players diversification.

Some of the components exposed above are part of the technological innovation system studied but do not comprise all of the functios. Therefore, as from now we point to the specific functions of the TIS that contribute the most to our study. We also present additional results of our research.

4.2 TIS: Functions, indicators and results

So far we have highlighted some key aspects to understand the evolution of the wind industry in Brazil. It will be presented the indicators of the TIS functions that contribute most to our aim in this project. We address here the TIS functions and indicators not mentioned so far. The selection was made in order to show the possible innovation stimuli in the country.

4.2.1 TIS in focus

In order to define the TIS in focus, three choices have been made, as suggested by Bergek et al (2008:412). Firstly, we choose the technology to generate energy from Wind in Brazil as a focusing device. Secondly, we observe the knowledge field related to it in the country. In this sense, aspects related to the capacity building for this technology to succeed are important.

The structural components of the TIS have been exposed in sections 4 and 4.1 of the analytical part. It is worth drawing some additional lines, though.

The activities of the companies exposed before is a focal point as regards capacity building, network formation and job creation. There are companies that are incumbent[24] and others classified as new entrants[25] in the Brazilian market. By the moment they operate commercially they produce dynamics that can be stimulus to the technology in focus. This is revealed in the energy auctions contracted by them, discussed previously.

With regards to the Government, the most influential actors are also used as sources for this study, such as Aneel, BNDES and EPE. They play different roles in the process but are interconnected and intertwined, providing support for innovation activities.

Furthermore, the networks should be pointed out. Firstly, the Brazilian Association for Wind Energy, which is composed by companies that belong to the production chain of wind power in Brazil. Additionally, we look at research institutes that develop studies in Wind power to think about these networks. Most of the considerations are made from the available data in CNPQ[26] platform.

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24 Incumbent companies refer to companies that are already consolidated in the national market. For instance: Enercon, Impasa, Suzlon and Vestras.

25 An incumbent company internationally can also be a new entrant in a local market, once it will have to adjust itself to the local institutions. For instansce: Vestas, Gamesa, GE, Alstom, Siemens, Acciona, LM Windpower, Sinovel, WEG entered the market in the last two years.

26 CNPQ: National Counsel of Technological and Scientific Development

4.2.2 Institutions

As mentioned before, there are three different kinds of institutions intrinsic to our framework. The regulatory, the normative and the cognitive institutions. “Institutions are sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations” (Edquist and Johnson 1997: 46).

Therefore, institutions are seen as the rules of the game. They influence the relations between universities and firms. (Edquist 2001)

As regulatory institutions we point out the legal framework set by PROINFA, which was already presented. Secondly the pattern of research agenda in the field, to be discussed subsequently.

The normative institutions are understood as the interaction of actors evolved in the industry. We relate it also to the interaction that is to take place among them. The patterns of energy supply and predominance of sources has also a normative domain and can be tracked in what has been discussed in section 4. The main point here is to remind us the fact that the energy sector in Brazil is predominately comprised with renewable sources.

Finally, there are the cognitive institutions. A careful assessment to the energy sector in Brazil as regards sustainability provides insights that suggest a disapproval of power plants in areas of natural reserves. Notably, a strong speech against hydro power in the Amazon region is defended.

Additionally, the fear shared by the population regarding new doughs in the dominant hydro supply suggests the justification and acceptance for additional sources.

Permeating these institutions there are issues concerning the wind energy. Mainly the fact that some wind farms were installed not following environmental laws, according to Scalabrini[27](2013). The nonconformity to environmental law are claimed to exist in wind farms located in sand dunes and mangroves that compromise the areas. In addition, the early installations were located close to residential areas.

27 Heitor Scalambrini is part of the Brazilian network for environmental justice. Source: www.cartacapital.com.br/

4.2.3 Relevant TIS functions to our study

The functions here studied help us describe what is actually taking place in the TIS. The most relevant function of the TIS for our study is related to knowledge creation and diffusion. The governmental funding for research is mainly provided by Finep (graph. 5), Aneel (graph. 6) and CNPq. Important to mention is that private companies can also apply for governmental funds to development research. Nevertheless, the funding is mainly related to research institutes, or partnership between these institutes and the private sector. We have tracked the investments done by companies according to field of research in wind industry (graph. 7).

We have also compiled the number of researcher and research institutes engaged in Wind technology as per field of studies (table 3). It reveals the concentration in the field of aerogenerator technology, wind resources and wind farms. Together they amount to 39 research institutes with 123 researchers. Grid connection and integration comes as a relevant field as well.

Table 3. Wind technology studies in Brazil, 2012

Field of Studies	NRI*	NR**
Aerogenerator technology	14	47
Wind resources	12	31
Wind Farms	13	45
Materials	2	2
Politics, economics and socio-environmental analysis	5	13
Standardization, certification and normatization	5	17
Planning and operation of power plants	6	24
Grid connection and integration: quality control	8	22
Engineering projects: maintenance and operation of parks	3	10
Total	68	211

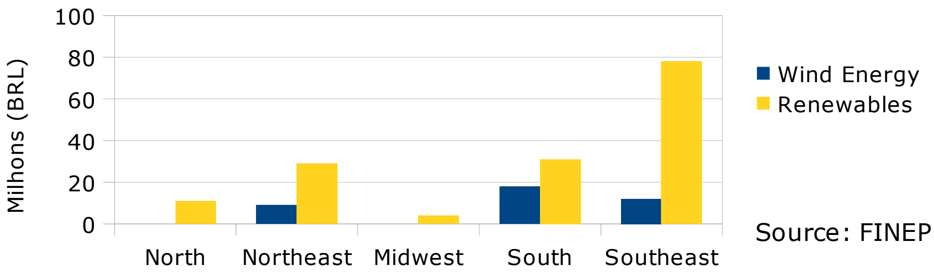
* Number of Research Institutes

** Number of Researchers

Source: MCTI

The trend in the research concerning wind coincide with the configuration of the market in Brazil, when it comes to having companies in need of meeting the local requirement in the production of wind turbines.

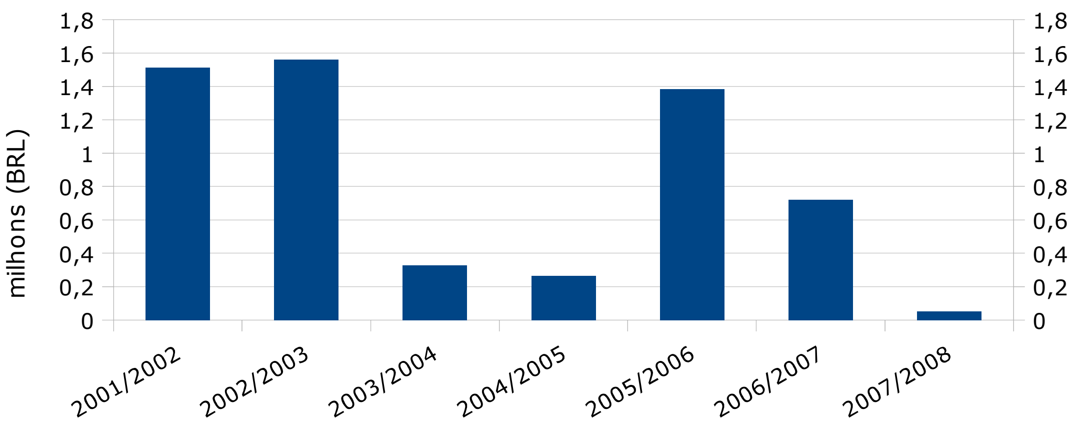
Graph. 5. Investments from FINEP in RD&I[28] projects in the last since 2003 per Region.



The investments shown on the left (graph. 5) demonstrate that out of the total invested in renewable sources in the last decade a sum of 25,4% was directed to wind technology. In addition, the figures disclose a concentration in the Southern and Southeastern Regions. From the total amount invested in Wind both regions received 76,9% of the investments.

Projects financed by CNPq had two rounds of investment so far. In 2003, 3,8 millions (BRL) were invested in Projects that developed studies on alternative energy generation in isolated communities of the "Legal Amazon". In 2010, 4,5 millions (BRL) were invested in projects of capacity building concerning labor market and the generation of human resources in renewable sources of energy.

Graph. 6. Investments in Wind energy of the R&D Program regulated by Aneel

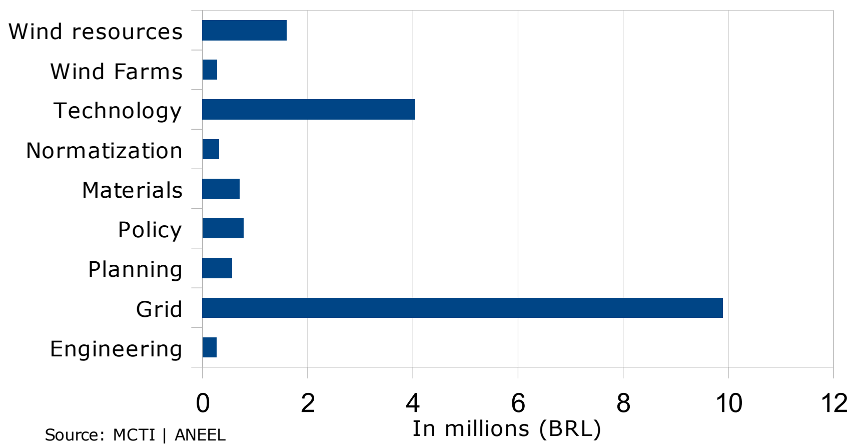


Investments regulated by Aneel demonstrate significant amounts in the first two cycles. The following two cycles show an expressive decrease. In 2005/2006 it can be seen a recovery in

28 RD&I: Research, Development and Innovation

investment followed by constant decrease. According to the agency (Annel 2012) the drops in investment are related to their program of P&D as a whole. It is not related to any specific dynamics underlying the field of wind power.

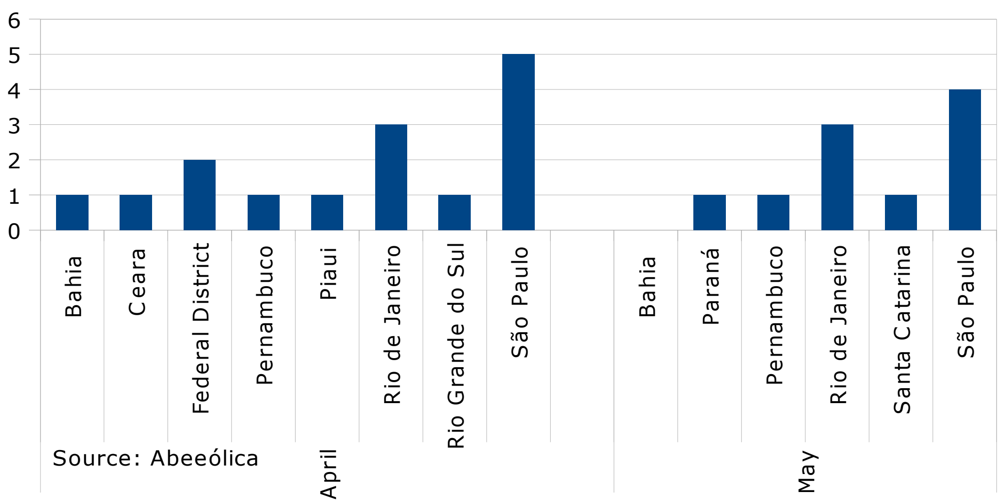
Graph. 7. Company investment by field of research in Wind energy, 2012



Concerning the investment by field in wind energy, the grid (energy quality control) was the one to receive the biggest flow of investments. It has been invested nearly 10 millons BRL, which accounts for 54% of the total investment. The wind turbine technology comes as second, receiving nearly 4 millions (BRL), which accounts for 22% of the total invested in the R&D program regulated by Aneel.

To draw considerations on the networking of the industry we have compiled the number of events and workshops linked to the Aeeólica (Graph. 8).

Graph. 8. Events and workshops scheduled for 2013



Out of 15 meetings scheduled 8 took place in São Paulo and Rio de Janeiro last April. In May, 7 out of 10 were also hold in these two states.

The numbers suggest that the network is not big, is still in process of development and there is a concentration in the Southeastern region.

The trends in the investment by field of study and concentration of researches developed suggest that focus is given to the supporting activities to the production of wind turbines, installation of wind farms and grid improvement. As regards to the development of the technology itself there has been little engagement. Therefore, we consider that an indigenous process of technology development is still far from the Brazilian reality. The adaptation of the already existent technologies regarding wind tends to be the catching-up strategy in place.

Another relevant TIS function for our analysis concerns resource mobilization. The indicators are entailed of financial, material and human capitals. Once we have discussed previously the production of wind turbines to supply wind farms we will address the financial and human capitals.

Financially, as seen above (graph 5, 6 and 7) there has been different shorts of stimulus to the development of research. When it comes to the larger scale of funds, we look at the role of BNDES.

According to BNDES (2012), the wind energy has been financed with 3.4 billion (BRL) in 2011 (investments of R$ 5.3 billion). An increase of 173% in comparison with 2010. The estimations for 2012 are between 4 and 4.25 billion (BRL). In addition, the price of commercialized energy coming from wind farms decreased. In 2005, it was commercialized for BRL 305/MWh. In 2011it dropped to BRL 100.9/MWh. This represents a relevant contribution that impels the bank to remain reducing tariffs.

The other indicator is the human capital. With the introduction of the manufacturing in Brazil job opportunities were created.

Simas (2012:139) suggests a projection that accounts for the demanded labor force to respond to the Wind energy installed capacity and the forecast capacity to be installed using EPE's projections. In that sense, between 3.721 and 29.365 direct and indirect workplaces are created per year. The estimations of installed capacity grow suggest 195.972 jobs/year from 2010 to 2020. To sum up, her estimation is the creation of 330 thousand jobs until 2020 if the wind industry remains meeting the targets set by the government as regards installed capacity. 70% of these vacancies are related to construction activities.

The characteristics of the job vacancies created suggest that the parts of the production chain with less aggregated value is what has been practiced in the country in order to meet the local content requirement.

The functions resource mobilization and knowledge creation and diffusion point to the direction of an incipient industry that has been stimulated but is yet not consolidated in terms of technological innovation.

5. Conclusions

After a timid start up the wind industry revealed a constant grow in terms of energy generation, creation of market, diversification of actors and articulation of institutions, notably after 2005 but mainly as from 2009.

Due to the incentives for the wind industry consolidation it can be stated that it has gained a niche market and the actors evolved are being able to take advantage of it. The fast grow puts pressure in creating and reformulating the legal framework constantly. As well, it requires diversification of investment sources.

At the same time that the local content requirement stimulates the industry it also makes it hard for companies to start operating in the country. Noteworthy is the fact that the requirements of BNDES funding stimulated the manufacturing in the country. Along with it industrial and technical capabilities were created. Nevertheless, it has also hindered the access to the market for other kinds of companies, aside from manufacturers. Still, the social capital is being developed in the sense that the creation of jobs also generates capacity building. However, this capacity is linked to the trends of the heavy part of the industry, concerning the production chain.

Therefore, it can be stated that even though the industry is likely to succeed in case the government shrinks the incentives, the technological innovation system we studied (technology to generate energy from Wind) is still incipient and in a building up towards consolidation process in slow pace.

Consequently, the technical regime is apparently changing but the way the wind power is being incorporated in Brazil does not suggest a change in the landscape. A socio-technical transition is in place but the transition has not yet entailed the high technology evolved in wind power generation. If the trajectory of the technology is to take advantage of the window of opportunity, a more incisive development of the human capital has to be stimulated.

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