

Barriers to onshore wind farm implementation in Brazil

Jamil Ramsi Farkat Diógenes^{a,b,*}, João Claro^a, José Coelho Rodrigues^a

^a INESC TEC and Faculdade de Engenharia, Universidade do Porto, Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal

^b NAGI - Núcleo Aplicado à Gestão e Inovação, Universidade Federal do Rio Grande do Norte, Centro de Tecnologia, Av. Senador Salgado Filho, 300, 59078-970, Natal, RN, Brazil

ARTICLE INFO

Keywords:

Renewable energy
Wind energy
Wind farms implementation
Barriers to implementation

ABSTRACT

Across the world, several developing countries with recent wind energy (WE) diffusion have been demonstrating an interest in expanding WE generation quickly and expressively. In Brazil, this fast and remarkable WE diffusion process started in the past decade, facing a variety of barriers. This research proposes to reliably identify and analyse current barriers to the implementation of onshore wind farms in the country, aiming at informing other developing countries with the intention to expand WE utilization about potential barriers, as well as assisting the Brazilian WE sector in its efforts to keep growing sustainably. To achieve this research goal, 41 key stakeholders from the Brazilian WE sector were interviewed. Based on a content analysis of the interviews, twenty-four barriers were identified, three of which with particular relevance: poor transmission infrastructure, unattractive financial loans and unstable macroeconomic environment. The data collected suggests a serious risk that Brazil's WE sector stops growing if the recovery of its national economy, the reestablishment of regular energy auctions, the access to competitive credit, and improvements to the transmission system infrastructure keep being held back. In the face of this scenario, this study concludes by providing policy recommendations concerning the sustainability of the Brazilian WE sector.

1. Introduction

Among various renewable energy sources (RES), wind energy (WE) is increasingly becoming established as a key option to replace conventional energy generation, and consequently as a key contributor to mitigating global climate change in the future (Saidur et al., 2010). Moreover, the expansion of WE around the world has been regarded as important to meet a rising energy demand and ensuring security of supply (Changliang and Zhanfeng, 2009).

In parallel with its increasing utilization, WE has been facing several barriers to its diffusion worldwide, more intensively in developing economies with a recent history of large-scale onshore wind farm implementation. In these economies, especially those with a continuous growth in WE installed capacity, field research to identify such barriers has been scarce. Studies with this focus, in particular based on interactions with stakeholders, are deemed necessary to offer a concrete perception about the obstacles that are hindering WE implementation (Painuly, 2001). Academics, policy makers, and practitioners can take advantage from this information as they seek to contribute to mitigate or overcome these barriers through research, policy making and wind farm project strategy design.

As part of the global WE diffusion, the installed WE capacity in Brazil grew over the past decade from 341 MW (GWEC, 2009) to 12,770 MW (ABEEólica, 2018; GWEC, 2018). This growth of more than 37 times placed the country in the top 10 nations with higher WE capacity installed, qualifying its WE diffusion process as fast and expressive. In addition, onshore wind farms implemented in the Northeast region, where 84% of the total Brazilian WE is generated (ABEEólica, 2018), have presented low levelized costs of electricity and high capacity factors (de Jong et al., 2016). Featuring an impressive and high-quality growth, the spread of WE in Brazil represents an example to be followed, especially by developing countries with the intention to start or to keep developing onshore wind farms in large-scale.

In spite of its success, the Brazilian case has been replete with barriers that over the years have hindered the development of wind farms across the country. Until the end of 2017, very few studies, while analysing the evolution of Brazilian WE, had mentioned these barriers (Aquila et al., 2017; Barroso et al., 2010; Brannstrom et al., 2017; Da Silva et al., 2005; De Melo et al., 2016; do Valle Costa et al., 2008; Geller et al., 2004; Kissel and Krauter, 2006; Martins and Pereira, 2011; Nogueira De Oliveira et al., 2016; Pereira et al., 2012; NFD et al., 2013; Tang and Taylor, 2014). In addition, the only study including field

* Corresponding author at: INESC TEC and Faculdade de Engenharia, Universidade do Porto, Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal.

E-mail addresses: jamil.farkatt@fe.up.pt (J.R.F. Diógenes), jclaro@fe.up.pt (J. Claro), jpcr@fe.up.pt (J.C. Rodrigues).

<https://doi.org/10.1016/j.enpol.2018.12.062>

Received 13 September 2018; Received in revised form 29 December 2018; Accepted 31 December 2018

Available online 11 January 2019

0301-4215/ © 2019 Elsevier Ltd. All rights reserved.

research with stakeholder interviews, allowing a reliable and full identification of the barriers and an understanding of how they impact wind farm development at a national level, was published in 2011 and is outdated (Martins and Pereira, 2011).

Seeking to address this gap in the literature, this study focuses on the following research question: “Which barriers to onshore wind farm implementation are present in cases of fast and expressive WE expansion?”.

An overall identification of the barriers to onshore wind farm development in Brazil was performed through interviews with several national WE stakeholders. The content of these interviews was analysed using the framework proposed by Painuly (2001) for barriers to the penetration of RES, to identify barriers with a national or a state scope of impact, barriers that emerged earlier or more recently, barriers with particular relevance, and barriers specific to the WE sector or related to Brazil's overall economic context, as well as assess the level of perception of each barrier for each category of stakeholders. Moreover, looking also at barriers that were not identified, this study highlights the main factors that have driven the fast and expressive WE expansion observed in the country. In addition to aiming at contributing directly to the efforts to overcome these barriers in the country, through their identification and characterization, this research also aims at pointing out the barriers to onshore wind farm implementation that will probably emerge in the context of developing economies with recent histories of WE diffusion and the intention to increase its utilization quickly and expressively.

Starting with this introduction, this paper additionally includes five sections. Section 2 presents the selected case study, highlighting its differentiated position in the global context of wind generation. The third section describes the methodology used, detailing how the interviews were performed and how the collected data were analysed. The results of the study are then presented, according to the barrier categories suggested by Painuly (Painuly, 2001). A discussion of the identified barriers follows the results, framing them in the literature. The paper concludes by stressing the barriers with stronger impact in the country and providing a set of policy recommendations concerning the sustainability of the Brazilian WE sector.

2. Large-scale wind energy expansion: a case study of Brazil

After a national energy crisis in the early 2000s, the Brazilian government recognized the urgency in promoting alternative sources to reduce its high dependence on hydropower (Luiz da Silva E, 2006; Rosa and Lomardo, 2004). Among the options to expand the energy matrix and re-establish security of supply (Kileber and Parente, 2015), WE emerged as a reliable option in Brazil, especially in the Northeast region, due to its excellent wind conditions (JBSOD et al., 2015; de Jong et al., 2013; Dester et al., 2012; Leitão, 2013; Pereira et al., 2012). Supported by a public auctioning system, the WE capacity installed in the country grew 37 times in the past decade, reaching 12,770 MW at the end of 2017 (see Fig. 1). Currently, Brazil occupies the eighth position among the top 10 nations with higher installed WE capacity (GWEC, 2018).

Using the currently installed WE capacity, the country generated 40.46 TWh of electricity, with 33.99 TWh coming from onshore wind farms located in the Northeast region, especially those operating in the states of Rio Grande do Norte (13.24 TWh), Bahia (7.79 TWh) and Ceará (5.10 TWh) (ABEEólica, 2018). This installed capacity represents still a small portion (7.8%) of Brazil's total installed electricity

generation capacity, which is dominated by non-renewable (17.2%) and hydropower (63.8%) sources (EPE, 2018).

As part of this fast and expressive national growth, wind farms located in the Northeast region have been continuously reporting an outstanding average capacity factor above 40% (ABEEólica, 2017, 2018; de Jong et al., 2016), much higher than country average across the world (IEA, 2015). Consequently, even facing barriers with an impact on development costs, the levelized cost of WE in the region has reached 0.035 USD/kWh (de Jong et al., 2016), a value much lower than those observed in others parts of the world (IRENA, 2015).

In fact, the future of WE seems promising in the region, both for expanding electricity generation and for replacing other main generation sources, since wind farms have been trading electricity with competitive tariffs in comparison with thermoelectric plants and lately also with hydropower plants (ANEEL, 2018b), and have their generation reliably foreseen and quantified (due to the existence of strong and stable trade winds – suitable for a wide integration in the grid). In the current scenario of high hydroelectric availability losses (due the frequent occurrence of droughts), a supply alternative is urgently required (de Jong et al., 2017).

Regarding the barriers to onshore wind farm implementation in Brazil, very few studies have attempted to identify them. After conducting an extensive search in Scopus and Web of Science databases, only thirteen studies on the subject were found (see Table 1).

Even though 21 barriers are mentioned across these studies, except for Martins and Pereira (Martins and Pereira, 2011), no other studies collected information through interactions with multiple stakeholders to reliably identify the existence of these obstacles (Painuly, 2001). In general, they focused on discussing existing incentive policies and the ongoing expansion of the national wind sector, and did not seek to address directly the barriers to onshore wind farm implementation (Eleftheriadis and Anagnostopoulou, 2015; Kucukali, 2016; Reddy and Painuly, 2004; Richards et al., 2012; Weis et al., 2008; Zhao et al., 2016).

3. Methodology

This study uses case research as methodological design. Case research was selected among other alternatives (quantitative methods and other qualitative methods, such as grounded theory) due to the fact that it allows rich, in depth empirical descriptions, based on a variety of data sources, providing a suitable way for examining and clarifying the type of complex relations that are faced in this research (Yin, 2009) – implementation processes involving a large number of critical actors and factors (Linton, 2002). Moreover, the lack of detailed and updated prior research about onshore wind farm implementation in developing countries (such as Brazil) leads to the need for exploration of the phenomenon (Mills et al., 2010), which corroborated this choice. Furthermore, compared to other qualitative methods, case research is a suitable method when there is an intention to combine an existing theoretical framework (such as the one proposed by Painuly (Painuly, 2001)) as a basis for the analysis of results with an in-depth exploration of the phenomenon (the implementation of onshore wind farms) (Yin, 2009).

3.1. Stakeholder interviews

To identify the barriers to onshore wind farm implementation in Brazil, information was collected through interviews with several

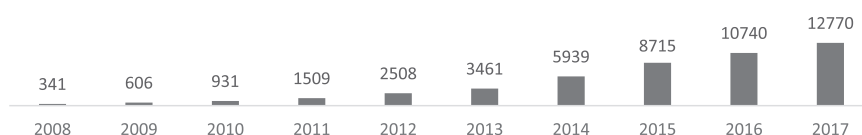


Fig. 1. Evolution of the Brazilian cumulative installed WE capacity (MW/year) (GWEC, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018).

Table 1

Barriers to onshore wind energy implementation in Brazil found in the literature, according to the categories proposed by Painuly (2001).

Barriers		Studies
MARKET FAILURES (MF)		
Lack of information and awareness	Lack of recent, detailed and accurate wind data	(Martins and Pereira, 2011; Nogueira De Oliveira et al., 2016; Pereira et al., 2012)
Poor market infrastructure	Underdeveloped home wind industry	(Aquila et al., 2017; Da Silva et al., 2005; do Valle Costa et al., 2008; Geller et al., 2004)
MARKET DISTORTIONS (MD)		
Favourable treatment to conventional energy	Subsidies to conventional energy generation	(Martins and Pereira, 2011)
Non-consideration of externalities	Exclusion of externalities in the calculation of energy costs	(de Jong et al., 2015; NFd et al., 2013; Tolmasquim et al., 2001)
ECONOMIC AND FINANCIAL (EF)		
High cost of capital	High interest rates on loans for wind farm development	(Kissel and Krauter, 2006)
Lack or inadequate access to capital	Difficult access to capital for wind farm implementation	(Aquila et al., 2017; Barroso et al., 2010; De Melo et al., 2016)
High up-front capital costs	High initial costs for wind farm implementation	(Martins and Pereira, 2011; Pereira et al., 2012)
INSTITUTIONAL (I)		
Lack of institutions and mechanisms	Entities with lack of specialized capability	(De Melo et al., 2016)
Lack of a legal/regulatory framework	Time-consuming procedures to get construction and connection approvals	(Barroso et al., 2010; do Valle Costa et al., 2008)
Problems in realising financial incentives	Collect the certified emission reduction (CER), a type of emissions unit, from the clean development mechanism (CDM)	(Tang and Taylor, 2014)
Unstable macroeconomic environment	High inflation rate	(Kissel and Krauter, 2006)
Lack of R&D culture	Unstable currency	(Aquila et al., 2017)
	Insufficient efforts to develop wind R&D	(Martins and Pereira, 2011; Nogueira De Oliveira et al., 2016; NFd et al., 2013)
TECHNICAL (T)		
Lack of standards, codes and certifications	Lack of appropriate standards for the promotion of innovation in the WE industry	(Nogueira De Oliveira et al., 2016)
Lack of skilled personnel	Shortage of WE specialized personnel	(Martins and Pereira, 2011)
System constraints	Weak grid infrastructure	(Da Silva et al., 2005; Martins and Pereira, 2011)
SOCIAL (S)		
Lack of consumer acceptance	Consumers with insufficient information about WE benefits	(NFd et al., 2013)
Lack of social acceptance	Local community opposition to wind farms	(Brannstrom et al., 2017; NFd et al., 2013)
OTHER BARRIERS (OB)		
Uncertain governmental policies	Support schemes with inadequate designs	(Barroso et al., 2010; do Valle Costa et al., 2008; Martins and Pereira, 2011)
Lack of infrastructure	Insufficient transmission infrastructure	(Aquila et al., 2017; Kissel and Krauter, 2006; Martins and Pereira, 2011)
	Limited road access to windy sites	(NFd et al., 2013)

stakeholders from the Brazilian WE sector. The interviews were complemented with a literature review and site visits, as recommended by Painuly (Painuly, 2001) to reliably identify and analyse the barriers to the penetration of RES.

The focus on stakeholders is justified by their crucial role in the implementation process (Painuly, 2001), as well as the wide adoption of a stakeholder perspective in other studies with similar objectives (da Silva et al., 2013; Martinot, 2001; Richards et al., 2012; Valentine, 2010; Zhao et al., 2016). The interviewed stakeholders included wind developers, engineers & consultants, manufacturers, support agents, public administrators, and researchers (see Table 2).

The stakeholders were identified in the report published by the *Agência Brasileira de Desenvolvimento Industrial* (ABDI) from the Brazilian Ministry of Industry, Foreign Trade and Services, which maps the entire supply chain of the Brazilian wind industry, listing the key players (ABDI, 2014). In addition, during the 7th edition of Brazil Wind Power - Conference & Exhibition (Aug-Sep '16), the main authorities

and the most important executives of the sector were also identified. Through telephone calls, e-mails and direct contacts, 128 stakeholders were invited and 41 (32%) accepted to contribute to the study.

The semi-structured interviews were based on the categorization of barriers to RES penetration suggested by Painuly (2001) (see Table 3). Participants were asked openly about the existence of these barriers, according to their categories, and how they interfere in wind farm development nationally, as well as in the three main WE generation states in the Northeast of Brazil. Additionally, at the end of the interviews, participants were asked to confirm the mentioned barriers and explain which were of higher relevance to the development of onshore wind farms in Brazil. The interviews were supported by a protocol that guided the interviewer in conducting the open questionnaire, as well as in identifying the stakeholder profiles.

Table 2

Stakeholder category descriptions.

Stakeholder category	Description
Developers (D)	Heads of wind farm project development teams in energy companies.
Engineers & consultants (EC)	Heads of engineering or consulting teams in energy companies specialised in wind farm construction and operation.
Manufacturers (Mf)	Business directors of the main manufacturing companies linked to the local WE supply chain.
Support agents (Sa)	Managers of financial, regulatory and think tank institutions that support the development of wind farms.
Public administrators (Pa)	State or municipal public administrators who support the development of wind farms.
Researchers (R)	Senior researchers with experience on WE R&D.

Table 3
Barriers to renewable energy implementation (Painuly, 2001).

Barrier category	Barriers
Market Failures (MF)	(1) Highly controlled energy sector; (2) lack of awareness and information; (3) restricted access to technology; (4) lack of competition; (5) high transaction costs; (6) poor market infrastructure; (7) high investment requirements.
Market Distortions (MD)	(8) Favourable treatment to conventional energy; (9) taxes on RES; (10) non-consideration of externalities; (11) trade barriers.
Economic and Financial (EF)	(12) Economically not viable; (13) high discount rates; (14) high payback period; (15) market size small; (16) high cost of capital; (17) lack/inadequate access to capital; (18) lack of access to credit to consumers; (19) high up-front capital costs for investors; (20) lack of financial institutions and instruments.
Institutional (I)	(21) Lack of institutions and mechanisms; (22) lack of a legal/regulatory framework; (23) problems in realising financial incentives; (24) unstable macro-economic environment; (25) lack of involvement of stakeholders in decision making; (26) clash of interests; (27) lack of R&D culture; (28) lack of private sector participation; (29) lack of professional institutions.
Technical (T)	(30) Lack of standards, codes and certification; (31) lack of skilled personnel; (32) lack of operation and maintenance (O&M) facilities; (33) lack of entrepreneurs; (34) system constraints; (35) product unreliable.
Social (S)	(36) Lack of consumer acceptance of the product; (37) lack of social acceptance for some RES.
Other Barriers (OB)	(38) Uncertain governmental policies; (39) environmental; (40) high risk perception for RES; (41) lack of infrastructure.

3.2. Data collection and analysis

Between August and December 2016, 41 interviews were performed with relevant stakeholders from the Brazilian WE sector. From these interviews, 28 were carried out personally (in Brazil) and 13 through videoconference (from Portugal).

The interviews were based on a protocol organized after a detailed study of barriers to renewable energy implementation (Painuly, 2001), which ensured reliability (Yin, 2009). An informed consent was signed by both parties, namely to ensure the confidentiality of the information provided by the interviewees. The interviews were recorded and transcribed using appropriate analysis software (Express Scribe). Transcriptions were performed as soon after the end of the interview as possible, which allowed the constant comparison of responses (Eisenhardt and Graebner, 2007), as well as a first analysis of the collected data and the improvement of the subsequent interviews (Barratt et al., 2011; Strauss and Corbin, 2015).

The interviews lasted from 10 min to 1 h and 36 min, with an average of 40 min and a total of approximately 27 h and 41 min, resulting in 345 pages of text transcribed verbatim (Yin, 2009). The sample was large enough to reach theoretical saturation (Eisenhardt, 1989; Strauss and Corbin, 2015).

In addition to their overall knowledge about the sector, the interviewees also had a specific range of WE development experience in the top three WE generation states in the Northeast (see Table 4), some of them with experience in more than one state.

The qualitative data collected in the 41 interviews were analysed using a qualitative content analysis method (Schreier, 2012), with category construction and coding frame (Krippendorff, 2012; Neuendorf, 2016) considering all the categories of barriers proposed by Painuly (see Table 3) in four regions, the country and each of the three states. The consideration of the four regions is justified by the fact that some barriers are linked to national energy policies and regulations that

Table 4
Interviewed stakeholders per category and range of experience.

Stakeholder category (Sc)	Range of experience (Re)			
	Brazil (BRA)	Rio Grande do Norte (RN)	Bahia (BA)	Ceará (CE)
Developers (D)	13	8	8	6
Engineers & Consultants (EC)	11	6	3	8
Manufacturers (Mf)	2	1	1	2
Support agents (Sa)	8	7	6	7
Public administrators (Pa)	2	1	1	1
Researchers (R)	5	5	1	1
Total	41	28	20	25

govern overall WE diffusion in the country, while others are linked to state institutions.

The data were explored iteratively, going back and forth between the qualitative data and theoretical arguments (Strauss and Corbin, 2015). Considering the four regions, the analysis was divided in two stages: (1) within unit analysis, selecting and organizing the relevant data and searching for within unit patterns, and (2) cross-unit analysis, searching for cross-unit patterns (Barratt et al., 2011; Eisenhardt, 1989). The descriptive and simultaneous coding was performed using appropriate analysis software (Qiqqa).

4. Results

24 currently existing barriers to onshore wind farm implementation in Brazil were identified in the interviews. The interviewees classified 13 of these as having a national scope of impact, i.e., as hindering wind farm development nationally, and 11 as having a state scope of impact, i.e., with their occurrence depending on state-level WE diffusion structures. Moreover, the respondents indicated that 18 barriers existed since the early stages of development of the local WE sector, while six others had emerged only recently, and pointed out that 12 of the barriers are general, i.e., related to Brazil's overall economic context, and the remaining 12 are specific to the sector (see Table 5).

The interviews also revealed patterns of perception for the identified barriers according to stakeholder category (see Table 6).

At the end of the interviews the participants indicated which barriers had particular relevance in the development of onshore wind farms (see Fig. 2).

4.1. MARKET

The interviewees indicated an underdeveloped home wind industry, restricted access to wind turbine technology, and lack of information about wind potential as the market obstacles to developing wind farms in Brazil.

An underdeveloped home wind industry was the most frequently mentioned market barrier, with 39% of the respondents arguing that the wind supply chain remains relying on imported core materials and components, especially those required for the assembly and further maintenance of wind turbines. Concerns about the impact of an underdeveloped national wind industry on wind farm project development and operating maintenance, namely on addressing the potential need to quickly replace malfunctioning components to avoid losses, were expressed by a director from an engineering consulting company in the following way:

“(…) well, it is not like in Europe and North America where you call the supplier, a broken bearing is quickly replaced, and a project is not hurt by generation outages. In Brazil, downtimes are a serious matter.”

Tablee 5
Percentage of responses according to stakeholder range of experience.

Barriers (B)	Scope of Impact	Stakeholders RE			
		BRA (41)	RN (28)	BA (20)	CE (25)
MARKET (M)					
(M.1) Underdeveloped home wind industry (<i>specific</i>)	National	39%	32%	45%	36%
(M.2) Restricted access to wind turbine technology (<i>specific</i>)	National	27%	29%	35%	24%
(M.3) Lack of information about wind potential (<i>specific</i>)	State	12%	11%	0%	8%
ECONOMIC AND FINANCIAL (EF)					
(EF.4) Inadequate access to capital (<i>general</i>)	National	83%	79%	95%	88%
(EF.5) High cost of capital (<i>recent and general</i>)	National	29%	25%	40%	24%
(EF.6) Insufficient financial institutions (<i>general</i>)	National	24%	21%	30%	16%
INSTITUTIONAL (I)					
(I.7) Unstable macroeconomic environment (<i>recent and general</i>)	National	78%	56%	41%	46%
<i>Inadequate regulations</i>					
(I.8) Environmental license (<i>general</i>)	State	66%	64%	70%	64%
(I.9) Land regularization (<i>general</i>)	State	56%	46%	50%	56%
(I.10) Archaeological license (<i>general</i>)	National	51%	46%	70%	52%
(I.11) Lack of R&D culture (<i>general</i>)	National	32%	43%	25%	20%
<i>Lack of governmental institutions and mechanisms</i>					
(I.12) Lack of state public institutions capacity (<i>general</i>)	State	27%	25%	30%	20%
(I.13) Lack of governmental cooperation (<i>general</i>)	National	20%	18%	5%	16%
(I.14) Inadequate state secretary of energy (<i>specific</i>)	State	10%	14%	0%	8%
TECHNICAL (T)					
(T.15) Grid system capacity limitation (<i>recent and specific</i>)	State	100%			
(T.16) Lack of skilled personnel (<i>specific</i>)	National	56%	46%	65%	52%
(T.17) Insufficient O&M services (<i>specific</i>)	National	51%	46%	45%	48%
(T.18) Insufficient quality of wind turbines and blades (<i>specific</i>)	National	12%	18%	5%	4%
SOCIAL (S)					
(S.19) Local community opposition (<i>specific</i>)	State	59%	57%	35%	56%
OTHER BARRIERS (OB)					
<i>Poor infrastructure</i>					
(OB.20) Transmission (<i>recent and specific</i>)	State	100%			
(OB.21) Roads (<i>general</i>)	State	68%	75%	75%	56%
(OB.22) Communication (<i>general</i>)	State	17%	18%	20%	7%
<i>Uncertain governmental policies</i>					
(OB.23) Auction occurrence uncertainty (<i>recent and specific</i>)	National	63%	57%	60%	60%
<i>Environmental</i>					
(OB.24) Competition for land (<i>recent and specific</i>)	State	29%	29%	25%	20%

Restricted access to wind turbine technology was the second most cited market barrier. In 27% of the interviews, turbine manufacturers established in Brazil were reported as resisting the transfer of technology to support the construction and the operation and maintenance (O&M) of wind farms. This resistance makes wind developers dependent on turbine manufacturers because both the construction of heavily customized foundations and towers and O&M services require access to core technological information from the manufacturers. Highlighting this dependence, a director of a wind farm construction engineering company mentioned:

“In spite of the wind developer having the capital, from the moment the contract is signed, the developer becomes dependent on the turbine manufacturer – the manufacturer feels as project owner – if the developer is not able to bring the manufacturer to its side, project development is a losing battle.”

The lack of information about wind potential was the least reported existing market barrier. The interviewees identified it as an obstacle in the states of Rio Grande do Norte (11%) and Ceará (8%), where the wind resource maps developed by the states' electric utilities are outdated, hindering the prospection of new windy sites.

The three market barriers were pointed out by almost all stakeholder categories, except for lack of information, in the case of support agents, and restricted access to wind turbine technology, for public administrators. It is worth noting the significant proportions of researchers and developers that mentioned the existence of an underdeveloped home wind industry.

4.2. Economic and financial

The participants reported an inadequate access to capital, high cost of capital and insufficient financial institutions as the economic and financial obstacles to wind farm implementation in Brazil.

Inadequate access to capital was the most discussed economic and financial barrier. Among the interviewees, 83% mentioned that *Banco Nacional de Desenvolvimento Econômico e Social* (BNDES), the main institution responsible for providing public funding to support wind farm construction, has been too strict in the approval of loans, and that the loans are frequently paid late. A director of a local company that provides engineering services to wind farm developers described the problem in the following terms:

“(…) oftentimes the money from the BNDES loans is only received in the final stage of the construction of the wind farms – equity participation moves past 20, 30, 40, 50%, and ends up at 100% – some investors are getting very distrustful and are refraining from investing because of these delays.”

High cost of capital was the second most reported economic and financial barrier, with 29% of the interviewees mentioning how expensive it currently is to raise funding for wind farm development in Brazil, even from public development banks such as BNDES. The interviewees stated that attractive loan interest rates have not been available since 2015, with a direct impact on the increase in wind farm development costs, and that BNDES decreased the equity participation from 70% to 80% to not more than 50%. This means that the public funding did not exceed half of the construction costs. A head of renewable projects development in a foreign energy consulting company

Table 6
Barrier perception according to stakeholder category.

Barriers	Stakeholder Category	D (13)	EC (11)	M (2)	Sa (8)	Pa (2)	R (5)
MARKET (M)							
(M.1) Underdeveloped home wind industry		46%	18%	50%	25%	50%	80%
(M.2) Restricted access to wind turbine technology		38%	18%	50%	13%	0%	40%
(M.3) Lack of information about the wind potential		8%	9%	50%	0%	50%	20%
ECONOMIC AND FINANCIAL (EF)							
(EF.4) Inadequate access to capital		92%	82%	50%	100%	50%	60%
(EF.5) High cost of capital		31%	27%	0%	25%	0%	60%
(EF.6) Insufficient financial institutions		46%	18%	0%	25%	0%	0%
INSTITUTIONAL (I)							
(I.7) Unstable macroeconomic environment		92%	55%	50%	88%	100%	80%
<i>Inadequate regulations</i>							
(I.8) Environmental license		69%	82%	50%	50%	100%	40%
(I.9) Land regularization		85%	73%	50%	13%	0%	40%
(I.10) Archaeological license		69%	55%	50%	38%	100%	0%
(I.11) Lack of R&D culture							
<i>Lack of governmental institutions and mechanisms</i>							
(I.12) Lack of state public institutions capacity		38%	27%	0%	25%	0%	0%
(I.13) Lack of governmental cooperation		31%	18%	0%	13%	0%	20%
(I.14) Inadequate state secretary of energy		23%	9%	0%	13%	0%	20%
TECHNICAL (T)							
(T.15) Grid system capacity limitation		100%					
(T.16) Lack of skilled personnel		54%	64%	0%	38%	50%	100%
(T.17) Insufficient O&M services		62%	55%	0%	38%	50%	60%
(T.18) Insufficient quality of wind turbines and blades		23%	0%	0%	13%	0%	20%
SOCIAL (S)							
(S.19) Local community opposition		69%	45%	100%	38%	50%	60%
OTHER BARRIERS (OB)							
<i>Poor infrastructure</i>							
(OB.20) Transmission		100%					
(OB.21) Roads		77%	45%	100%	63%	50%	100%
(OB.22) Communication		31%	0%	0%	13%	0%	40%
<i>Uncertain governmental policies</i>							
(OB.23) Auctions occurrence uncertainty		85%	64%	50%	38%	50%	60%
<i>Environmental</i>							
(OB.24) Competition for land		38%	18%	50%	38%	0%	20%

commented, regarding this barrier:

“Lately, it has been increasingly difficult and selective to become a wind developer in Brazil, mainly due to the high levels of equity required.”

Among the cited economic and financial barriers, insufficient financial institutions was the least frequent (24%), with BNDES alone not being considered sufficient to fund wind farm developments throughout the country.

Except for the omission of high cost of capital and insufficient

financial institutions by manufacturers and public administrators, the three economical and financial barriers were mentioned by all stakeholder categories. In this category, it stands out that the inexistence of adequate access to capital was consensual among support agents and reported by the vast majority of developers and engineers & consultants.

4.3. Institutional

The respondents reported the unstable macroeconomic environment, inadequate regulations and lack of research and development (R & D) culture, as the institutional obstacles to wind farm implementation in Brazil.

The unstable macroeconomic environment currently experienced in Brazil was the most frequently mentioned institutional barrier. The ongoing economic crisis was regarded by 78% of the respondents as having affected WE implementation, along four aspects: demand for new wind farms, funding availability, unstable wind turbine prices, and lagging infrastructure reinforcements.

First, they observed that the economic crisis resulted in a reduction of industrial and commercial activity in the country, which consequently reduced the demand for electricity and the need to develop more wind farms. They also mentioned that the industrial and commercial slowdown limited the main sources of fiscal revenue, which led to a reduction in the capacity of public development banks to provide loans, forcing them to restrict the equity participation and increase the interest rates. They stressed as well that the uncertainty regarding the economic recovery has caused frequent fluctuations in the value of the Brazilian Real relative to the U.S. Dollar, affecting the prices of the contracts established with turbine manufacturers. Finally, they reported that public investment to reinforce infrastructure, especially the transmission grid investments urgently needed to accommodate more WE, had also been decreased due to the reduction in fiscal revenue, which consequently decreased the availability of public resources for investments of this magnitude.

The interviewees associated this critical economic scenario with the unstable political environment currently experienced by the country. A head of project development on a foreign energy company described the current economic and political context in the following terms:

“I am not optimistic in the short term. The Brazilian political instability has been constraining economic development, and affecting the organization of WE auctions.”

The inadequate regulations for obtaining approvals – land, environmental, and archaeological – to develop wind farms were the second most cited institutional barrier.

Regarding land regularization, in addition to mentioning that the states need to encourage the land owners to register their properties, the participants argued that the current legislation needs to be simplified in all three. A full professor and energy researcher from a public university stressed this problem:

“Registering a property requires going through national, state, and municipal procedures, which is time-consuming. For sure, land regularization is a huge bottleneck in the selection of sites to implement wind farms, especially in the areas away from the coast.”

For environmental licenses, despite multiple improvements carried out by the states, the respondents noted that further simplification of the process is still needed in the three states. In the case of archaeological licenses, 51% of the interviewees mentioned that due to the digging required for tower foundations, the current national legislation classifies wind farms in the highest level of archaeological impact. A director from an energy association noted:

“The *Instituto do Patrimônio Histórico e Artístico Nacional* (IPHAN) needs to recognize wind developers as partners in the discovery and

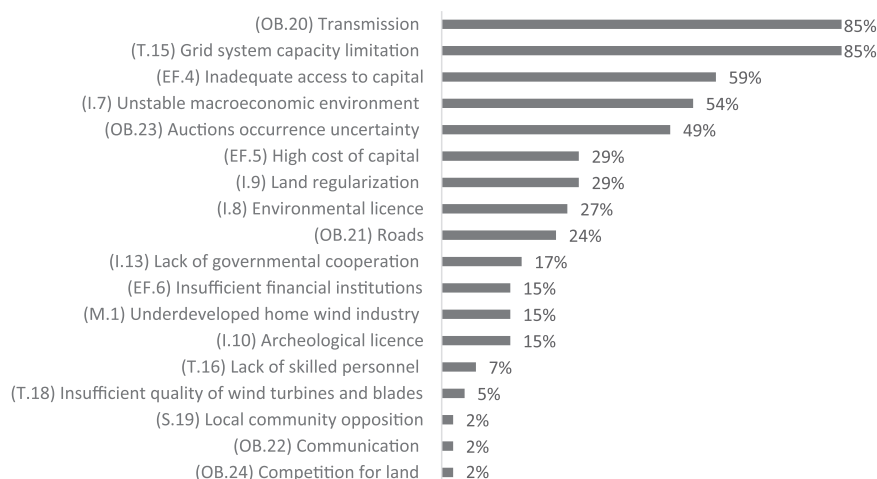


Fig. 2. Main barriers to onshore wind farm implementation in Brazil according to stakeholder perception.

protection of archaeological heritage, not as damaging agents. They need to rethink the current regulations and stop blocking wind farm construction.”

The lack of R&D culture was the third most reported institutional barrier, with 32% of the participants observing that it is generally absent at the country level, but especially in the Northeast region. The country lacks technological parks specifically designed to promote WE R&D and support the development of national wind technology. A director from a public development bank regretted the lack of R&D culture and the consequent absence of Brazilian wind technology, stating:

“For the future, WE should tend to keep an expressive growth in the country, but with foreign technology, which is deeply regrettable. We need to make up for lost time and create our national wind technology.”

The lack of governmental institutions and mechanisms was the least-cited existing institutional barrier. First, interviewees mentioned that the three states face limitations in terms of skilled personnel in charge of emitting licenses and approvals for wind farm development, at public institutions. This causes delays in the development processes, as stressed by a head of project development on an energy company:

“State public institutions lack workers, and licenses take a long time to be available. The wind developer normally needs one to two years to collect all the required approvals. Because of these delays, some projects are shut down due to the impossibility of meeting the energy auction deadlines.”

Second, 20% of the respondents agreed that federal government agencies and institutions with the responsibility for regulating and coordinating the Brazilian energy sector have failed to establish mechanisms to cooperate with wind developers and inform them in advance of regulatory changes. A director of a wind farm project development engineering company acknowledged the problem:

“(…) they changed the regulations and informed us on very short notice, at the same time that we had ongoing wind farm projects. They gave us no flexibility to adapt to the new rules.”

Finally, the interviewees mentioned that state energy secretaries had been failing in promoting WE investments, namely in the states of Rio Grande do Norte (14%) and Ceará (8%).

Land regularization, for public administrators, archaeological licensing, for researchers, and lack of governmental institutions and mechanisms, in the case of manufacturers and public administrators, were the only exceptions to the eight institutional barriers being reported by all stakeholder categories. The current unstable

macroeconomic environment and its consequences was consensually indicated as a barrier by public administrators, and by a vast majority of developers, support agents, and researchers.

4.4. Technical

As technical barriers, the participants indicated grid system limitations, lack of skilled personnel, insufficient O&M services, and unsatisfactory quality of wind turbines and blades.

Grid system capacity limitations were the most cited technical barrier. The participants consensually confirmed the recent existence of capacity restrictions to the integration of more WE in their grids for the three states. A director from a regional energy think tank noted:

“Just yesterday I received a notice that the Brazilian transmission system operator (TSO) is blocking the participation of wind farm projects from Rio Grande do Norte and Bahia in the next energy auction due to incapacity from both state grid systems to absorb more WE.”

The lack of skilled personnel was the second most reported technical barrier. 56% of the interviewees stated that, except for the civil construction aspect of wind farms, the national WE supply chain faces a shortage of specialized workers, particularly in the technical areas.

The insufficient availability of O&M services was the third most mentioned technical barrier, with 51% of the participants highlighting that the country is lacking O&M services, and that this scenario is worrisome due to the need to monitor and even repower the already large number of installed wind turbines. A director of a foreign wind turbine component manufacturer summarized the problem:

“Today, there is no single company in Brazil offering full O&M services to wind farms.”

The unsatisfactory quality of wind turbines and blades was the least mentioned existing technical barrier. According to 12% of the interviewees, foreign wind turbines and blades need to be better adapted to the conditions of local wind, which is more consistent and powerful in terms of occurrence and, consequently, speed. A director from a wind farm maintenance engineering company described the issue:

“The wind turbines commercialized here in Brazil were designed for European winds with more or less 30% of capacity factor. Here, especially in the Northeast region, it reaches 50%.”

In addition, the same director pointed out:

“The wind turbine operates more constantly here than in Europe, and the O&M schedule proposed by the manufacturer needs to be

different, the periods need to be shorter. However, this is not being done. The manufacturers need to have a higher regard for the clients, because you can see wind farms around with broken blades and turbines.”

The four technical barriers were noted by almost all stakeholder categories, with the exception of the lack of skilled personnel and insufficient O&M services, in the case of manufacturers, and the insufficient quality of wind turbines and blades, for engineers & consultants, public administrators, and manufacturers. It is worthy of note that the existence of grid system capacity limitations was consensual among all categories. In addition, the lack of skilled personnel was also reported by all the researchers, and most developers and engineers & consultants.

4.5. Social

Social barriers to the implementation of wind farms were reported by the interviewees as originating only from local communities living nearby windy sites, and not from general consumers.

This opposition has occurred in the three states, with the respondents arguing that near the coast opposition came from international NGOs, fishermen, and tourism entrepreneurs who claimed that wind turbines interfered with beach landscapes or with their economic activities. Regarding the inland areas, the interviewees mentioned that opposition occurs if the wind developers do not offer any benefits, or do not attend to the requests from poor local communities. The participants agree that these communities see wind projects as an opportunity to finally develop health posts, schools, libraries, public squares, sports courts, and other non-existent essential pieces of infrastructure. The interviewees also noted that social opposition sometimes delays wind farm construction.

This barrier was indicated by all stakeholder categories, without exception. For all manufacturers and most developers and researchers interviewed, community opposition is an important threat to onshore wind farm developments in the country.

4.6. Other barriers

“Other barriers” identified by the interviewees included poor infrastructure, uncertainty in the occurrence of auctions, and competition for land.

Poor infrastructure was the most frequently cited “other barrier”, especially regarding the availability of transmission lines and roads. The participants pointed out the poor transmission system across the Northeast region, especially in the three states, which currently have very low availability of substations and high voltage lines, in particular in the parts far from the coast. According to the participants, the Brazilian government has failed to promote efforts to build more lines, with the companies contracted to develop this infrastructure either quitting or completing the projects after the deadlines, leading to the postponement of the connections of the wind farms. A director from a WE project development engineering consulting company framed the problem in the following way:

“We have many transmission constraints, especially regarding the availability of connections. This means that we currently have wind farms that are implemented but are unable to dispatch electricity. In general, when you identify a good site, you will probably not find any close transmission lines, which will make the project unfeasible”.

The interviewees also reported that poor road infrastructure was a constraint in the three states. They mentioned that, with the exception of a few roads near the coast, in general they were not two-lane, making it difficult to transport the large wind components to farm sites. According to a director from a regional energy think tank:

“The major problem faced in the logistics of wind turbines and blades, is the fact that the roads in the region usually are not dual-lane. Usually they are one-lane, requiring a request to the public department of transportation to block the traffic in order to perform the transport. This is a bureaucratic and time-consuming process.”

Finally, regarding the poor communication infrastructure, the interviewees mentioned difficulties again across the three states in accessing the broadband internet connections required to allow real time communication of all the information related to wind farm operation. The participants described this connection as crucial, as the Brazilian TSO depends on real-time information to authorize electricity dispatch, and the commercial chamber also depends of that information to compute revenues. A head of project development on an energy company commented on these consequences:

“Because of the lack of communication, I have already seen a wind farm have its operation disabled by the TSO.”

The uncertainty in the occurrence of auctions was the second most cited “other barrier”. Despite the overall recognition of the current public auction system as the main driver of WE expansion in the country, offering wind developers long and stable Power Purchase Agreements (PPAs), 63% of the respondents reported that uncertainty in their occurrence has influenced negatively the interest of wind developers in keeping investing. A director from a WE project development engineering consulting company described the situation in the following terms:

“Between 2009 and 2015, the auctions occurred regularly. They ceased this year (2016) due to the political and economic crisis, which has reduced electricity demand in the country.”

Another participant, a director from a national energy association, described the confidence of wind developers in the Brazilian government and its auction system in the following way:

“(…) with the constant auction cancellations, the credibility of the government with wind developers has decreased significantly. It is a really dramatic situation.”

The interviewees mentioned that auction uncertainty was made worse by inadequate electricity expansion planning, which only considers short-term and not long-term electricity demand evolution. Moreover, they stressed that this barrier affects the national wind industry, which depends on the existence of a steady stream of PPAs to keep supplying its products and services. The same director from a national energy association added:

“We have information from some turbine manufacturers that they will face a production capacity idleness above 60% in 2018. If this is not quickly reversed, it will be hard for these manufacturers to maintain production in the country.”

Competition for land was the least-cited existing “other barrier”. The interviewees reported that currently the three states have their best wind areas already taken by wind farms or featuring high values due to tourism activities, especially along the coast. A director from a national energy system operator described the situation, stating that:

“(…) along the coast it is very hard to find good sites at competitive prices because the owners are overvaluing their properties.”

Except for poor communication infrastructure, for engineers & consultants, manufacturers and public administrators, and land competition, in the case of public administrators, all “other barriers” were mentioned by all stakeholder categories. Due to the grid system capacity limitations, poor transmission infrastructure was consensual as a barrier across all stakeholder categories. In addition, the uncertainty in the occurrence of auctions was acknowledged by a clear majority of developers, as well as most engineers & consultants and researchers.

5. Discussion

The very promising and distinguished future of WE in Brazil became true (Filgueiras et al., 2003). However, this study has confirmed that 24 barriers, from six categories, have played a role in hindering the successful large-scale implementation of onshore wind farms in the country.

With few exceptions, stakeholders from all categories widely mentioned these 24 barriers. It is remarkable that some barriers such as inadequate access to capital, unstable macroeconomic environment, auction uncertainty, inadequate regulations, poor roads, and especially insufficient transmission infrastructure and grid capacity limitations, had an expressive consensus among the interviewed parties.

Among the barriers with high consensus are those that the interviewees reported as most striking in the development of wind farms nationally, some related to Brazil's overall economic context, and thus with general impact, and others with specific impact on the wind sector: the inadequate access to capital associated with the high cost of capital (a general problem for the Brazilian economy); the unstable macroeconomic environment (another general problem) and its main consequence, auction uncertainty (a specific problem for the Brazilian wind sector); and the poor transmission infrastructure and the related current grid system constraints (also a specific problem for the Brazilian wind sector). In general, the interference of the barriers on the implementation of wind farms was increasing while the fast and expressive WE took place. In fact, the local energy market institutions (supply chain manufacturers, development banks, licensing and governmental agencies) and the national infrastructure (grid, road and communication) did not develop at the same pace as the Brazilian wind farms, failing to provide essential services inherent to the development of these energy facilities.

Regarding market barriers, the dependence of the Brazilian wind supply chain on imported key wind turbine components, especially the electromechanical parts inside the nacelle, has acted as a factor inhibiting the reduction of the high WE development costs (Yuan et al., 2014), which is important to enable the competitiveness and the growth of the contribution of WE to the Brazilian energy matrix (Li, 2010). However, this dependence has been decreasing because BNDES Finame – the most important public funding instrument used by wind developers in Brazil to finance machines and equipment – has evolved in terms of access rules, requiring that wind turbines deployed on Brazilian wind farms include, at least in part, locally produced high-tech components, which has naturally increased the establishment and expansion of foreign manufacturers in the country and fostered, as well, the emergence of national manufacturers (Tolmasquim, 2016). Nonetheless, government taxes of 26.5% applied to local turbine production, in comparison with the 14% applied to imported turbines, are slowing down the consolidation and development of the Brazilian wind industry (ABIMAQ, 2013). In addition, it is important to highlight the need that this supply chain, especially the manufacturers and assemblers of large and weighty wind components, and the suppliers of subcomponents, expand towards the Northeast region, closest to the wind sites, seeking to reduce the supply chain's current geographic dispersion and consequent logistics difficulties (ABDI, 2014).

The resistance of turbine manufacturers to cooperate also contributes to jeopardize the successful operation of the wind farms, especially in a current national scenario with low availability of skilled personnel and O&M services, which consequently affects the dissemination of knowledge fundamental to local wind technology development (He et al., 2016). The outdated wind potential information, especially in Rio Grande do Norte and Ceará, also represents a difficulty for local wind developers as they seek to identify new sites for wind farm construction (Sawangphol and Pharino, 2011).

Among the economic and financial barriers, the current high cost of capital and low equity participation, associated with a history of delays in transferring the loans, have indisputably made it unattractive to

invest in new wind farms in the country. Attractive financial loans are essential to deal with the high up-front costs required by wind farm implementations (Beck and Martinot, 2004; Celiktas and Kocar, 2009; NFD et al., 2013; Yue et al., 2001), and their availability is important to speed up RES developments (Liu et al., 2002; Mignon and Rudinger, 2016). Despite being the largest public development bank, with an extremely large investment capacity, BNDES alone has been considered operationally unable to support the increasing onshore wind farm implementation across the country.

Concerning institutional barriers, the current unstable macroeconomic environment in Brazil, which is a general barrier to national economic development, can be considered the main barrier to wind farm implementation in the country recently. The economic crisis experienced nationally decreased the government's capacity to offer competitive loans to wind developers, perform investments to reinforce the existing critical transmission infrastructure, as well as maintain the value of the local currency stable relative to the U.S. Dollar. The effects of the crisis have a negative impact on new wind farm projects, which mainly require loans and transmission lines, as well as on existing wind farms, which fundamentally need a local currency that is valued and stable relative to the U.S. Dollar, in order to pay wind turbine manufacturers within their budgets. Because turbine supply contracts are normally established in Euros or U.S. Dollars (Friebe et al., 2014; Schaefer et al., 2012), if the local currency fluctuates drastically, the profitability of wind farms may be jeopardized. It is important to acknowledge that just the wind turbines and equipment account for more than 70% of the total cost of a wind farm (Blanco, 2009; Liu et al., 2002).

Above all, the ongoing crisis has affected the demand for electricity, causing a reduction in the auctions and consequently in the development of new wind farms across the country (Bird et al., 2005; Jagadeesh, 2000). The auctions are planned based on short-term demand forecasts informed by the electricity retailers in the state, via the federal government. In these forecasts, retailers have been adopting a conservative stance, and have not considered a potential recovery of economic growth, and consequently of electricity consumption, that would reverse the effect of the recent 2014 economic crisis on WE auction occurrence. In addition to the impact of the economic crisis on the regulated market and the frequency of auctions, the electricity consumers in the free market (usually large industrial and retail companies) – a growing alternative for wind developers to establish PPAs – have resisted medium-long term electricity supply contracts in a period of economic recession, leading to an increase in revenue uncertainty.

Anyway, the occurrence of auctions to contract large wind farms should be independent from national electricity consumption growth, since the main electricity source in Brazil – hydropower – suffers from frequent capacity losses due to droughts, and its typical alternative – thermoelectric supply – generates electricity with a tariff that is much higher than WE's. In fact, the expansion of WE in the country is recommended to diversify the current energy matrix not only due to its low tariffs, but also to the increasing ability to predict when and how much WE can be generated, ensuring security of supply (de Jong et al., 2017, 2016).

Furthermore, the implementation of onshore wind farms in the country can be stimulated by making the current electricity free market legislation (ANEEL, 2018a) more flexible, namely by: decreasing the contractual power limit (currently 500 kW), in order to offer consumers that require less power, in particular Brazilian small and medium-sized enterprises (SMEs), the chance to buy electricity direct from wind farms at more competitive tariffs; and by encouraging large companies to build their own wind farms, becoming self-producers and selling their generation surplus in the free market (as in the pioneer case of Honda Motors in Brazil), helping to consolidate this market as more wind farms are implemented.

Another alternative to be considered, to keep encouraging the implementation of WE in the country, is the liberalization of the retail

market. In this scenario, households can choose which retailer they want to buy electricity from, as already happens in several European countries. Such liberalized market provides end-consumers the opportunity to select a retailer that sells, for instance, greener and more affordable electricity – as is the case of the Brazilian Northeast WE nowadays. The need to find alternatives to resume the growth in the implementation of onshore wind farms is also important to drive a market demand that is fundamental to support national WE supply chain development (He et al., 2016).

The reported difficulties with environmental and archaeological licensing and land regularization need to be urgently mitigated. Still prior to wind farm construction, these authorizations are required to request loans from BNDES and to participate in public auctions. During construction, especially in the case of the environmental and archaeological licenses, the related inspections carried out by the public licensing bodies need to be performed appropriately, namely avoiding unnecessary interruptions and consequently risking hurting the confidence of the wind developer (Duc Luong, 2015).

The lack of R&D culture in the country has contributed to the current status of underdevelopment of the home wind industry (Li, 2010; Martins et al., 2011; Sawangphol and Pharino, 2011; Zhou et al., 2012), leaving onshore wind farm developers in the country dependent on imports (Huang et al., 2013; Klagge et al., 2012; Walwyn and Brent, 2015; Zhao et al., 2014, 2013), and causing the profitability of Brazilian wind farms to be highly affected by U.S. Dollar exchange variations. Moreover, this weak R&D environment will continue to limit the “tropicalization” of wind technology (i.e., the adaptation of equipment to the characteristics of Brazil), which would be essential to keep adapting it to the specific wind conditions of Brazil.

The lack of cooperation between market regulators and wind developers, and the lack of support and capability from specific relevant governmental entities, have made it difficult for wind developers to collect all the licenses and approvals required to participate on the auctions, as well as to meet the generation deadlines defined in the PPAs. Cooperating regulators and specialized and proactive governmental institutions are fundamental for an efficient wind farm implementation across the country (El Fadel et al., 2013; Li, 2010; Tang et al., 2013).

In terms of technical barriers, the current grid capacity limitations are particularly salient and have constrained wind farm expansion in the country, especially in the states with poor transmission infrastructure. Even if the economy were to enter a period of fast recovery and the auctions to restart again with appropriate frequency, PPAs for new wind farms in the states of Rio Grande do Norte and Bahia would not be possible due to the incapacity of the grids to deliver the generated electricity. Nevertheless, at least for the wind farms already in place, the Brazilian TSO has guaranteed the grid access necessary for stability in the transmission of their generation, avoiding wind curtailment and the consequent revenue losses (Gatzert and Kosub, 2016; Kaldellis et al., 2004; Klessmann et al., 2008; Zeng et al., 2014). The lack of skilled personnel, especially in O&M services, has also been a reason for concern among wind farm owners in the country. Wind farm construction started back in 2005, and in recent years many farms have begun to complete one decade of operation, and naturally to require O&M services provided by skilled personnel, whose absence compromises sustainability in a growing industry (Friebe et al., 2014; Huang et al., 2013; Klessmann et al., 2011). This lack of skilled personnel with high expertise in wind technology in fact hinders the whole expansion of the local WE industrial cluster, fundamental to keep reducing the dependence on foreign technology (He et al., 2016). The need to adapt turbine technology to local wind conditions, in order to avoid downtimes and increase the capacity factor and lifetime (Sawangphol and Pharino, 2011; Yuan et al., 2014), is still another prominent technical issue in the country.

Regarding social barriers, the resistance from local communities has had an impact in the analysed states, in the worst cases leading to

delays in the construction of wind farms (Agterbosch et al., 2009; Aitken et al., 2008; Fischlein et al., 2010; Mulvaney et al., 2013; Toke et al., 2008). The opposition from local communities has been frequent in coastal areas, due to a local perception that wind turbines interfere with the natural landscape and consequently with economic activities, in particular tourism, which is one of the main economic activities in the states of Rio Grande do Norte, Bahia and Ceará. The local landscapes are perceived by many as perfect beauty (Betakova et al., 2015; Pasqualetti, 2000; Wolsink, 2007), and their disruption by wind turbines is believed to hamper tourism activities (Kucukali, 2016; Sperling et al., 2010). Local resistance was also observed in inland areas, as part of the bargaining for improvements to municipal infrastructures, although less severely than in coastal areas.

Among “other barriers”, poor infrastructure conditions, in particular insufficient access to the transmission network, have undoubtedly been the major constraints to the development of new wind farms in the three states. Additional investment efforts by wind developers may allow them to overcome road and communication infrastructure restrictions, but given the magnitude of transmission construction costs, without public investment it is impossible to build the long-distance, high voltage transmission lines required to cope with the overloaded grid capacity (Herran et al., 2016; Swisher, 2009). The uncertainty in the occurrence of auctions has also affected wind developers, as well as the other companies that are part of the national WE supply chain, which highly depends on a stable market demand to keep producing and avoiding idle capacity (Lewis and Wiser, 2007). In the case of small to medium size wind developers, the financial resources that have to be committed to prepare a wind farm project may compromise their financial health when auctions are postponed. In this unpredictable investment context, only large developers can sustain long planning cycles and cope with the uncertainty in auction occurrence (Stenzel and Frenzel, 2008). For this reason, instead of considering additional expansion, namely to bring core components to be produced locally, manufacturers have been looking at potential reductions or even shutting down their activities in the country. Finally, the competition for coastal properties, due to the concentration of wind farms along the coast, has led to excessively high prices for available windy sites, and a recent trend of migration of wind farm investment to inland areas, decreasing the number of new wind farms built near the coast.

Even acknowledging their ability to interfere, barriers such as the following do not feature a significant impact in the development of the Brazilian wind farms: (Market) restricted access to wind turbine technology, lack of information about the wind potential; (Institutional) lack of R&D culture, lack of state public institutions capacity, inadequate state secretary of energy; (Technical) insufficient O&M services, lack of skilled personnel, insufficient quality of wind turbines and blades; (Social) local community opposition; (Other barriers) lack of communication infrastructure and competition for land. Nevertheless, the mitigation of these barriers, as well as the main ones, certainly will create a very welcoming investment atmosphere to expand the development of onshore wind farms in the country.

This study identified the occurrence in Brazil of 24 of the 41 barriers to RES implementation outlined by Painuly (2001), which suggests that the absence of the remaining barriers, at earlier or more recent stages of WE diffusion in the country, has allowed it to develop fast and expressively.

Among the barriers absent since early stages, it is worthwhile pointing out the non-existence of a highly controlled energy sector, which means that a legal framework to support RES investments has been in place (Beck and Martinot, 2004), as well as a need recognized by the local government to establish alternatives to electricity generation from conventional sources (Li et al., 2014; Tang et al., 2013). In addition, the omission of references to market distortions by the interviewees is also remarkable. Such absence points to the existence of a reverse auction mechanism (support scheme) that offers identical selling possibilities to WE in comparison with conventional sources,

especially in terms of remuneration tariffs (Beck and Martinot, 2004; Georgiou et al., 2008; Mezher et al., 2012; Vidadili et al., 2017), providing wind farms an opportunity to commercialize their generation in the local energy market (Afsharzade et al., 2016; De Melo et al., 2016; del Rio and Tarancon, 2012; Lema and Ruby, 2007; Liu and Li, 2011; Osmani et al., 2013; Schaefer et al., 2012). In spite of the existence of identical selling opportunities, as reported by the participants, it is important to note that the current support scheme prevents appropriate evaluation and does not consider the social, environmental and transmission externalities, effectively providing conventional sources a cost advantage in the country (de Jong et al., 2015).

Other barriers absent at earlier stages emerged only more recently, such as the contribution of economic growth to increasing electricity demand and ensuring continuous and stable energy auctions at a national level. This early positive scenario led to the conclusion of many PPAs and incentivized the development of many wind farms in the country (Barradale, 2010; Darmani et al., 2014). In that context of stability in the occurrence of energy auctions, the government was also experiencing a significant financial health, which allowed it to offer loans with low interest rates and high equity participation, increasing even more the incentives to the development of wind farms (De Melo et al., 2016; Kar and Sharma, 2015; Rickerson et al., 2013). At earlier stages, two other factors jointly facilitated the fast expansion: the high availability of good wind sites near the coast, and the consequent feasibility of access to the transmission network (Baringo and Conejo, 2012; Mentis et al., 2015; Wang et al., 2012), due to the fact that the transmission network in coastal areas is reinforced in order to be able to supply the largest electricity consumption centres which are located there.

6. Conclusions and policy recommendations

Focusing on the Brazilian case of fast and expressive WE diffusion, this study identifies barriers to large-scale onshore wind farm implementation. The study included interviews with various stakeholders from the local WE sector, with expertise in wind farm development across the country, and especially in the three Northeast states that feature highest WE generation. Most barriers were acknowledged by all stakeholder categories, which shows a widely shared understanding of what is happening in the sector by all its key players.

Among the 24 barriers identified, the interviewees classified 13 as having a national scope of impact, and 11 as having a state scope. The barriers with national scope, hindering implementation across the whole country, differ from those with state scope, which need state-level analysis to confirm whether they interfere or not with wind farm development. Moreover, the interviewees pointed out that 12 of the barriers are general, i.e., related to Brazil's overall economic context, and the remaining 12 are specific to the sector.

The participants also classified six barriers as having a recent history of occurrence, which means that at earlier stages their absence may have acted to boost onshore wind farm implementation in Brazil. The interviewees made clear that these barriers, especially the difficulty in connecting new wind farms to the transmission network, the unattractive loan conditions with high interest rates and low equity participation, and the unstable macroeconomic environment in its relation with the uncertain occurrence of auctions are those that most severely threaten the continuity of the fast and expressive WE diffusion observed in the country.

Poor transmission infrastructure has been recognized as the barrier with the highest impact. The existing grid capacity limitations, especially in the Northeast states of Rio Grande do Norte and Bahia, prevent the development of new wind farms. In the upcoming years, if the national government does not support the construction of new transmission lines and the reinforcement of the existing ones, there will be no high-voltage transmission capacity available across the country to accommodate generation expansion.

Unattractive loan conditions, one of the 12 general barriers, were considered the barrier with the second highest impact. With the exception of very few wind developers, supported by foreign investment funds, the interviewees have observed a generalized difficulty in raising the vast amount of financial resources required to cope with the very high up-front costs in competitive terms.

The unstable macroeconomic environment, also one of the 12 general barriers, was considered the barrier with the third highest impact, due to its direct relation with the uncertainty in the auctions, one of the barriers specific to the WE sector. In periods of economic stagnation or decline, electricity consumption tends to decrease, especially in industry and commerce. With an ongoing economic crisis, and assuming its maintenance for the next few years, the Brazilian government has declared the expansion of WE contracts unnecessary. However, the frequent reduction of the capacity available from hydropower plants and use of thermoelectric generation as an alternative, could be addressed by the currently tariff-competitive and predictable WE generation, thus providing the government an important motivation for keeping promoting auctions even when the economy does not suggest an electricity consumption increase.

The free market provides another important alternative to stimulate the implementation of onshore wind farms in the country, through a revision of the current legislation, which restricts the participation of several potential consumers. Policy changes may allow attracting to this market a larger consumer base, which may naturally select WE – one of the most tariff-competitive electricity sources in the country nowadays. On the other hand, more WE may become available in the free market, to satisfy this increasing consumer base, if more large companies are encouraged to become self-producers and sell their surplus in the market.

The liberalization of the retail market is another option of interest to keep promoting the implementation of large onshore wind farms across the country. However, the current long-term contracts signed between the government and the monopolistic state retailers, and a possible lack of political will, may be powerful impediments to this opening of the market. A scenario under which household consumers can decide to buy electricity from retailers that sell greener and lower tariff energy can thus take a long time to materialize.

Additionally, macroeconomic instability has contributed to the emergence of other barriers, such as an impoverished transmission infrastructure and an inadequate access to capital. This instability affects the national public financial soundness, which is essential for the government to be able to support infrastructure reinforcement and provide competitive funding.

In spite of the uncertainty created by the set of identified barriers regarding the future of WE utilization in Brazil, all the interviewees revealed optimism, believing a turnaround of the economy to be soon on its way, and the growth in electricity consumption to be soon resumed, leading periodic energy auctions to be restored, as well as competitive public funding and transmission infrastructure to be reinforced.

Nevertheless, further questions arise that might have a decisive impact on the future of WE in Brazil: How long will it take for a sustained economic recovery to happen in Brazil? How long will political instability persist in the country, holding back the desired economy recovery? How long are wind manufacturers and developers interested in implementing wind farms willing to wait for this recovery? If manufacturers and developers move their attention to other markets what will happen to an industry that took years to reach this level of development?

Seeking to avoid a pessimistic response to these questions, the government can implement efforts to mitigate the 24 identified barriers through public policies. Aiming at providing guidance in the definition of policies to overcome those barriers, 13 recommendations emerged from the analysis of the interviews, focused on establishing development stability and consequently promoting the sustainability of the

Brazilian WE sector. Considering first the barriers with highest impact, it would be advisable to implement the recommendations according to the following priority:

- (i) Expand the *Programa de Aceleração do Crescimento* (PAC) initiative promoted by the federal government, to invest further in infrastructures (high voltage transmission lines, substations, and roads) in the regions with windy sites, aiming at enabling future development of wind farms;
- (ii) Implement specific legislation to facilitate competitive funding for RES projects, ensuring the debureaucratization of the credit granting processes and the existence of attractive conditions (low taxes and high equity participation), including opening the market to foreign institutions willing to fund RES;
- (iii) Promote WE expansion independently of the level of economic growth, so that even when electricity consumption does not increase, auctions for wind farms still occur, aiming at promptly reducing the use of expensive thermoelectric plants and gradually decreasing the dependence on hydroelectric power;
- (iv) Make the current free market legislation more flexible, to allow attracting and retaining more consumers, namely SMEs;
- (v) Create specific legislation to encourage large companies to become WE self-producers and stimulate their participation in the free market;
- (vi) Liberalize the electricity retail market, creating the conditions for household consumers to have the opportunity to choose a retailer that supplies green and tariff-competitive WE;
- (vii) Review the incentives to WE, taking especially into consideration the externalities of all energy sources;
- (viii) Implement federal legislation to standardize and simplify the processes of land regularization, and environmental and archaeological licensing, required for wind farm development, improving efficiency while still addressing environmental and archaeological concerns;
- (ix) Create specific channels of cooperation between the federal government and WE generation states, in partnership with local governments and the *Associação Brasileira de Energia Eólica* (ABEEólica), to provide instructional support for the development of wind farms;
- (x) Establish a package of incentives, such as tax exemptions and competitive public credit, to encourage Brazilian companies to integrate the national WE supply chain, e.g., construction companies for tower and blade production, metalworking companies for turbine components production, and electric generator factories or aeronautic companies for wind turbines production;
- (xi) Expand technical training programs in the Federal Institutes of Education, Science and Technology in partnership with local universities, foreign technology institutes, the *Serviço Nacional de Aprendizagem Industrial* (SENAI), turbine manufacturers and wind developers, to attend to the local wind industry needs for skilled human resources;
- (xii) Create WE technology parks, led by the state's research foundations, in partnership with turbine manufacturers, federal universities, foreign technology institutes and ABEEólica, to foster wind technology R&D efforts that promote the national production of high-tech parts for wind turbines, blades and towers;
- (xiii) Create a federal program led by the *Instituto Nacional de Pesquisas Espaciais* (INPE) and the *Empresa de Pesquisa Energética* (EPE) in partnership with energy utilities, federal universities, and state energy secretaries, to update the detailed wind atlas for each state with WE potential, prioritizing windy sites, taking into consideration existing infrastructures (roads, transmission lines and communication services), and making the information publicly available online.

In addition to contributing to support further research, policy

making, and wind farm project strategy design, on topics related to overcoming barriers to the sustainability of large-scale WE implementation efforts in Brazil, this study also informs other countries, especially developing economies with recent histories of WE diffusion, and the intention to increase its utilization quickly and expressively, about the barriers to onshore wind farm implementation that they will probably see emerge. This generalization objective would benefit from further individual and comparative studies considering other cases of fast and expressive WE expansion.

Acknowledgements

The authors gratefully appreciate the financial support provided by the European Commission, through the IBRASIL Project – “Inclusive and Innovative Brazil”. We thank Prof. João Abel Peças Lopes, University of Porto, Prof. Paula Fernanda Varandas Ferreira, University of Minho, Prof. Eurico Vasco Amorim, University of Trás-os-Montes e Alto Douro, Carlos Alberto Pereira, MIT Portugal, and the journal reviewers, for helpful suggestions and comments. This work was partially financed by the ERDF – European Regional Development Fund through the COMPETE Programme (operational programme for competitiveness) and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within projects «UID/EEA/50014/2013» and «FCOMP-01-0124-FEDER-037281».

References

- ABDI, 2014. Mapeamento da cadeia produtiva da indústria eólica no Brasil. Agência Brasileira de Desenvolvimento Industrial, Brasília, pp. 147.
- ABEEólica, 2017. Boletim Anual de Geração Eólica 2018. Associação Brasileira de Energia Eólica, São Paulo, pp. 31.
- ABEEólica, 2018. Boletim Anual de Geração Eólica 2017. Associação Brasileira de Energia Eólica, São Paulo, pp. 27.
- ABIMAQ, 2013. Panorama da indústria brasileira na cadeia de subfornecedores. Associação Brasileira da Indústria de Máquinas e Equipamentos, Fórum Nacional Eólico, Salvador.
- Afsharzade, N., Papzan, A., Ashjaee, M., Delangizan, S., Van Passel, S., Azadi, H., 2016. Renewable energy development in rural areas of Iran. *Renew. Sustain. Energy Rev.* 65, 743–755.
- Agterbosch, S., Meertens, R.M., Vermeulen, W.J.V., 2009. The relative importance of social and institutional conditions in the planning of wind power projects. *Renew. Sustain. Energy Rev.* 13, 393–405.
- Aitken, M., McDonald, S., Strachan, P., 2008. Locating ‘power’ in wind power planning processes: the (not so) influential role of local objectors. *J. Environ. Plan. Manag.* 51, 777–799.
- JBSOD, Andrade Guerra, Dutra, L., NBC, Schwinden, Andrade, S.Fd, 2015. Future scenarios and trends in energy generation in Brazil: supply and demand and mitigation forecasts. *J. Clean. Prod.* 103, 197–210.
- ANEEL, 2018a. Ambiente de Contratação Livre (ACL). Brasília: Agência Nacional de Energia Elétrica.
- ANEEL, 2018b. Resultados de Leilões. Brasília: Agência Nacional de Energia Elétrica.
- Aquila, G., EdO, Pamplona, Queiroz, A.Rd, Rotela Junior, P., Fonseca, M.N., 2017. An overview of incentive policies for the expansion of renewable energy generation in electricity power systems and the Brazilian experience. *Renew. Sustain. Energy Rev.* 70, 1090–1098.
- Baringo, L., Conejo, A.J., 2012. Transmission and wind power investment. *IEEE Trans. Power Syst.* 27, 885–893.
- Barradale, M.J., 2010. Impact of public policy uncertainty on renewable energy investment: wind power and the production tax credit. *Energy Policy* 38, 7698–7709.
- Barratt, M., Choi, T.Y., Li, M., 2011. Qualitative case studies in operations management: trends, research outcomes, and future research implications. *J. Oper. Manag.* 29, 329–342.
- Barroso, L., Rudrick, H., Sensfuss, F., Linares, P., 2010. The green effect. *IEEE Power Energy Mag.* 8, 22–35.
- Beck, F., Martinot, E., 2004. Renewable energy policies and barriers. *Encycl. Energy* 5, 18.
- Betakova, V., Vojar, J., Sklenicka, P., 2015. Wind turbines location: how many and how far? *Appl. Energy* 151, 23–31.
- Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., Parsons, B., 2005. Policies and market factors driving wind power development in the United States. *Energy Policy* 33, 1397–1407.
- Blanco, M.I., 2009. The economics of wind energy. *Renew. Sustain. Energy Rev.* 13, 1372–1382.
- Brannstrom, C., Gorayeb, A., de Sousa Mendes, J., Loureiro, C., Meireles, A.Jd.A., Silva, E.Vd, et al., 2017. Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state. *Renew. Sustain. Energy Rev.* 67, 62–71.

- Celiktas, M.S., Kocar, G., 2009. A quadratic helix approach to evaluate the Turkish renewable energies. *Energy Policy* 37, 4959–4965.
- Changliang, X., Zhanfeng, S., 2009. Wind energy in China: current scenario and future perspectives. *Renew. Sustain. Energy Rev.* 13, 1966–1974.
- Da Silva, N.F., Rosa, L.P., Araújo, M.R., 2005. The utilization of wind energy in the Brazilian electric sector's expansion. *Renew. Sustain. Energy Rev.* 9, 289–309.
- da Silva, N.F., Rosa, L.P., Vasconcelos Freitas, M.A., Pereira, M.G., 2013. Wind energy in Brazil: from the power sector's expansion crisis model to the favorable environment. *Renew. Sustain. Energy Rev.* 22, 686–697.
- Darmani, A., Arvidsson, N., Hidalgo, A., Albers, J., 2014. What drives the development of renewable energy technologies? Toward a typology for the systemic drivers. *Renew. Sustain. Energy Rev.* 38, 834–847.
- de Jong, P., Dargaville, R., Silver, J., Utembe, S., Kiperstok, A., Torres, E.A., 2017. Forecasting high proportions of wind energy supplying the Brazilian Northeast electricity grid. *Appl. Energy* 195, 538–555.
- de Jong, P., Kiperstok, A., Sánchez, A.S., Dargaville, R., Torres, E.A., 2016. Integrating large scale wind power into the electricity grid in the Northeast of Brazil. *Energy* 100, 401–415.
- de Jong, P., Kiperstok, A., Torres, E.A., 2015. Economic and environmental analysis of electricity generation technologies in Brazil. *Renew. Sustain. Energy Rev.* 52, 725–739.
- de Jong, P., Sánchez, A.S., Esquerre, K., Kalid, R.A., Torres, E.A., 2013. Solar and wind energy production in relation to the electricity load curve and hydroelectricity in the northeast region of Brazil. *Renew. Sustain. Energy Rev.* 23, 526–535.
- De Melo, C.A., Jannuzzi, G.D.M., Bajay, S.V., 2016. Nonconventional renewable energy governance in Brazil: lessons to learn from the German experience. *Renew. Sustain. Energy Rev.* 61, 222–234.
- del Rio, P., Tarancon, M.A., 2012. Analysing the determinants of on-shore wind capacity additions in the EU: an econometric study. *Appl. Energy* 95, 12–21.
- Dester, M., Andrade, M.T.O., Bajay, S.V., 2012. New renewable energy sources for electric power generation in Brazil. *Energy Sources, Part B: Econ., Plan., Policy* 7, 390–397.
- do Valle Costa, C., La Rovere, E., Assmann, D., 2008. Technological innovation policies to promote renewable energies: lessons from the European experience for the Brazilian case. *Renew. Sustain. Energy Rev.* 12, 65–90.
- Duc Luong, N., 2015. A critical review on potential and current status of wind energy in Vietnam. *Renew. Sustain. Energy Rev.* 43, 440–448.
- Eisenhardt, K.M., 1989. Building theories from case study research. *Acad. Manag. Rev.* 14, 532–550.
- Eisenhardt, K.M., Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. *Acad. Manag. J.* 50, 25–32.
- El Fadel, M., Rachid, G., El-Samra, R., Boutros, G.B., Hashisho, J., 2013. Knowledge management mapping and gap analysis in renewable energy: towards a sustainable framework in developing countries. *Renew. Sustain. Energy Rev.* 20, 576–584.
- Eleftheriadis, I.M., Anagnostopoulou, E.G., 2015. Identifying barriers in the diffusion of renewable energy sources. *Energy Policy* 80, 153–164.
- EPE, 2018. Brazilian Energy Balance: Year 2017. Empresa de Pesquisa Energética, Rio de Janeiro, pp. 292.
- Filgueiras, A., eSilva, T.M.V., 2003. Wind energy in Brazil - Present and future. *Renew. Sustain. Energy Rev.* 7, 439–451.
- Fischlein, M., Larson, J., Hall, D.M., Chaudhry, R., Peterson, T.R., Stephens, J.C., et al., 2010. Policy stakeholders and deployment of wind power in the sub-national context: a comparison of four US states. *Energy Policy* 38, 4429–4439.
- Friebe, C.A., Von Flotow, P., Täube, F.A., 2014. Exploring technology diffusion in emerging markets - the role of public policy for wind energy. *Energy Policy* 70, 217–226.
- Gatzert, N., Kosub, T., 2016. Risks and risk management of renewable energy projects: the case of onshore and offshore wind parks. *Renew. Sustain. Energy Rev.* 60, 982–998.
- Geller, H., Schaeffer, R., Szklo, A., Tolmasquim, M., 2004. Policies for advancing energy efficiency and renewable energy use in Brazil. *Energy Policy* 32, 1437–1450.
- Georgiou, P., Tourkolias, C., Diakoulaki, D., 2008. A roadmap for selecting host countries of wind energy projects in the framework of the clean development mechanism. *Renew. Sustain. Energy Rev.* 12, 712–731.
- GWEC, 2009. Global Wind Report 2008. Global Wind Energy Council, Brussels.
- GWEC, 2010. Global Wind Report 2009. Global Wind Energy Council, Brussels.
- GWEC, 2011. Global Wind Report 2010. Global Wind Energy Council, Brussels.
- GWEC, 2012. Global Wind Report 2011. Global Wind Energy Council, Brussels.
- GWEC, 2013. Global Wind Report 2012. Global Wind Energy Council, Brussels.
- GWEC, 2014. Global Wind Report 2013. Global Wind Energy Council, Brussels.
- GWEC, 2015. Global Wind Report 2014. Global Wind Energy Council, Brussels.
- GWEC, 2016. Global Wind Report 2015. Global Wind Energy Council, Brussels.
- GWEC, 2017. Global Wind Report 2016. Global Wind Energy Council, Brussels.
- GWEC, 2018. Global Wind Statistics 2017. Global Wind Energy Council, Brussels.
- He, Z., Xu, S., Shen, W., Long, R., Yang, H., 2016. Overview of the development of the Chinese Jiangsu coastal wind-power industry cluster. *Renew. Sustain. Energy Rev.* 57, 59–71.
- Herran, D.S., Dai, H., Fujimori, S., Masui, T., 2016. Global assessment of onshore wind power resources considering the distance to urban areas. *Energy Policy* 91, 75–86.
- Huang, S.C., Lo, S.L., Lin, Y.C., 2013. Application of a fuzzy cognitive map based on a structural equation model for the identification of limitations to the development of wind power. *Energy Policy* 63, 851–861.
- IEA, 2015. IEA WIND: 2014 Annual Report. International Energy Agency, United States, pp. 200.
- IRENA, 2015. Renewable Power Generation Costs in 2014. International Renewable Energy Agency, Abu Dhabi, UAE, pp. 164.
- Jagadeesh, A., 2000. Wind energy development in Tamil Nadu and Andhra Pradesh, India institutional dynamics and barriers – a case study. *Energy Policy* 28, 157–168.
- Kaldellis, J.K., Kavadias, K.A., Filios, A.E., Garofallakis, S., 2004. Income loss due to wind energy rejected by the Crete island electrical network – the present situation. *Appl. Energy* 79, 127–144.
- Kar, S.K., Sharma, A., 2015. Wind power developments in India. *Renew. Sustain. Energy Rev.* 48, 264–275.
- Kileber, S., Parente, V., 2015. Diversifying the Brazilian electricity mix: income level, the endowment effect, and governance capacity. *Renew. Sustain. Energy Rev.* 49, 1180–1189.
- Kissel, J.M., Krauter, S.C.W., 2006. Adaptations of renewable energy policies to unstable macroeconomic situations – case study: wind power in Brazil. *Energy Policy* 34, 3591–3598.
- Klagge, B., Liu, Z.G., Silva, P.C., 2012. Constructing China's wind energy innovation system. *Energy Policy* 50, 370–382.
- Klessmann, C., Held, A., Rathmann, M., Ragwitz, M., 2011. Status and perspectives of renewable energy policy and deployment in the European Union—what is needed to reach the 2020 targets? *Energy Policy* 39, 7637–7657.
- Klessmann, C., Nabe, C., Burges, K., 2008. Pros and cons of exposing renewables to electricity market risks—a comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy* 36, 3646–3661.
- Krippendorff, K., 2012. Content Analysis: An Introduction to Its Methodology. Sage.
- Kucukali, S., 2016. Risk scorecard concept in wind energy projects: an integrated approach. *Renew. Sustain. Energy Rev.* 56, 975–987.
- Leitão, S., 2013. Energia, um debate vital para o país. *Estud. Av.* 27, 9.
- Lema, A., Ruby, K., 2007. Between fragmented authoritarianism and policy coordination: creating a Chinese market for wind energy. *Energy Policy* 35, 3879–3890.
- Lewis, J.I., Wiser, R.H., 2007. Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms. *Energy Policy* 35, 1844–1857.
- Li, C.B., Li, P., Feng, X., 2014. Analysis of wind power generation operation management risk in China. *Renew. Energy* 64, 266–275.
- Li, J., 2010. Decarbonising power generation in China-Is the answer blowing in the wind? *Renew. Sustain. Energy Rev.* 14, 1154–1171.
- Linton, J.D., 2002. Implementation research: state of the art and future directions. *Technovation* 22, 65–79.
- Liu, W., Li, H., 2011. Improving energy consumption structure: a comprehensive assessment of fossil energy subsidies reform in China. *Energy Policy* 39, 4134–4143.
- Liu, W.Q., Gan, L., Zhang, X.L., 2002. Cost-competitive incentives for wind energy development in China: institutional dynamics and policy changes. *Energy Policy* 30, 753–765.
- Luiz da Silva E, 2006. Supply adequacy in electricity markets based on hydro systems—the Brazilian case. *Energy Policy* 34, 2002–2011.
- Martinot, E., 2001. Renewable energy investment by the World Bank. *Energy Policy* 29, 689–699.
- Martins, A.C., Marques, R.C., Cruz, C.O., 2011. Public-private partnerships for wind power generation: the Portuguese case. *Energy Policy* 39, 94–104.
- Martins, F.R., Pereira, E.B., 2011. Enhancing information for solar and wind energy technology deployment in Brazil. *Energy Policy* 39, 4378–4390.
- Mentis, D., Hermann, S., Howells, M., Welsch, M., Siyal, S.H., 2015. Assessing the technical wind energy potential in africa a GIS-based approach. *Renew. Energy* 83, 110–125.
- Mezher, T., Dawelbait, G., Abbas, Z., 2012. Renewable energy policy options for Abu Dhabi: drivers and barriers. *Energy Policy* 42, 315–328.
- Mignon, I., Rudinger, A., 2016. The impact of systemic factors on the deployment of cooperative projects within renewable electricity production – an international comparison. *Renew. Sustain. Energy Rev.* 65, 478–488.
- Mills, A.J., Durepos, G., Wiebe, E., 2010. Encyclopedia of Case Study Research. Thousand Oaks, California.
- Mulvaney, K.K., Woodson, P., Prokopy, L.S., 2013. A tale of three counties: understanding wind development in the rural Midwestern United States. *Energy Policy* 56, 322–330.
- Neuendorf, K.A., 2016. The Content Analysis Guidebook. Sage.
- Nogueira De Oliveira, L.P., Rodriguez Rchedo, P.R., Portugal-Pereira, J., Hoffmann, B.S., Aragão, R., Milani, R., et al., 2016. Critical technologies for sustainable energy development in Brazil: technological foresight based on scenario modelling. *J. Clean. Prod.* 130, 12–24.
- Osmani, A., Zhang, J., Gonela, V., Awudu, I., 2013. Electricity generation from renewables in the United States: resource potential, current usage, technical status, challenges, strategies, policies, and future directions. *Renew. Sustain. Energy Rev.* 24, 454–472.
- Painuly, J.P., 2001. Barriers to renewable energy penetration: a framework for analysis. *Renew. Energy* 24, 73–89.
- Pasqualetti, M.J., 2000. Morality, space, and the power of wind-energy landscapes. *Geogr. Rev.* 90, 381–394.
- Pereira, M.G., Camacho, C.F., Freitas, M.A.V., Silva, N.F., 2012. The renewable energy market in Brazil: current status and potential. *Renew. Sustain. Energy Rev.* 16, 3786–3802.
- Reddy, S., Painuly, J.P., 2004. Diffusion of renewable energy technologies—barriers and stakeholders' perspectives. *Renew. Energy* 29, 1431–1447.
- Richards, G., Noble, B., Belcher, K., 2012. Barriers to renewable energy development: a case study of large-scale wind energy in Saskatchewan, Canada. *Energy Policy* 42, 691–698.
- Rickerson, W., Hanley, C., Laurent, C., Greacen, C., 2013. Implementing a global fund for feed-in tariffs in developing countries: a case study of Tanzania. *Renew. Energy* 49, 29–32.
- Rosa, L.P., Lomardo, L.L.B., 2004. The Brazilian energy crisis and a study to support building efficiency legislation. *Energy Build.* 36, 89–95.
- Saidur, R., Islam, M.R., Rahim, N.A., Solangi, K.H., 2010. A review on global wind energy

- policy. *Renew. Sustain. Energy Rev.* 14, 1744–1762.
- Sawangphol, N., Pharino, C., 2011. Status and outlook for Thailand's low carbon electricity development. *Renew. Sustain. Energy Rev.* 15, 564–573.
- Schaefer, M.S., Lloyd, B., Stephenson, J.R., 2012. The suitability of a feed-in tariff for wind energy in New Zealand—a study based on stakeholders' perspectives. *Energy Policy* 43, 80–91.
- Schreier, M., 2012. *Qualitative Content Analysis in Practice*. Sage Publications.
- Silva, N.F.d., Rosa, L.P., Freitas, M.A.V., Pereira, M.G., 2013. Wind energy in Brazil: from the power sector's expansion crisis model to the favorable environment. *Renew. Sustain. Energy Rev.* 22, 686–697.
- Sperling, K., Hvelplund, F., Mathiesen, B.V., 2010. Evaluation of wind power planning in Denmark – towards an integrated perspective. *Energy* 35, 5443–5454.
- Stenzel, T., Frenzel, A., 2008. Regulating technological change—the strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets. *Energy Policy* 36, 2645–2657.
- Strauss A.C., Corbin J., 2015. *Basics of qualitative research*.
- Swisher, R., 2009. Keys to achieving 20 percent wind by 2030. cogeneration and distributed generation. *Journal* 24, 66–77.
- Tang, A., Taylor, J.E., 2014. Renewable energy investment in emerging markets: evaluating improvements to the clean development mechanism. *J. Sustain. Dev. Energy, Water Environ. Syst.* 2, 152–173.
- Tang, A., Taylor, J.E., Mahalingam, A., 2013. Strategic structure matrix: a framework for explaining the impact of superstructure organizations on the diffusion of wind energy infrastructure. *Energy Policy* 63, 69–80.
- Toke, D., Breukers, S., Wolsink, M., 2008. Wind power deployment outcomes: How can we account for the differences? *Renew. Sustain. Energy Rev.* 12, 1129–1147.
- Tolmasquim, M.T., 2016. *Energia Renovável: Hidráulica, Biomassa, Eólica, Solar, Oceânica*. Empresa de Pesquisa Energética (EPE), Rio de Janeiro.
- Tolmasquim, M.T., Seroa da Motta, R., La Rovere, E.L., Barata, M.M.d.L., Monteiro, AG, 2001. Environmental valuation for long-term strategic planning — the case of the Brazilian power sector. *Ecol. Econ.* 37, 39–51.
- Valentine, S.V., 2010. A step toward understanding wind power development policy barriers in advanced economies. *Renew. Sustain. Energy Rev.* 14, 2796–2807.
- Vidadili, N., Suleymanov, E., Bulut, C., Mahmudlu, C., 2017. Transition to renewable energy and sustainable energy development in Azerbaijan. *Renew. Sustain. Energy Rev.* 80, 1153–1161.
- Walwyn, D.R., Brent, A.C., 2015. Renewable energy gathers steam in South Africa. *Renew. Sustain. Energy Rev.* 41, 390–401.
- Wang, Z.Y., Qin, H.Y., Lewis, J.I., 2012. China's wind power industry: policy support, technological achievements, and emerging challenges. *Energy Policy* 51, 80–88.
- Weis, T.M., Ilinca, A., Pinard, J.-P., 2008. Stakeholders' perspectives on barriers to remote wind–diesel power plants in Canada. *Energy Policy* 36, 1611–1621.
- Wolsink, M., 2007. Planning of renewables schemes: deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. *Energy Policy* 35, 2692–2704.
- Yin, R.K., 2009. *Case Study Research: Design and Methods*, 4th ed. SAGE Publications, Thousand Oaks, CA.
- Yuan, J., Sun, S., Shen, J., Xu, Y., Zhao, C., 2014. Wind power supply chain in China. *Renew. Sustain. Energy Rev.* 39, 356–369.
- Yue, C.D., Liu, C.M., Liou, E.M.L., 2001. A transition toward a sustainable energy future: feasibility assessment and development strategies of wind power in Taiwan. *Energy Policy* 29, 951–963.
- Zeng, M., Liu, X.M., Li, Y.L., Peng, L.L., 2014. Review of renewable energy investment and financing in China: status, mode, issues and countermeasures. *Renew. Sustain. Energy Rev.* 31, 23–37.
- Zhao, Z.Y., Chang, R.D., Chen, Y.L., 2016. What hinder the further development of wind power in China? A socio-technical barrier study. *Energy Policy* 88, 465–476.
- Zhao, Z.Y., Chang, R.D., Zillante, G., 2014. Challenges for China's energy conservation and emission reduction. *Energy Policy* 74, 709–713.
- Zhao, Z.Y., Sun, G.Z., Zuo, J., Zillante, G., 2013. The impact of international forces on the Chinese wind power industry. *Renew. Sustain. Energy Rev.* 24, 131–141.
- Zhou, Y.C., Zhang, B., Zou, J., Bi, J., Wang, K., 2012. Joint R&D in low-carbon technology development in China: a case study of the wind-turbine manufacturing industry. *Energy Policy* 46, 100–108.