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# THE INFLUENCE OF IMPLEMENTATION BARRIERS ON THE DEVELOPMENT OF ONSHORE WIND FARMS

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ao Brasil, minha pátria amada

à Miriam, minha insubstituível mãe

ao Francisco, meu admirável pai

à Maria, minha amorosa irmã

ao Hidelbrando, meu herói irmão

à Catarina, minha destemida tia

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à Marta, meu anjo na terra

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# ABSTRACT

In a world for which the decarbonisation of the economy has currently become, more than a wish, a need, in order to ensure the well-being of future generations, wind energy (WE) has increasingly been used to replace conventional energy sources for electricity generation. However, WE expansion has faced several barriers that make it difficult to implement new wind farms around the world.

Motivated by the importance of overcoming this interference of implementation barriers on the development of onshore wind farms, especially in countries which are beginning to experience significant wind energy utilization, the research presented in this thesis aims at: (a) improving the current understanding about the barriers to the implementation of wind farms; and (b) recognizing how they can be addressed.

To achieve both goals, a systematic literature review (SLR) and case research were carried out. The SLR presents a broad review about which WE implementation barriers can be found, and which countries have faced these hurdles as they seek to expand their WE utilization. In addition, the performed case research identifies which are the existing barriers to WE diffusion, and how they may be overcome, in cases of fast and expressive WE integration.

The SLR was based on the full reading of 529 studies, and the findings highlight the existence of barriers in 159 countries. Moreover, the findings also point to uncertain governmental policies, insufficient transmission grids, and poor market infrastructure as barriers to WE diffusion that are frequently observed, among those countries. These three barriers normally have long historic occurrences and significant impacts on wind farm implementations.

The case research was performed for the fast and expressive WE integration observed in Brazil. In a first part of this investigation, interaction with local wind energy stakeholders sought to identify the existing barriers to the implementation of wind farms in the country. In the second part, interaction with the same stakeholders focused on identifying how it would be possible to overcome these barriers.

Through interviews and subsequent qualitative content analysis, twenty-four barriers that make it difficult to implement wind farms in the country were recognized, three of which with particular relevance: poor transmission infrastructure, unattractive financial loans

and the currently unstable macroeconomic environment. In addition, it was recognized that most of these twenty-four barriers were successfully mitigated by wind developers, in advance, at the wind farm project planning stage. However, the three barriers highlighted above escape their control and require direct governmental efforts to be overcome.

According to this scenario, if the recovery of Brazil's national economy, the reestablishment of regular energy auctions, the access to competitive loans, and improvements to the transmission system infrastructure take too long, the country faces an elevated risk of its wind sector collapsing. In the face of this scenario, the case research provides a set of policy recommendations focused on the sustainability of the Brazilian wind energy sector.

In addition to contributing to strengthening the literature about WE implementation barriers, this thesis also provides practical insights for wind developers and policy makers, to improve wind farm planning and energy markets, respectively.

# RESUMO

Com o objetivo de garantir o bem-estar das próximas gerações, descarbonizar a economia global deixou de ser apenas um anseio e transformou-se atualmente numa necessidade. A Energia Eólica (EE) tem-se vindo a evidenciar cada vez mais, neste quadro, entre as alternativas renováveis para a substituição das fontes convencionais de energia na geração da eletricidade. A expansão da EE enfrenta, contudo, diversas barreiras que dificultam a implementação de parques eólicos em várias regiões do mundo.

Motivada pela importância de superar estas interferências de barreiras na implementação de parques eólicos, especialmente nos países que recentemente começaram a incentivar a utilização da EE, a investigação apresentada nesta tese foi conduzida com dois objectivos centrais: (a) melhorar o entendimento actual sobre as barreiras à implementação de parques eólicos *onshore*; e (b) reconhecer como elas podem ser superadas.

Para alcançar ambos os objetivos, foi realizada uma revisão sistemática da literatura (RSL), e posteriormente foi desenvolvido um estudo de caso. A RSL revê de forma abrangente que barreiras à implementação da EE podem ser identificadas, e que países têm enfrentado esses desafios nos seus esforços de expansão da utilização de EE. A investigação levada a cabo no estudo de caso identifica ainda quais as barreiras à difusão da EE presentes, e como podem estas ser superadas, em contextos de integração rápida e expressiva da EE.

A RSL baseou-se na leitura completa de 529 estudos, e os seus resultados evidenciaram a existência de barreiras em 159 países. Os resultados da RSL apontaram ainda as insuficiências na infraestrutura de transporte de energia elétrica, a inexistência ou inadequação de políticas de apoio e subdesenvolvida cadeia de suprimento como as barreiras à difusão da EE registadas com mais frequência. Por fim, verificou-se que essas barreiras possuem normalmente históricos de ocorrência longos e se encontram entre as que têm impactos mais significativos na implementação de parques eólicos *onshore*.

Considerando o rápido e expressivo crescimento da EE no Brasil, os respetivos *stakeholders* foram entrevistados, no âmbito de um estudo de caso, sobre as barreiras à implementação de parques eólicos atualmente existentes no país, bem como sobre as formas de superação dessas barreiras.

Através da análise de conteúdo das entrevistas, foram identificadas vinte e quatro barreiras que dificultam a implementação de parques eólicos no país, com especial destaque para as seguintes três: debilidades na infraestrutura de transporte de energia elétrica, condições de financiamento com baixa atratividade e o atual ambiente macroeconómico instável. Foi posteriormente constatado que a maioria das barreiras são mitigadas com sucesso pelos desenvolvedores eólicos locais na fase de planeamento dos parques. Já as três barreiras principais anteriormente citadas acabam por ficar fora da esfera de influência dos desenvolvedores, exigindo apoio governamental para que possam ser superadas.

De acordo com este cenário, se a recuperação da economia brasileira, o restabelecimento do regular funcionamento dos leilões de energia, o acesso a financiamento competitivo, e a melhoria da infraestrutura do sistema de transporte, tardarem muito em ocorrer, o país corre um risco elevado de colapso do setor eólico. Face a este cenário, é proposto no âmbito do estudo de caso um conjunto de recomendações de políticas públicas focadas na sustentabilidade do setor eólico brasileiro.

Além de contribuir para o fortalecimento da literatura dedicada às barreiras à implementação da EE, esta tese disponibiliza também linhas de orientação práticas, úteis para os promotores eólicos e para os decisores políticos no aperfeiçoamento do planeamento dos parques eólicos e dos mercados de energia, respetivamente.

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ABDI – *Agência Brasileira de Desenvolvimento Industrial*

ABEEólica – *Associação Brasileira de Energia Eólica*

AWEA – American Wind Energy Association

BA – State of Bahia

BRA – Brazil

CanWEA – Canadian Wind Energy Association

CE – State of Ceará

CEC – Clean Energy Council

CEO – Chief Executive Officer

CF – Capacity Factor

D – Developers

EC – Engineers & Consultants

EF – Economical and Financial

EPE – *Empresa de Pesquisa Energética*

GWEC – Global Wind Energy Council

I – Institutional

IFs – Federal Institutes of Education, Science and Technology

INPE – *Instituto Nacional de Pesquisas Espaciais*

IWEA – Irish Wind Energy Association

LCOE – Levelized Cost of Electricity

M – Market

Mf – Manufacturers

MME – Ministry of Mines and Energy

MNRE – Ministry of New and Renewables Energy of the Indian Government

NGOs – Non-governmental organizations

O&M – Operations and Maintenance

OB – Other Barriers

Pa – Public administrators

PAC – *Programa de Aceleração do Crescimento*

PDBs – Public Development Banks

PPAs – Power Purchasing Agreements

R – Researchers

R&D – Research and Development

REAP – Renewable Energy Alaska Project

RES – Renewable Energy Sources

RN – State of Rio Grande do Norte

RP – Research Paper

RQ – Research Question

S – Social

Sa – Support agents

SENAI – *Serviço Nacional de Aprendizagem Industrial*

SLR – Systematic Literature Review

SoE – State-owned Enterprise

T – Technical

TSO – Transmission System Operator

WE – Wind Energy

# 1 INTRODUCTION

## 1.1 MOTIVATION AND OVERVIEW

Electrical energy is a fundamental resource for modern human life [4, 60]. However, from a world population of 7 billion [78], about 1.2 still live without supply of electricity [47].

Energy and development are inseparable factors, and the absence of this resource has a deep impact on the level of poverty and economic growth [5, 34]. For this reason, all countries, but especially developing countries, need to diversify their energy matrix and offer access to electricity to their entire populations [33, 67]. In order to diversify the energy matrix and expand electricity access, the implementation of an electricity supply based on security, reliability, quality, and environment-friendliness is recommended [21, 55, 57, 79-81]. Concerning the environment-friendliness dimension, it has been recognized that energy supply worldwide still relies too much on conventional energy sources, which are the main cause of global warming [59, 65].

In recent years, seeking to reduce greenhouse gas emissions, decarbonize their economies, and consequently stop global warming, several nations have demonstrated an interest in the implementation of renewable energy sources (RES) [13, 23], with the number of countries which have committed at least one RES to their energetic matrix increasing from 43 in 2005 to 164 in 2015 [48]. Besides the environment-friendliness and human quality of life improvement prerogatives, RES implementations currently happen also due to advances in technology maturity and cost-competitiveness [30, 45]. Among RES, wind energy (WE) has gained prominence by holding the lowest development costs [20, 75], being recognized as the cheapest option to generate electricity in several world regions [71]. As result of this cost advantage, until the end of 2017, WE reached 539.12 GW of installed capacity, with the expectation that its implementation will keep increasing for the next decades [44].

The continuous worldwide growth of WE implementation has nevertheless been constrained by several barriers [12, 22, 54, 63]. These barriers may emerge earlier, during wind farm project development, or later, in the implementation and operation phases [66, 70].

However, even facing barriers [27, 33, 61, 74], the wind farm projects implemented in Brazil are among those with the highest capacity factors [1, 46] and lowest levelized costs [25] worldwide.

Taking into account that wind farm implementation success is only possible with an excellent development plan [29, 51], it is thus also clear that wind farm projects in Brazil have been planned in ways that have allowed them to overcome the existing barriers. In fact, these barriers may be addressed during the project planning phase [8], as well as by the creation or improvement of public policies [11, 16, 32].

## 1.2 Background and Key Concepts

### 1.2.1 Barriers to renewable energy implementation

The barriers to RES implementation emerge in many ways. Painuly [63], in the study "Barriers to renewable energy penetration; a framework for analysis", produced a landmark categorization of these barriers (see Table 1.1). These barriers have the ability to increase the costs and time to develop wind farm projects, as well as to hamper wind farm operation performance. The mentioned factors (cost, time and performance) are recognized as the "Iron Triangle", fundamental to achieving project success [10, 62, 68].

| **Barrier category** | **Barriers** |
|---|---|
| 1. Market Failure (MF) | Highly controlled energy sector; Lack of information and awareness; Restricted access to technology; Lack of competition; High transaction costs; Missing market infrastructure; High investment requirements |
| 2. Market Distortions (MD) | Favour (such as subsidies) to conventional energy; Taxes on RES; Non-consideration of externalities; Trade barriers |
| 3. Economic and Financial (EF) | Economically not viable; High discount rates; High payback period; Market size small; High cost of capital; Lack of access to capital; Lack of access to credit to consumers; High up-front capital costs for investors; Lack of financial institutions to support RES; Lack of instruments. |
| 4. Institutional (I) | Lack of institutions/mechanisms to disseminate information; Lack of a legal/regulatory framework; Problems in realising financial incentives; Unstable macro-economic environment; Lack of involvement of stakeholders in decision making; Clash of interests; Lack of research and development (R&D) culture; Lack of private sector participation; Lack of professional institutions. |
| 5. Technical (T) | Lack of standard and codes and certification; Lack of skilled personnel/training facilities; Lack of O&M facilities; Lack of entrepreneurs; System constraints; Product not reliable. |

| Barrier category | Barriers |
|---|---|
| 6. Social (S) | Lack of consumer acceptance of the product; Lack of social acceptance for some RES. |
| 7. Other Barriers (OB) | Uncertain governmental policies; Environmental; High risk perception for RES; Lack of infrastructure. |

Table 1.1 – Barriers to renewable energy implementation, according to Painuly [63].

It is therefore important to identify which barriers exist and how they interfere on development costs and times, and on the operational performance, of wind farms. However, until 2016 few studies had attempted to study this influence. Additionally, no studies were found with the purpose of widely reviewing the literature about the occurrence of all these barriers around the world.

### 1.2.2 Planning the onshore wind farm implementation

The project development for onshore wind farms consists of the execution of several steps. Taking into account the methods proposed by the American Wind Energy Association [9], the Renewable Energy Alaska Project [69], the Irish Wind Energy Association [50], the Clean Energy Council [19], the Ministry of New and Renewables Energy of the Indian Government [64], and the Canadian Wind Energy Association [18], the following twelve steps can be identified:

(i) Perform the wind resource assessment, ensuring the existence of enough wind power to generate electricity at profitable levels;

(ii) Verify grid capacity, ensuring connection and consequent electricity transmission;

(iii) Select the site and define its utilization, establishing land use contracts and verifying the existence of adequate access infrastructure until the site;

(iv) Verify the site viability, according to social, environmental and geological conditions for the project implementation;

(v) Verify the technical and operational viability, confirming the availability and reliability of wind turbines, components, specialized labour and other resources required for the project implementation, and subsequently propose a layout with optimized infrastructure micrositing (towers, wind turbines, sub-stations, etc.);

(vi) Get permissions and licences, legitimizing the project implementation according to socio-environmental laws and guidelines;

(vii) Prove the techno-economic viability, verifying criteria of cost and performance, and the existence of suitable turbines, components and management tools;

(viii) Ensure project operation and maintenance (O&M), confirming that during the project's lifespan, it will not face technical failures (interruptions, obsolescence of turbines and components, etc.);

(ix) Collect funding resources, internally with the project owner, or externally with financial institutions, to overcome the high up-front implementation costs;

(x) Find buyers for the generated electricity, establishing power purchase agreements (PPAs) and consequently ensuring revenues to enable the project’s economic viability;

(xi) Develop the decommissioning plan, ensuring that after the project's lifespan, the wind farm infrastructure will be removed in a cost-efficient and environmentally-friendly way;

(xii) Check the possibility of implementing the project in a hybrid system, together with other renewable energy technology or storage systems, ensuring the efficient utilization of available transmission infrastructure (intermittency reduction).

Among these twelve steps, the first eight are common in the six methods (see Table 1.2).

| **Methods** | **Steps** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) | (vii) | (viii) | (ix) | (x) | (xi) | (xii) |
| AWEA [9] | x | x | x | x | x | x | x | x | x | x | | |
| REAP [69] | x | x | x | x | x | x | x | x | x | | | |
| IWEA [50] | x | x | x | x | x | x | x | x | x | x | x | |
| CEC [19] | x | x | x | x | x | x | x | x | | | | |
| MNRE [64] | x | x | x | x | x | x | x | x | | | x | x |
| CanWEA [18] | x | x | x | x | x | x | x | x | x | | | |

Table 1.2 – Steps to develop wind farm projects.

Despite a relatively high commonality, it should be noted that some methods do not consider the action of collecting funding resources as a step to develop wind farm projects. Furthermore, most methods do not include the processes of finding buyers, developing the decommissioning plan, and especially the analysis of the possibility of using hybrid systems.

Whatever the steps used by the wind developer, the existing barriers start to interfere on the wind farm implementation since the planning phase [66, 70]. Thereby, efforts to overcome these barriers need to begin preferably in this same phase.

### 1.2.3 LARGE-SCALE WIND ENERGY IMPLEMENTATION: 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 diminish its high dependence on hydropower [58, 72].

Among the options to expand the energy matrix and consecutively re-establish security of supply [53], WE emerged as a reliable option in Brazil, especially in the Northeast region due its excellent wind conditions [6, 26, 28, 56, 67].

As a consequence of the deployed public auction system, the installed capacity of WE in the country increased 37 times in the past decade, reaching 12,770 MW in the end of 2017 (see Figure 1.1). Currently, Brazil occupies the eighth position among the top 10 nations with more WE capacity installed [44].

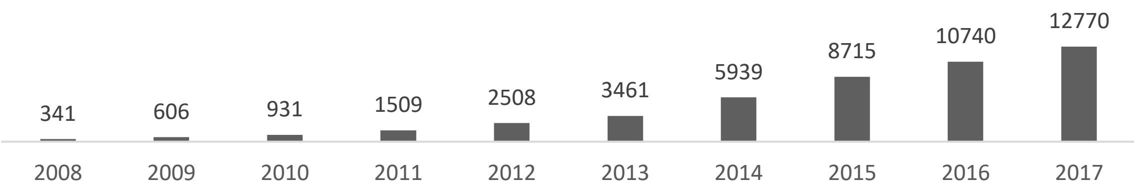


Figure 1.1 – Evolution of the Brazilian WE cumulative installed capacity (MW/year) [35-44].

From the current installed capacity, the country generated 40.46 TWh of electricity, of which 33.99 TWh came 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) [3]. This installed capacity still represents a small portion (7.8%) in Brazil's total electricity installed generating capacity, which is dominated by the Non-renewable (17.2%) and Hydropower (63.8%) [31].

Associated to this fast and expressive national WE growth, the wind farms located in the Northeast region have continuously reported an outstanding average capacity factor above 40% [2, 3, 25], much higher than the average found across countries worldwide [46]. Consequently, even facing barriers that influence implementation costs, the levelized cost of WE in the region has reached 0.035 USD/kWh [25], much less than the costs of WE generation observed in other world regions [49].

In fact the WE future seems promising in the region, either for expanding electricity generation or replacing the other main sources of generation, since wind farms have been negotiating electricity with competitive tariffs in comparison with thermoelectric plants and lately also with hydropower plants [7], and have their generation reliably foreseen and quantified (due to the existence of strong and stable trade winds - suitable for a wide integration on the grid). In the current scenario of high hydroelectric availability losses (due the frequent occurrence of droughts) a supply alternative is urgently required [24].

## 1.3 RESEARCH QUESTIONS AND METHODOLOGY

Among existing RES, WE is a clearly cost-competitive option for an environmentally-friendly expansion of electricity generation worldwide. However, from as early as the project development stage in the wind farm project lifecycle, WE expansion is constrained by barriers to implementation, which may be addressed by public policies seeking to create a favorable environment to boost WE expansion.

These policies could benefit from a better understanding of the occurrence of WE implementation barriers around the world, a study that is currently a gap in the literature, as well as a better understanding of the links between the barriers and the wind farm development process, for which studies are scarce. A country such as Brazil, which, despite the presence of implementation barriers, has observed a fast and expressive WE expansion, especially in its Northeast region, whose wind farms feature the highest CF and the lowest LCOE in the world, provides a relevant case for the detailed study of such links.

With the above motivation, this thesis addresses the following research questions (RQs):

(RQ1) Which implementation barriers are faced by countries worldwide as they seek to expand WE utilization?

(RQ2) Which WE implementation barriers are present in cases of fast and expressive WE expansion?

(RQ3) How do wind developers plan their wind farm projects to overcome these barriers?

The research that was carried out to address these RQs had naturally an applied nature, and consisted in part of bibliographic research, and in part of exploratory empirical research based on the interaction with stakeholders of the Brazilian wind energy sector, delineated by a qualitative approach.

Applied research aims at providing information to address societal problems, including solutions for problems, or deeper understanding of the problems under analysis [15]. This research in fact seeks to both achieve a better understanding about barriers to WE implementation worldwide (RQ1) and in a specific category of cases of interest (RQ2), and identify with wind developers how they currently overcome those barriers (RQ3).

The bibliographic research component, through the Systematic Literature Review (SLR), served as a base to address all RQs proposed, mainly RQ1. In addition, it supported the theoretical consolidation of the research [52], and was fundamental at the beginning of the research to define the RQs, as well as to choose an adequate methodology to address them.

Within the topic of WE expansion, the ways to overcome WE implementation barriers early on, right from the wind farm project development phase, can be regarded as a "new problem", rarely addressed by previous scientific studies, especially in cases of fast and expressive WE expansion, as observed in Brazil. This type of problems, not clearly defined in the scientific literature, and previously unaddressed, or addressed by only few researchers, are well suited for exploratory research [17, 76], and may involve bibliographic research, interviews with experts and case analysis to support problem understanding [73]. Specifically, a qualitative [14] case research approach [77, 82] was used to analyse the Brazilian WE sector, focusing on the occurrence of barriers across the whole sector, especially in the three main WE generation states: Rio Grande do Norte (RN), Bahia (BA) and Ceará (CE).

Further details of the methodology, namely about the procedures used to conduct the SLR and the interviews, and about how the collected information was treated and analyzed, are presented in the Method sections of chapters 2, 3 and 4.

## 1.4 THESIS OUTLINE

The thesis is composed of five chapters, with the second, third, and fourth addressing the RQs, and each consisting of a potential original research paper (RP).

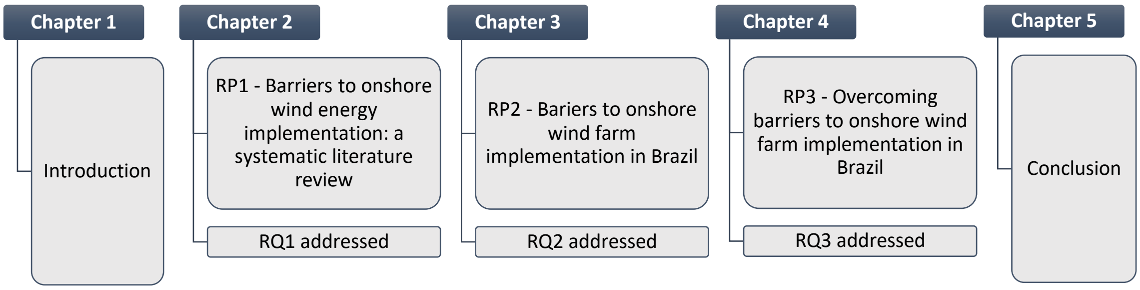


Figure 1.2 – Chapters of the thesis

The current chapter contextualizes the research theme, introducing the key theoretical concepts, outlining the research questions, and describing the scientific methodology used to address those questions. It is important to highlight that some of the information presented in this introductory chapter is essential for each of the original papers, and thus some paragraphs from this introduction will be repeated in the corresponding chapters.

Chapter 2 consists of a SLR about the barriers to wind energy implementation worldwide, identifying the occurrence of barriers per category and place, and characterizing the barriers according to the level of economic development and stage of WE diffusion in the countries where they were identified.

Chapter 3 presents, based on interviews with stakeholders, an analysis of the barriers to onshore wind energy implementation in Brazil, highlighting those with a stronger role in inhibiting the actual implementation of wind farms.

Chapter 4 introduces the efforts used by developers to overcome the barriers faced in the implementation of wind farms, based on the same set of stakeholder interviews.

Finally, chapter 5 summarizes the thesis, brings together the conclusions of the three main chapters, and propose themes for future research.

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# 2 BARRIERS TO ONSHORE WIND ENERGY IMPLEMENTATION: A SYSTEMATIC LITERATURE REVIEW

## ABSTRACT

A large number of studies have looked at the diffusion of onshore wind energy, which has achieved a significant expression worldwide, and reported the existence of barriers to the large-scale implementation of wind farms. The literature, however, is lacking a systematized overview of these barriers, their categories and places of occurrence. Based on a framework for the analysis of barriers to the penetration of renewable energy sources proposed by Painuly [354], the systematic literature review presented in this paper addresses this gap, identifying the occurrence of barriers per category and place, and characterizing the barriers according to the level of economic development and stage of diffusion in the countries where they were identified. The original generic framework demonstrated an adequacy of 75.6%, allowing the identification of 31 barriers to the large-scale implementation of onshore wind farms, in 159 countries. Among these 31 barriers, uncertain governmental policies, insufficient transmission grids, and poor market infrastructure were the three most frequent. The occurrence of these barriers is mostly linked to developing economies with a recent diffusion. Nonetheless, some barriers feature a broad occurrence in developed economies regardless of the stage of diffusion.

## KEYWORDS

Renewable energy; Onshore wind energy; Barriers to implementation; Systematic literature review

## 2.1 INTRODUCTION

As countries seek to reduce the greenhouse gas emissions associated with electricity generated from conventional sources, onshore wind energy (WE) has emerged as a major renewable energy source (RES) alternative. Over the past decade, global onshore wind capacity grew more than fivefold, reaching an installed capacity of 486.79 GW [174]. By 2030, if this expansion trend remains the same, WE will be responsible for savings of nearly 23 billion tonnes of $CO_2$ besides providing other benefits, such as the creation of millions of new job positions [173].

However, several barriers create difficulties and even block onshore WE expansion across the world, thus challenging the realization of those potential benefits [51, 249, 297, 527]. In a broader RES perspective, these barriers have been classified by Painuly [354] according to the following categories: market failures; market distortions; economic and financial; institutional, technical, social, cultural and behavioural, and others [354]. The identification of these barriers is fundamental to define and understand the challenges faced by large scale onshore WE investments [199, 386], which suggests the research question addressed by this study: which implementation barriers have been faced by countries worldwide as they seek to expand WE utilization?

In addition to identifying these barriers, it is also important to know which are specific or new for this technology, how frequent they are, and which have higher impact in large scale onshore WE implementation. So far, this type of information has mostly had to be retrieved from scattered empirical data. The very few available review and literature review studies have focused on a specific barrier [366, 392, 395], and an overall systematization has been missing.

To address the research question, the systematic literature review (SLR) presented in this paper gathers and systematizes the literature on barriers to large scale onshore WE implementation, looking in particular at the countries where they were studied. The SLR summarizes barrier occurrence patterns, regarding the economic situation and the local level of wind energy diffusion in the countries where they were identified, as well as which barriers have had a high impact on onshore WE implementation, and where. In addition, this review check if the original generic framework proposed by Painuly [354] is appropriate to analyse the barriers to WE diffusion. The SLR creates a useful basis for future research work, as well as a systematization of value for practitioners interested in implementing onshore WE farms, who may benefit from a clear understanding of the challenges they may face. The SLR may also be useful to guide policy makers in establishing policies to mitigate or eliminate barriers in their energy markets.

The following section introduces the applied systematic review method. The ensuing section details the general characteristics of the review studies, emphasizing the countries for which these studies have reported the occurrence of barriers. The findings from the review are presented next, grouped according to broad barrier categories, with the description of each barrier and its impact as it applies to large scale WE implementation. This section also presents barrier occurrence rates and patterns, based on detailed data provided in the appendices. The discussion section then analyses the data summarized in the findings and included in the appendices. The review concludes with a brief outline of the key findings and discussion points, as well as suggestions for future research on barriers to large scale WE implementation.

## 2.2 METHODOLOGY

With the purpose of fully exploring the literature on worldwide barriers to WE implementation, this study adopts a SLR method. The SLR method assures that complete and detailed information is provided with accuracy and impartiality [454]. The method is oriented by a set of flexible and unrestricted principles which ensure veracity, neutrality and extent about a specific scientific knowledge, and produces results that allow professionals and academics to support decisions based on a wide and reliable information basis [71]. The procedures to perform the SLR are briefly described below.

### 2.2.1 REVIEW PROTOCOL

The SLR was performed according to the procedures suggested by Briner and Denyer [71]. Its protocol includes: (a) background and motivation for the SLR; (b) its objective; (c) research (or review) questions; (d) search strategy; (e) paper selection process; (f) procedures for data analysis, including the assessment of methodological quality; and, (g) procedures for the synthesis of findings. Parts (a) to (c) have already been covered previously in the paper.

### 2.2.2 SEARCH STRATEGY

The search was performed on journal articles and reviews included in two academic databases: Scopus and Web of Science. Titles, abstracts, and keywords were queried considering the following combination of sets of terms:

(a) barrier* OR challeng* OR conflict* OR critic* OR hurdle* OR impediment* OR inhibit* OR limit* OR obstacl* OR obstruct* OR opposit* OR constrain* OR reject* OR risk* OR threat*;
(b) driv* OR promot* OR opportunit* OR enabl* OR enhanc*;
(c) "wind energy" OR "wind power" OR "wind-generated".

The first set of terms contains the key-word “barrier” and expressions with the same or approximate meaning. The second set contains antonyms of barrier and was included because studies of drivers of technology implementation are usually based on the discussion of barriers or inhibiting factors. Lastly, the third set contains expressions which refer to wind energy sources. The asterisk (*) is added to encompass variations of the terms included in the search query, e.g., challeng* will return articles that include words such as challenge, challenges, challenged, challenging, and challenger, among others.

The terms used to define this search query were selected from keywords of previous studies on: (a) barriers to RES implementation; (b) SLRs focused on studies of barriers, drivers, diffusion and WE related to other subjects. In addition, the terms used in the queries were confirmed by RES experts. The search was restricted to studies written in English, in the multidisciplinary field of Energy and published only in peer reviewed journals until 2017. The earliest study found is dated 1976. The search was conducted in March 2017 and updated in February 2018.

### 2.2.3 Selection of Papers for Review

The same query, based on a combination of the sets of terms presented above, was submitted to the two databases. The combination sought to assure a broad collection of studies, as presented in Table 2.1.

| **Query (terms combination)** | **Database** | | |
|---|---|---|---|
| ((a) OR (b)) AND (c) | Scopus: 5,911 | Web of Science: 3,726 | Total: 9,637 |

Table 2.1 – Search query and number of studies identified in each database.

A total of 9,367 studies were identified, from which 6,704 remained after excluding duplicates. In an initial selection, the titles and abstracts of the studies were analysed independently by three researchers, and out of the 6,704 studies, 1,048 were selected for reading. Selection discrepancies were discussed among the researchers and full text sourcing for the selected articles resulted in the identification of 70 articles potentially appropriate for the review but not accessible. After reading the 1,048 studies, 476 were considered to contain information of relevance for the SLR. By following the bibliography cited in these 476 studies, 53 were selected, leading to a total of 529 studies considered for analysis. Additionally, 4 reports and 3 studies are used in the introduction, methodology and appendices, resulting in a global utilization of 536 references.

The selection process considered both inclusion and exclusion criteria. The inclusion criteria were based on the seven categories of barriers to RES penetration described in Painuly’s framework (Table 2.2). The exclusion criteria were defined by the team of researchers and targeted topics that were not the focus of this study, including: barriers to the diffusion or implementation of other RESs, hybrid onshore WE systems; offshore WE systems; micro/small generation; engineering process of wind turbines, components, towers, foundations and other elements of wind farm projects.

### 2.2.4 DATA ANALYSIS

The 529 selected studies were reviewed to identify the barriers according to the categorization proposed by Painuly [354]:

| **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 standard, codes and certification; (31) lack of skilled personnel; (32) lack of 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. |

Table 2.2 – Barriers to renewable energy implementation [354].

### 2.2.5 SYNTHESIS OF FINDINGS

Interpretation [389] together with narrative synthesis [71] was used to elaborate the synthesis of the findings. The purpose of the synthesis was to provide an overall understanding about the barriers that inhibit onshore WE diffusion worldwide.

## 2.3 GENERAL CHARACTERISTICS OF THE REVIEWED STUDIES

The 529 reviewed studies were published between 1991 and 2017, as described in Figure 2.1.

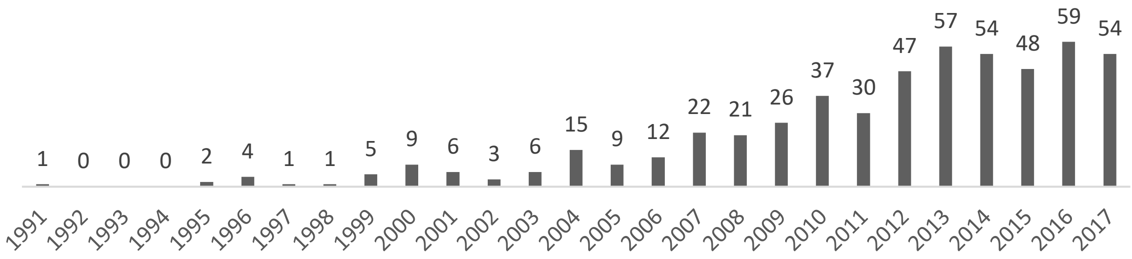


Figure 2.1 – Temporal distribution of the studies included in the review.

Until the 2000s, the number of relevant studies was very low when compared to the presence of the topic the literature in more recent years. It is nowadays more prevalent, with more than 30 publications published each year, since 2010, with a maximum of 59 in 2016. The studies included in this review were published in 64 journals, with a large majority (71%) found in three journals: Energy Policy (168), Renewable & Sustainable Energy Reviews (160) and Renewable Energy (49).

Crossing the locations addressed by the studies and the top 10 WE producers [174], 100 studies referenced barriers found in China, 40 in the United States, 21 in Germany, 18 in India, 26 in Spain, 39 in the United Kingdom, 9 in France, 18 in Canada, 14 in Brazil, and 6 in Italy. As presented in Figure 2.2 and Appendix D, the studies also identify barriers to onshore WE diffusion in 146 other countries.

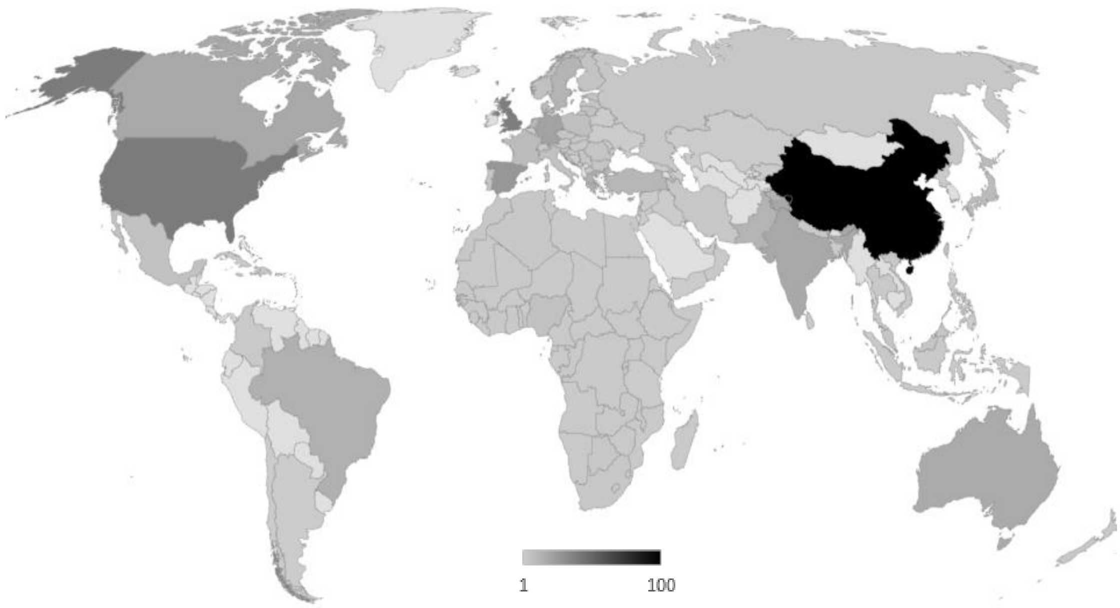


Figure 2.2 – Geographic incidence of the studies – number of studies citing barriers for each country.

# 2.4 FINDINGS

## 2.4.1 MARKET FAILURES

Among seven market failures that hinder the diffusion of RES described by Painuly [354], six were identified in the reviewed studies as inhibiting factors to implement onshore wind farms in large-scale:

1. Highly controlled energy sector

   Energy markets are highly controlled when public utilities are managed by governments or private companies which hold, simultaneously or not, the monopoly of generation, distribution and grid connection [354]. These monopolist utilities inhibit the investment in WE by authoritatively supporting the absence of a legal framework for RES [51] and maintaining conventional energies as their core generation sources [271, 445]. Conventional energies play a significant role in the generation portfolio of these monopolies because they already have an established infrastructure, generating electricity at low prices (if external costs are ignored) [106, 265]. Normally, these monopolies only invest in WE when they are forced to comply with minimum quotas of non-hydro RES generation settled by their governments [271]. Besides the authority to choose the generation source, monopolist utilities also have the autonomy to decide which sources can access their transmission grids, which allows them to hamper the integration of WE in their distribution systems [460]. The reviewed studies reported the occurrence of highly controlled energy markets in 11 countries, mostly in developing economies with recent WE diffusion (see Appendix A, B and C).

2. Lack of awareness and information

   The absence or the inadequacy of information and awareness about potential, costs, technologies, and markets leads energy stakeholders to losing interest and commitment to promoting RES [354, 379], especially financing banks [233, 412, 480]. In the case of WE, the potential is mainly understood in terms of wind assessment. The siting wind resource assessment is an important first step to establish a wind farm [224, 362], allowing wind developers to optimize the wind turbine selection and micrositing that are required to maximize the economic advantages [153, 339, 407] and consequently minimize the investment risks [81, 302]. In general, siting wind assessments start with guidance obtained from macro-scale assessments.

However, these assessments have often failed to produce detailed and accurate information, because they are based on meteorological data from weather stations that are inadequate to identify the real potential of WE generation [224, 312]. Moreover, some macro-scale assessments are outdated, contributing even more to the inaccuracy of siting assessments, WE target setting [399], and the integration of wind power in electric grids [50, 199, 251, 525]. Wind assessments tend to be inaccurate when they are based on estimation [460], use short anemometric towers to collect wind data [244, 298, 360], and the collected data is sparse in space and inconsistent in time [2, 345, 407, 501]. In addition, recent, detailed, and accurate information about WE development aspects (costs, technology, infrastructure, energy markets, socio-environmental impacts, etc.) is essential to promote WE [121, 198, 199]. The absence of this general information, for instance, makes it difficult to quantify the costs of wind generation [289], select areas to build wind farms [132, 347], and connect these farms to the grid [125, 343]. Lack of information and awareness about WE was reported for 91 countries, mostly for developing economies with recent WE diffusion.

3. Restricted access to technology

   Technology access is restricted when the local market lacks a structured supply chain and technology developers are unwilling to transfer knowledge. Moreover, technology access is limited when restrictive policies and taxes on technology or equipment imports exist [354]. Excessive taxes and import duties lead to high implantation costs and loss of competitiveness for RES developments [51]. In the case of WE, import duties for wind turbines can be two [465] to three times more than the import duties for conventional energy technologies [275, 465]. These excessive duties impact directly the economics of WE investments, since wind turbines are responsible for more than 70% of wind farm implementation costs [60]. Restricted access to WE technology was observed in 7 countries, mainly developing economies with recent WE diffusion.

4. Lack of competition

   Competitive markets support an efficient use of energy resources [379]. However, competition is not possible when incumbent utilities dominate energy markets, creating a competitive environment unfair for new entrants [88]. This unfair competitive environment is established through prohibitive regulation, implemented with the purpose of inhibiting the participation of private RES developers [428]. Incumbent utilities already have conventional generation or even wind farms implemented, and end up having no interest in buying electricity from these new developers, mainly to avoid competing against themselves [62, 66, 324, 400]. In the reviewed studies, lack of competition was reported for 10 countries, essentially developed economies with advanced levels of WE diffusion.

5. High transaction costs

   The transaction costs of RES projects are related to the time and money necessary to perform the activities of the energy project plan. These activities include resource assessment, siting, permitting, planning, project proposal development, financing package assembly, and power-purchase contract negotiation [51, 354]. In the case of WE, high transactions costs are a result of slow and complex procedures to obtaim approvals to build wind farms [287], connect to the grid [300, 452, 473], and establish power purchase agreements [287, 428]. High transaction costs to implement wind farms were found in 7 countries, for the most part developed economies with an advanced level of WE diffusion.

6. Poor market infrastructure

   The studies analysed in this review addressed market infrastructure issues related to the wind industry level of development. The wind industry is a high-tech industry, integrating aerodynamics, mechanics, electricity and electronics, automatic control, and highly reliable designs [119]. An advanced wind industry implantation followed by technology adaptation is essential for a successful large-scale diffusion of WE [275]. Once established, an advanced local wind industry can reduce the dependence on imports and dramatically reduce the development costs of wind farms [505]. Several countries intending to implement WE have early stage wind industries [38, 244, 473], while others countries have well developed wind industries, although not enough to be independent from foreign technology [30, 31, 429, 505, 529]. The occurrence of poor market infrastructure was reported in 93 countries, mostly least developed and developing economies with recent WE diffusion.

China is the country facing the widest range of market failures, featuring all the six. It is followed by Russia with five, Japan and South Africa with four, and Greece, India, Pakistan, United Kingdom and Vietnam with three (Appendix D).

### 2.4.2 MARKET DISTORTIONS

Three of the four generic market distortions described by Painuly [354] were identified in the reviewed studies as relevant for large-scale onshore wind farm implementation.

1. Favourable treatment to conventional energy

   This mainly occurs when conventional sources are subsidized, allowing them dominate energy markets [88] with significantly lower tariffs [51]. As a consequence, WE is unable to compete in this scenario unless these advantages be eliminated [8, 101, 106, 267, 285, 350, 400]. Conventional energy sources were reported to receive favourable treatment in 25 countries, mostly developing economies with recent WE diffusion.

2. Taxes on WE

   The existence of these taxes can make the investment unattractive, discouraging private investors and companies from implementing RES projects [3]. One way to tax WE is through import duties, as previously mentioned. In addition, WE can be taxed in its generation process [514, 532], or after the electricity is commercialized, through generation income taxes [162, 287]. The occurrence of generation process/income taxes on WE was observed in 4 countries, for the most part developing economies with recent WE diffusion.

3. Non-consideration of externalities

   Conventional energy sources often produce substantial socio-environmental impacts [51, 68]. All these externalities have associated costs, which are rarely included in methods to calculate energy costs [178, 460]. The non-consideration of externalities in these calculations results in an unreal cost for conventional energy sources, hindering the cost-competitiveness of RES projects [76, 141], including wind farms [343, 386, 405, 449]. Externalities often are not considered in the formulation of energy costs, and when they are, existing methods to calculate negative impacts have provided unreliable values [51, 265, 506]. The non-consideration of externalities from conventional energy sources has been found in 13 countries mainly with developing and developed economies, and recent WE diffusion.

China, Greece and Pakistan are countries that feature all three market distortions, while for Australia, Brazil, Canada, Japan, Kazakhstan, Morocco, Taiwan, Turkey, United Arab Emirates, and United States, two market distortions are reported.

### 2.4.3 ECONOMIC AND FINANCIAL

Among the nine economic and financial barriers to RES diffusion described by Painuly [354], six were present in the reviewed studies.

1. Economic non-viability

   Economic non-viability is explained at earlier stages by the technological immaturity of wind technology. This immaturity was common in the 80s [227, 433], and despite global technological improvements, the technology is not yet cost-effective in some places [39]. In addition, viability is hindered by high generation costs, due to the unfair comparison with conventional technologies, which typically see their externality costs ignored [199, 204, 244, 267, 294, 342, 380]. Generation costs also increase significantly with high turbine prices [87, 178, 323, 392, 532] and the lack of transmission infrastructure near windy sites [66, 187, 199, 303, 348]. Even in the face of excessive costs, wind farms can be economically viable if the electricity prices applied to remunerate this generation are not too low [158, 314, 468]. This barrier was observed in 35 countries, mostly developed economies with recent WE diffusion.

2. Long-payback period

   In a wind farm investment process, the rate of return, as well the payback period, are the key criteria to decide whether to build the energy plant or not [159]. Long-payback periods were reported 8 countries, for the most part developing economies with recent WE diffusion.

3. High cost of capital

   Wind farms require a large amount of capital to be implemented, and competitive financial loans play a crucial role to enable farm construction [51, 82, 509]. However, historically, high interest rates have been applied to the loans offered to WE investments, due to improper interference of governmental policies on the cost of capital [66, 150, 209], capital shortage as consequence of financial crisis [231, 278, 303, 456], and lack of information about local WE potential and commercial viability [153, 233, 265, 387, 412]. High cost of capital was observed in 86 countries, essentially least developed and developing economies with recent WE diffusion.

4. Lack or inadequate access to capital

   Access to capital is fundamental to speed up RES developments [287, 315]. In general, the government's reluctance in providing public funding [6, 133, 407, 409, 460] and the conservatism of financial institutions [132, 194, 209, 315] have acted as the main obstacles to fundraising for the implementation of wind farms. As part of this conservative behaviour, the procedures of financing banks are too inflexible to deal with the typical risk level of WE investments, and in order to grant the loans they require wind developers to provide very strong guarantees, such as long and stable power purchasing agreements (PPAs) or their own capital [231, 275]. However, due to unstable governmental RES support, the availability of PPAs is uncertain, exposing wind developers to unpredictable wind power revenues streams [53, 75, 233, 278, 322, 392, 428]. In the absence of PPAs, only larger companies have been able to offer their own capital as guarantee, and new and small-medium wind developers have been excluded from competing in the market [46, 113, 428]. Even when PPAs are obtained and accepted as a guarantee, financial institutions often only provide small loans, with high co-financing requirements, i.e., substantial amounts of capital required from the developers to start-up the wind farm implementation [101, 233, 387]. These barriers have been reported for 48 countries in the scope of the reviewed studies, mostly developing economies with recent WE diffusion.

5. High up-front capital costs

   Wind developers need substantial financial resources to implement wind farms [119, 400]. These up-front capital costs are even higher when loans are small [101, 133, 409]. In the reviewed studies, high up-front capital costs are reported for 15 countries, the majority being developing economies with recent WE diffusion.

6. Lack or limited financial institutions or instruments

   Financial institutions play a vital role in the financing of RES projects [287]. It is advantageous for countries to have public development banks available to support wind farm implementations in the local financial environment [147], due to their ability to provide larger and more competitive funding, essential to support the high wind farm up-front costs [258]. However, financial institutions capable and willing to support wind farm development, especially public financial institutions, are lacking or operate with strong limitations in several nations. As a consequence, wind developers are forced to seek funding from commercial banks, at higher interest rates [245], thus imperilling the wind farm implementations [119]. A lack or limited financial institutions or instruments has been observed in 77 countries, mostly observed least developed economies with recent WE diffusion.

India and Turkey are particularly afflicted by this category of barriers, both featuring five of the identified barriers. Brazil, China, Pakistan, Russia and Vietnam follow, with four.

### 2.4.4 INSTITUTIONAL

Painuly [354] listed in his original framework nine barriers in the category of institutional barriers, seven of which were identified in the reviewed studies.

1. Lack of institutions and mechanisms

   Institutions and their mechanisms are fundamental for RES development [208, 320] enabling the application of legislation, regulations, standards [101, 315], and policy incentives [447], and encouraging stakeholder cooperation to effectively develop RES projects [121, 275, 445]. These institutions or mechanisms may be lacking, or when they exist, they may fail in spreading information, enhancing energy markets, creating a regulatory framework, or planning and operationalizing energy systems [354]. The lack of specialized public energy entities to support wind farm development, or the underperformance of those that exist, is a consequence of the absence of specialized capability and interest on WE, as well as uncoordinated and uncooperative behaviour. This behaviour from energy entities can lead to poor outcomes in the negotiation with foreign suppliers [150], and delays in wind farm construction [11, 209] and connection to the grid [403, 514], in addition to investors losing faith [119]. The absence of institutions and mechanisms has been mentioned as a barrier for 70 countries, mostly least developed and developing economies with recent WE diffusion.

2. Lack of a legal/regulatory framework

   Examples of unfavourable regulatory frameworks widely addressed in the reviewed studies relate to wind farm planning permission and project approval. Planning permission are hard to obtain in many places due to the lack of specific legislation [300, 339, 347], or when it exists, to its formulation and application being under the control of municipal authorities, which are influenceable by local public opposition [53, 337, 452]. After receiving permission to implement a wind farm according to planning rules, wind developers have faced time-consuming procedures to get construction and grid connection approvals in several locations [30, 38, 80, 228, 271, 302]. The reviewed studies also identified places with price regulations inappropriate for the definition of a competitive tariff to remunerate WE generation [52, 219, 254, 359]. A lack of legal/regulatory framework has been found for 27 countries, for the most part developed economies with recent or advanced WE diffusion.

3. Problems in realising financial incentives

   RES projects can be developed more rapidly and be economically viable when the implementation of financial incentives is optimized [318, 412]. The problems in realising financial incentives for wind farm implementations occur mainly due to the bureaucratic processes required to collect all the necessary documents against tight application deadlines [444] and, next, to the long-time taken to analyse the requests and release the incentives [296, 318]. Problems in realising financial incentives are noted only in 4 countries, mostly developing economies with recent WE diffusion.

4. Unstable macroeconomic environment

   An unstable macroeconomic environment has been found to hurt the implementation of wind farms when it has a negative influence on national economic growth, causes high inflation rates, or leads to an unstable currency. A slowdown in the economy reduces the demand for electricity [58, 209], rendering the prompt investment in new wind farms, as well any types of energy projects, unnecessary. A high inflation rate increases wind farm investment risks [227, 245], as it can drive implementation costs to values higher than estimated [257]. An unstable currency is a critical concern because initial investments in wind farm implementations are often in Euros or US Dollars, while electricity generation is paid in the local currency. Thereby, if the local currency fluctuates drastically, the wind farm can become unprofitable over time [147, 400]. Impact from an unstable macroeconomic environment was identified in 6 countries, essentially developing economies with recent WE diffusion.

5. Lack of involvement of stakeholders in decision making

   Stakeholder integration is essential for the implementation of wind farms, especially in emerging energy markets [147]. The lack of stakeholder engagement leads to problems with planning permissions [11, 211, 347, 448, 452] and access to the grid [197], as well as in guaranteeing a participation in national energy expansion targets [68, 323]. This barrier was reported in 7 countries, most of which developed economies at recent or advanced stages of WE diffusion.

6. Clash of interests

   RES implementations may conflict with the interests of traditional energy utilities [265, 299], which may become powerful lobbies against renewables, if they feel that their dominance is threatened [354]. These lobbies strive to maintain utility prices competitive, and discourage governments from implementing mechanisms for financial support to WE [265, 305, 428, 452] and for the internalization of the external costs from conventional source generation [460]. Besides energy utilities, private companies, environmentalist groups and other local agents can exercise strong lobbying with the capacity to delay, or even block, the implementation of wind farms [374]. The reviewed studies mentioned the occurrence of lobbies against WE in 26 countries, mainly developed economies with recent or advanced stages of WE diffusion.

7. Lack of R&D (research and development) culture

   R&D is an important driver for improving WE technology and reducing its generation costs [259, 274, 278, 395, 405, 407]. In the case of WE, insufficient R&D capability has inhibited the establishment of a local wind industry [20, 38, 119, 287, 292] and the improvement of already existing industries with in-house technology [275, 303, 399, 535] necessary to reduce the dependence on imports [198, 247, 473, 528, 531]. Moreover, weak R&D efforts affect the continuous improvement of wind technology [73, 132, 260, 494], especially in the production of reliable large wind turbines [275, 278, 496, 531], as well as its adaptation to specific climatic conditions [345, 472] and isolated areas [347]. As the large-scale implementation of wind farms depends in a critical manner on grid access, the reviewed studies also reported as a barrier limited R&D initiatives to optimize the expansion of grid infrastructure [346] and its ability to integrate high levels of WE [233, 247, 323, 496]. In the reviewed studies, insufficient efforts to develop wind R&D are reported for 22 countries, the majority being developing economies with recent WE diffusion.

Greece faces all the seven institutional barriers, and Turkey six. Brazil, China and India follow with five, and Japan, Netherlands, Norway and Taiwan with four.

### 2.4.5 TECHNICAL

Five of the six technical barriers considered by Painuly [354] were identified in the reviewed studies.

1. Lack of standards, codes and certifications

   The technical viability of RES is highly dependent on adoption and application of adequate standards and codes [320]. In the case of WE, the reviewed studies reported mainly a lack of standards for selection of imports and production of wind turbines, and grid integration codes. For wind turbine selection, cases of inappropriate procedures leading to the import of obsolete and low-quality technology were observed [77, 209, 407]. Regarding the production phase, the lack of standards has affected the production quality of large wind turbines [274, 479, 504], as well as the establishment of local wind turbine industries [244, 252] and innovation in already existing industries [345, 440, 505]. Concerning the standardization of grid codes, it has been recognized that these standards can provide the grid the stability required to integrate more WE [372, 436], however the lack of technical grid code standards for WE integration has been observed in multiple places [49, 84, 137, 377]. The reviewed studies mentioned the lack of standard, codes and certifications in 12 countries, mainly developing economies with recent WE diffusion.

2. Lack of skilled personnel

   Skilled personnel is fundamental to install, operate, maintain [51] and further expand the implementation of RES [421], and includes policy analysts, teachers, scientists, researchers and engineers [106, 492]. In the case of WE, to implement wind farms in a large scale a considerable volume of skilled personnel [198] is necessary. However, their availability around the world, except for Denmark [269], has been scarce [147, 249]. The shortage of WE specialized personnel is felt for various functions, including wind technology R&D [496], WE education and training [492], project development [119, 456], implementation [5, 302], maintenance [30, 339, 456], wind farm operation and management [297, 530], and wind turbine manufacturing [527, 530]. To achieve future WE expansion targets, more specialized labour will be needed [30, 222, 315, 494, 533], and insufficient WE education and training efforts have contributed even more to this shortage of personnel [6, 315, 404, 439, 492]. This barrier was reported in 74 countries, most of which least developed and developing economies with recent WE diffusion.

3. Lack of O&M facilities

   The availability of operation and maintenance (O&M) facilities is one of the prerequisites for a successful implementation of WE [275]. The services offered by these facilities can avoid the occurrence of defective components/turbines, which leads to unplanned wind farm downtimes and consequent revenue losses [153, 385]. These services are typically provided by wind component/turbine manufacturers, but most are located overseas, which delays O&M execution [209, 323]. In an attempt to overcome the lack of O&M facilities, wind developers have tried to perform this service themselves, but without success due to their inexperience with these activities [527]. Insufficient availability of O&M facilities was identified in 8 countries, essentially developing economies with recent WE diffusion.

4. System constraints

   The intermittent nature of WE leads to a volatile and less controllable electricity supply [85, 241, 265]. This has restricted the diffusion of WE, since the integration of WE on grids has been a challenging and difficult task [27, 157, 188, 225, 382, 431], due to the need to handle carefully its potential harmful effects on power quality [405], grid scheduling plans [160, 271, 426], grid stability [198, 258, 308, 510], and supply-demand adequacy [34, 330, 348, 488, 507]. These harmful effects are exacerbated by the presence of weak grid infrastructures, featuring congestion or transmission losses [61, 160, 233, 398]. Weak grid infrastructures, resulting from inexistent or insufficient high-voltage transmission lines, are a worldwide constraint to WE integration [275, 525, 526], inhibiting the implementation of new wind farms, or even curtailing existing ones [3, 249, 489, 493], leading to large revenues losses [228, 250, 318]. System constraints were noted in 52 countries, mostly least developed and developing economies with recent WE diffusion.

5. Unreliable product

   In the case of WE, the reviewed studies report mainly cases of product unreliability with wind turbine manufacturing. The absence of defective components in wind turbines is critical to avoid under-performance or breaking off, which lead to lost revenues [153]. Quality deficiencies reported in the literature are broadly associated with the production of bearings [478], rotor blades [209, 504], gearboxes [278, 504], converters [478], and control systems [209, 478, 504]. Moreover, many wind turbines are observed to run in underproductive regimes in many farms due to inadequate equipment selection [77, 247], improper preventive maintenance [209, 212, 247, 275], poor adaptation to local conditions, such as climate and wind regime [399, 472, 505], wrong micro-siting [247, 275, 323], and weak wind resources [25, 83, 158, 228, 347, 480]. Unreliable wind turbines can, in addition, interfere with the reliability of power grids [193, 505] and increase the risk of accidents [213, 504, 527], with damages to lives and properties [332]. Unreliability of wind turbines has been found for 12 countries, for the most part developing economies with recent WE diffusion.

China and India face a noteworthy burden in this category, both featuring all the five identified barriers. Pakistan, Taiwan and Turkey follow, with four, and Brazil, Japan, Lebanon, Nigeria, Serbia and Thailand with three technical barriers.

### 2.4.6 SOCIAL

The two social barriers to the diffusion of RES cited by Painuly [354] were also identified in the reviewed studies.

1. Lack of consumer acceptance

   Consumer acceptance of wind farms is mainly achieved with the disclosure of proper information [80, 199]. This information needs to be prepared highlighting the benefits of wind generation in comparison with conventional sources, and effectively shared among the public [471]. In general, the public needs to become aware of the total costs of conventional sources, in order for the perception of economic disadvantage assigned to WE to be eliminated [460], and consequently for the willingness to pay for it to increase [166]. However, WE is still broadly unknown in multiple places, where consumers have insufficient information or are misinformed about its overall benefits. The general public has experienced difficulty to get to know and fully understand the benefits of WE [379, 462], due the absence of successful demonstrations [326, 465], educational efforts [8, 17, 326, 380, 404, 509] and public information campaigns [8, 17, 103, 380]. Consumers misconceptions normally exist because the media convey negative messages about WE [97, 334], sometimes biased towards cases of local opposition [194, 455]. In addition, public acceptance of WE has suffered because many people believe that wind turbines drastically change landscapes visually [54, 356, 363, 433, 484]. The opposition to WE has been intensified by the opposition to transmission lines, resulting from their negative impacts on landscape [89, 134, 143, 418], as well as on property value, biodiversity [110] and human health [253, 348, 512]. Lack of consumer acceptance was identified in 91 countries, essentially least developed and developing economies with recent WE diffusion.

2. Lack of social acceptance

   The analysed literature recognizes that social/local community acceptance can be a powerful barrier to the diffusion of WE [70, 192, 339, 381, 462, 490], due to its ability to slow down [11, 14, 142, 334, 452] or even stop [349, 383, 469, 470] the implementation of wind farms. Local communities justify their opposition with their concerns about visual impacts, annoyance factors such as noise, light and shadow flicker, and effects on wildlife [88, 109, 194, 393, 442, 485]. The visual impact of turbines on landscapes has been a dominant motive of local opposition [54, 214, 338, 356, 357, 401, 485]. This impact has been described by the literature as a subjective matter [99, 194, 433], usually invoked by locals in association with economic value variations [451]: for those who collect economic benefits from installed turbines, land occupation and visual impacts are minimal or non-existent [36], while for those with existing economic benefits at risk, such as the possibility of loss of property value [7, 53, 330, 347] or limitations to tourism activity [146, 154, 257, 425], land occupation and visual impact are a true concern. Furthermore, and still related to the economic viewpoint, the threat of job losses as a consequence of replacing conventional energy plants by WE, has contributed to local opposition [424, 460]. Indeed, economic interests have a strong influence on local acceptance of wind farms [86, 280]. In addition, experts have indicated that soon annoyance factors, such as disturbances caused by noise pollution, will replace visual impacts as the main motive for local opposition [309], due to their potential to cause a range of health risks for those who live near wind farms [48, 90, 135, 268, 457]. Lastly, the impacts on wildlife have gained emphasis among the motives for local opposition, mainly for the cases of avifauna mortality [136, 307, 442, 455, 475]. These impacts have been minimized, since wind turbines are less noisy than traffic on a highway [258] and the number of dead avifauna is extremely low in comparison with other common causes [258, 422, 423]. Based on at least one of these motives, the reviewed studies reported the occurrence of local opposition to wind farm implementation in 25 countries, mostly developed economies in recent or advanced stages of WE diffusion.

The occurrence of this barrier is often explained by the literature as the result of the “Not In My Backyard” (NIMBY) effect [57, 170, 349, 428], i.e., citizens generally agreeing with a given project (not necessarily related to energy) only if it is implemented far from their “backyard” [384]. However, this concept has been criticized for being too simplistic [219, 486], and unable to fully explain the local opposition against wind farms [218, 375, 432, 441]. In general, the reviewed studies verified that local opposition to wind farms has not been avoided due to the lack of community involvement in wind project permitting and development [12, 70, 190, 256, 262, 279, 351, 363, 417, 451, 513].

Australia, Brazil, Canada, Czech Republic, Germany, Greece, India, Italy, Japan, Mexico, Norway, Poland, Spain, United Kingdom and United States are all countries featuring both barriers.

### 2.4.7 Other Barriers

Among four other barriers described by Painuly [354], two were identified in the reviewed studies.

1. Uncertain governmental policies

   Among policies to foster wind farm implementation, support schemes such as feed-in tariffs, feed-in premiums, tenders, quota obligations [246] are the most important [59, 106, 117, 163, 344, 371, 427]. Without these, it is difficult to implement wind farms, as well as other RES, because they are not yet cost-competitive in comparison with conventional energies [68, 101, 118, 452, 463], especially when externalities are not considered [343, 386, 405, 449]. Besides their absence, the analysed literature reports instances of improper designs, instability, reductions, interruptions and even removal of the support schemes. In general, unstable support schemes lead to increased insecurity from the private-sector investment [45, 100] which may affect the profitability of wind farms [147, 415]. Indeed, due to its impact on the long-term rate of return [72], wind developers prefer that the support schemes be stable more than attractive [444], and avoid investing in countries with a history of volatile policies [367]. It must be recognized that support scheme design and implementation is replete of challenges and missteps [151, 463], and rethinking their development and use [104, 306, 340, 372, 467] is fundamental to further promote WE diffusion [203, 264].

   In addition, the analysed literature reports that uncertain governmental policies have inhibited the establishment of a wind industry structure [73, 132, 197, 275, 317, 321, 460, 516], wind industry technical standards and certifications [142, 209, 275, 403, 436, 504], WE R&D efforts and education [3, 247, 321, 402, 460, 504, 527], financing channels to wind farm projects [38, 76, 95, 144, 199, 315, 364, 434, 460], optimized public administrative procedures to perform wind farms construction approvals [100, 236, 267, 300], effective environmental licensing procedures [46], adequate spatial planning to siting wind turbines [136, 178, 485], actions to minimize social opposition to wind projects [123, 195, 201], transmission infrastructure and integration of wind farms on grid [143, 249, 271, 275, 287, 296, 317, 346, 436, 460, 488, 489, 498, 514, 520, 525].

Several studies highlighted that the lack adequate policies for WE is a consequence of distorted policies in favour of conventional energy sources [68, 150, 195, 364, 439, 460] and lack of political commitment to wind power development [17, 38, 66, 70, 82, 141, 204, 315, 324, 343, 380, 404, 439, 446, 460, 509]. Regarding political commitment, many politicians justify the lack of support with the argument that increasing WE, as well as other RES, would increase electricity costs for the population [51, 66, 234, 380]. In fact, paying less for electricity sounds good for politicians and consumers, however this behaviour defeats the efforts to mitigate climate change and improve energy security [295].

Uncertain governmental policies were noted in 114 countries, mostly least developed and developing economies with recent WE diffusion. In addition, this barrier was found to be the most experimented obstacle to large-scale onshore wind energy implementation all over the world.

2. Lack of infrastructure

   Infrastructures such as roads, ports, communications, and transmission and distribution networks, are fundamental to explore RES [320], and their development is central for the expansion of RES [63, 143]. In the case of WE, windy sites are quite often far from the densely-populated regions where electricity demand is higher [142, 248, 365, 414, 511], increasing the dependence of wind farm implementations on the availability of transmission lines [44, 310, 479]. Preferably, these lines need to be extended near windy sites, to avoid high grid connection costs [107, 257, 433], but transmission reinforcements have been affected by the lack of development plans [372] or, when these exist, by uncertainty in the location of wind farms [177], administrative procedures [66, 249], technical challenges [157, 275], or very high implementation costs [3, 178, 185, 265, 289]. Moreover, even when approved for implementation, these plans may not deliver the new lines according to schedule [527] and delay wind farm operation start-up [101]. In terms of logistics infrastructure, the existence of robust roads and bridges is essential to the delivery of heavy and large wind turbines and components to the farm sites [257]. This kind of infrastructure, when properly available, avoids transportation disruptions which may lead to equipment damages and start-up delays, and consecutively to revenue loss [153].

Considering grid system constraints as evidence of insufficient grid infrastructure, the reviewed studies reported the occurrence of lack of infrastructure in 110 countries, mostly least developed and developing economies with recent WE diffusion. This barrier was the second most reported obstacle, right next to uncertain governmental policies.

## 2.5 DISCUSSION

Among the 41 barriers to RES penetration described by Painuly [354], this SLR confirmed that 31 barriers, from seven categories, have played a role in hindering worldwide diffusion of onshore WE in large-scale.

The 10 barriers are out of this final count was due two reasons. The first one is because five barriers were related to others six identified, as the case of high investment requirements with high up-front capital costs [119, 400], trade barriers with restricted access to technology and taxes on WE [354], lack of entrepreneurs and lack of private sector participation with lack of competition [62, 66, 324, 400] and environmental with lack of consumer [54, 356, 363, 433, 484] and social acceptance [88, 109, 194, 393, 442, 485]. The second reason was simply because another five barriers it has not been found in the literature, as the case of high discount rates, market size small, lack of access to credit to consumers, lack of professional institutions and high-risk perception for WE technology. Thus not considering the five related barriers, the following framework demonstrated an adjustment of 75.6% in the analyse of the barriers to onshore WE implementation identified in the 529 reviewed studies.

Mostly of these 31 barriers has occurred in developing economies with a recent introduction of WE. However, except for the technical and other barriers (uncertain governmental policies and lack of infrastructure) categories, all other categories had at least one barrier with broad occurrence in developed economies, regardless of their stage in terms of WE diffusion.

From the six market failures identified, lack of competition and high transaction costs were widely reported for developed economies, in this case with advanced WE diffusion, mainly for economies that failed to liberalize their energy markets, and thus to encourage competition and establish efficient energy market procedures and infrastructure [460].

Only one of the three reported market distortions, the non-consideration of externalities, was largely connected to developed economies – here with a recent WE diffusion – with an unfavourable treatment of WE vis-à-vis its competitors, which are economically benefited and consequently achieve a higher insertion in energy matrices [312, 347, 435].

Similarly, only one among six economic and financial barriers, economically not viable, was broadly associated with developed economies – here as well with recent WE diffusion. These countries have mainly been failing to provide the effective support schemes [396] and financial mechanisms [122, 194, 336] that are fundamental to deal with the high upfront costs that are intrinsic to wind farm implementations [60].

Three of seven institutional barriers observed – lack of legal/regulatory framework, lack of involvement of stakeholders in decision making, and clash of interests – were widely reported for developed economies with both recent and advanced stages of WE diffusion, lacking public and private organizations with a strong interest in supporting WE [324, 477], prepared to confront adverse conditions, either unfavourable macroeconomic scenarios [58, 227, 400] or opposition from traditional energy utilities [140, 292, 380, 428, 460].

Only one of the two observed social barriers, lack of social acceptance, was broadly linked to developed economies, regardless of the stage of WE diffusion, that suffer from the implementation of wind farms being generally conducted without public awareness and community engagement [12, 70, 190, 256, 262, 279, 351, 363, 417, 451, 513].

As mentioned above, technical barriers, uncertain governmental policies, and insufficient transmission and logistic infrastructure were typically observed in least developed and developing economies, especially with recent WE diffusion. Nonetheless, the last two are respectively the first and second most reported barriers. They are followed by poor market infrastructure, lack of information and awareness, lack of consumer acceptance, as the top five barriers. Furthermore, the five less reported barriers were problems in realising financial incentives, taxes on wind energy, unstable macroeconomic environment, restricted access to technology and lack of involvement of stakeholders in decision making.

Among these seven barrier categories, the literature reviewed has frequently addressed issues around the other barriers, namely about the uncertain governmental policies and their unproperly support schemes, barely indicating the existence of market distortions and its interference on WE competitiveness. In fact, even with some design limitations, the support schemes have been decreasing the competitive gulf between the RES and conventional energy sources [68, 101, 118, 452, 463].

It may be argued that inadequate policies and support schemes are the main reasons for the existence of barriers to WE diffusion [28, 153, 287]. However, this may not be generalized to the level of impact due to the fact that, according to several studies, different drivers and barriers are among those that highest impact the WE diffusion in different locations:

- Argentina: support schemes with inadequate designs [378];
- Australia: subsides to conventional energy sources [388] and insufficient transmission infrastructure [300];
- Belarus: lack of general information about WE [376];
- Bangladesh: misinformation about the WE benefits [23];
- Brazil: absence of recent, detailed and accurate wind data, subsides to conventional energy sources, weak grid infrastructure [304], high initial capital costs [304, 360] and support schemes with inadequate designs [46, 113, 304];
- Canada: support schemes with inadequate designs [460];
- Caribbean Region: lack of access to capital for the financing of wind farms [181];
- Chile: support schemes with inadequate designs [46];
- China: high initial capital costs [178, 294, 532], shortage of WE specialized personnel [179, 247], weak grid infrastructure [302], wind curtailment [503], support schemes with inadequate designs [150, 178, 197, 271] and insufficient transmission infrastructure [178, 184, 193, 271, 275, 479, 505, 531, 532];
- Czech Republic: powerful lobbying against WE from the conventional energy sectors [380];
- Denmark: unfavourable regulations to obtain planning consent [335] and local community opposition to wind farms [425];
- Estonia: support schemes with inadequate designs [96];
- France: local community opposition to wind farms [123];
- Germany: insufficient transmission infrastructure [346];
- Greece: subsides to conventional energy sources, high initial capital costs, lack of access to capital for the financing of wind farms, unfavourable regulations to obtain planning consent [122] and insufficient transmission infrastructure [122, 347];

- India: high initial capital costs, public energy entities not encourage coordination and cooperation, support schemes with inadequate designs [216] and lack of access to capital for the financing of wind farms [133, 216];
- Iran: subsidized electricity tariffs [103];
- Japan: powerful lobbying against WE from the conventional energy sectors, weak grid infrastructure and support schemes with inadequate designs [324];
- Kyrgyzstan: misinformation about the WE benefits [284];
- Lebanon: lack of support schemes [204];
- Lithuania: high initial capital costs [149];
- Morocco: generation monopoly and subsidized electricity tariffs [341];
- New Zealand: unfavourable regulations to obtain planning consent [400];
- Nigeria: lack of support schemes [6];
- Norway: support schemes with inadequate designs [62];
- Pakistan: absence of recent, detailed and accurate wind data [2], lack of access to capital for the financing of wind farms and generalized lack of knowledge about WE [377];
- Poland: powerful lobbying against WE from the conventional energy sectors [380];
- Russia: insufficient transmission infrastructure [66];
- South Africa: lack of general information about WE [404];
- Sub-Sahara Africa: lack of support schemes [326];
- Spain: weak grid infrastructure [107, 316];
- Sweden: unfavourable regulations to obtain planning consent [53] and local community opposition to wind farms [417];
- Taiwan: lack of support schemes [509];
- Turkey: high initial capital costs, weak grid infrastructure [339] and public energy entities not encourage coordination and cooperation [239];
- United Arab Emirates: high initial capital costs [314];
- United Kingdom: absence of recent, detailed and accurate wind data [369], unfavourable regulations to obtain planning consent [169] and misinformation about the WE benefits [52, 433];
- United States: unfavourable regulations to obtain planning consent [481] and support schemes interruptions [350].

In general, the countries with significant WE installed capacity (≥ 1GW) were those which had experimented more barriers (≥10). China, the world top one with 188 GW installed, by far was the world and Asian nation which the reviewed studies indicated the occurrence of more obstacles to onshore WE implementation. The same trend was still verified in Asia with India and Japan, as well in Africa with South Africa, Europe with Greece, Turkey and United Kingdom, Latin America & Caribbean with Brazil, North America with United States, Canada and Mexico, and Pacific region with Australia. Countries with significant WE installed capacity, which had experimented few barriers (<10) are found mainly found in Europe nations, such as Germany, Spain, France, Italy, Sweden, Poland, Denmark and especially Portugal, with only 2 barriers reported.

## 2.6 CONCLUSIONS

This work presents a systematic review of barriers to implementing onshore WE in large-scale, highlighting their location, the patterns of economic situation and level of WE diffusion in the location, and their level of impact.

To identify and summarize these barriers, a theoretical framework proposed by Painuly [354], consisting of 41 barriers to RES implementation grouped according to seven categories, was used as a starting point. The findings confirm the adequacy of the categories. However, for the case of large-scale onshore WE implementation, only 31 barriers were reported in the reviewed studies, which suggests the interest of a more restricted and specific framework.

From this whole theoretical knowledge analysed, it is possible to conclude that the successful WE expansion highly depends of political commitment to establish financial support schemes, technological efforts to build a local supply chain and especially infrastructural reinforcements to integrate on grids this new decentralized way of generating electricity. Thus, it was not a surprise verified that mostly of the barriers found by this review had occurred with developing economies with recent experience in WE diffusion.

However, it's worrying acknowledge that several advanced economies, despite their significant level of WE installed capacity, still do not have an energy market fully liberalized, which consider the social and environmental externalities generated by the conventional sources, as main reason to invest massively on WE as well in the other RES.

Moreover, the reviewed literature provides arguments to state that "learning by doing" is not an appropriate strategy to drive a national WE diffusion, once China, India, Brazil, Turkey and other countries with more relevant installed capacity in their continents are those who face the greatest number of barriers. Despite facing few barriers, the European countries such as Germany, Spain, France, Italy, Sweden, Poland, Denmark and Portugal, are successful cases of WE diffusion to be benchmarked by those nations which wants to expand sustainably the source utilization.

Lastly, must be highlighted that political commitment towards RES is the key to the existence of those schemes as well as infrastructure, in addition to other conditions favouring the development of wind farms. Nevertheless, political will is always subject to uncertainty, even in fundamental matters for human life such as the decarbonisation of the economy and climate change. In this sense, it is likely that large scale onshore WE implementation across the world will always be constrained by barriers.

For this reason, updating and expanding studies similar to this one is highly relevant for academics, policy makers, and especially for practitioners, who benefit from being aware about barriers, their patterns of occurrence, and how they are hindering the implementation of wind farms. Especially for wind developers, the information included in this type of study may be very useful in decision processes for the implementation of wind farms in specific countries, as well as in the definition of strategies to mitigate barriers, when they intend to or have already carried out investments in a specific country with a specific profile of existing barriers.

Natural extensions to this would include the inclusion of studies presented in conferences and articles not published in English, as well as more detailed studies focusing on specific barrier categories. A systematized review of efforts to overcome these barriers across the world would also be relevant, with a focus on the enhancement of both public policies and wind farm project plans.

## APPENDIX

Supplementary data related to this chapter can be found at: Appendix A, Appendix B, Appendix C and Appendix D.

# APPENDIX A

Table 2.3 – Barriers to onshore wind energy implementation per country/region identified in this SLR

| Barrier | | Country/Region | References |
|---|---|---|---|
| MARKET FAILURES | | | |
| Highly controlled energy sector *(11 Countries)* | Generation monopoly | China | [68, 273, 287, 476, 524, 534] |
| | | Japan | [323, 460, 461] |
| | | Morocco | [341] |
| | | Serbia | [252] |
| | | South Africa | [404] |
| | | Sweden | [477] |
| | | Taiwan | [460, 509] |
| | | Vietnam | [342, 343] |
| | Transmission monopoly | Australia | [460] |
| | | Canada | [460] |
| | | China | [165, 193, 277, 287] |
| | | Japan | [460, 461] |
| | | Russia | [301] |
| Lack of information and awareness *(91 Countries)* | Lack of recent, detailed and accurate wind data | Africa | [310, 483] |
| | | Arabian Peninsula | [501] |
| | | Austria | [152] |
| | | Bangladesh | [398] |
| | | Brazil | [304, 345, 360] |
| | | Bosnia & Herze. | [536] |
| | | Botswana | [127] |
| | | Cambodia | [343] |
| | | China | [68, 276, 288, 298, 302, 505, 527, 534] |
| | | India | [209, 407] |
| | | Indonesia | [183] |
| | | Iran | [8] |
| | | Japan | [460] |
| | | Laos | [343] |
| | | Lebanon | [244] |
| | | Maldives | [465] |
| | | Malta | [134] |
| | | Mexico | [79] |
| | | Nepal | [439] |
| | | Nigeria | [6] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| MARKET FAILURES | | | |
| Lack of information and awareness *(91 Countries)* | Lack of recent, detailed and accurate wind data | North Korea | [499] |
| | | Oman | [19] |
| | | Pakistan | [2, 33, 37, 56, 377] |
| | | Russia | [301] |
| | | Taiwan | [83, 460] |
| | | Thailand | [343] |
| | | Turkey | [257, 339, 412] |
| | | Vietnam | [119, 343] |
| | | United Kingdom | [369] |
| | Lack of general information about wind energy | Belarus | [376] |
| | | Cambodia | [343] |
| | | China | [276, 289] |
| | | Greece | [347] |
| | | Iraq | [240] |
| | | Italy | [132] |
| | | Laos | [343] |
| | | Lebanon | [204] |
| | | Malaysia | [144] |
| | | Maldives | [465] |
| | | Mexico | [79] |
| | | Nigeria | [17, 26, 38] |
| | | North Korea | [499] |
| | | Oman | [19] |
| | | Pakistan | [2, 33, 321] |
| | | Russia | [301] |
| | | South Africa | [404] |
| | | Sri Lanka | [480] |
| | | S. Sahara Africa | [326, 387] |
| | | Taiwan | [84] |
| | | Thailand | [343] |
| | | Turkey | [82, 239, 352] |
| Restricted access to technology *(7 Countries)* | High customs duties for wind turbines | Bangladesh | [398] |
| | | China | [150, 275, 276, 287] |
| | | Egypt | [392] |
| | | Maldives | [465] |
| | | Nigeria | [17] |
| | | Oman | [20] |
| | | Pakistan | [37] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| MARKET FAILURES | | | |
| Lack of competition *(10 Countries)* | Prohibitive and unwieldy regulations for entry of new competitors | China | [131, 267, 275, 289, 532] |
| | | Japan | [324] |
| | | Netherlands | [11] |
| | | New Zealand | [242, 400] |
| | | Norway | [62] |
| | | Russia | [66] |
| | | United Kingdom | [428] |
| High transaction costs *(10 Countries)* | To approve the implementation of wind farms | China | [223, 287] |
| | | India | [209] |
| | To construct and connect wind farms to the grid | Australia | [300] |
| | | China | [223, 282] |
| | | Greece | [122] |
| | | South Africa | [473] |
| | | Spain | [107, 452] |
| | To establish Power Purchase Agreements (PPAs) | China | [287] |
| | | United Kingdom | [428] |
| Poor market infrastructure *(93 Countries)* | Home wind industry at early stage | Algeria | [189] |
| | | Caribbean | [487] |
| | | Lebanon | [244] |
| | | Nigeria | [15, 17, 38] |
| | | South Africa | [473] |
| | | Sri Lanka | [480] |
| | | Sub-Sahara Africa | [326] |
| | Underdeveloped home wind industry | Brazil | [31, 98, 113, 156] |
| | | Bosnia & Herze. | [536] |
| | | China | [68, 115, 138, 178, 179, 223, 230, 247, 267, 271, 273, 275, 276, 278, 282, 287, 288, 438, 494, 521, 524, 527, 529, 532, 534] |
| | | Finland | [35] |
| | | Greece | [122] |
| | | Italy | [132] |
| | | India | [413] |
| | | Japan | [323] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| MARKET FAILURES | | | |
| Poor market infrastructure *(93 Countries)* | Underdeveloped home wind industry | Mexico | [78, 361] |
| | | Norway | [73] |
| | | Pakistan | [3, 320, 321, 377] |
| | | Poland | [72] |
| | | Russia | [66, 416] |
| | | Serbia | [370] |
| | | Thailand | [399] |
| | | Turkey | [239, 339] |
| | | United States | [30, 429, 440] |
| | | Vietnam | [119] |
| MARKET DISTORTIONS | | | |
| Favourable treatment to conventional energy *(25 Countries)* | Subsidies to conventional energy generation | Australia | [388, 459, 460] |
| | | Brazil | [304] |
| | | Canada | [311, 460] |
| | | Canary Islands | [77] |
| | | China | [267, 285] |
| | | Greece | [122, 347] |
| | | Japan | [460, 461] |
| | | Malaysia | [144] |
| | | Morocco | [255] |
| | | Nepal | [439] |
| | | New Zealand | [400] |
| | | Nigeria | [17] |
| | | Pakistan | [2, 56, 320] |
| | | Russia | [301] |
| | | Serbia | [47, 252] |
| | | Sweden | [477] |
| | | Taiwan | [460] |
| | | Turkey | [239] |
| | | United States | [350] |
| | | U. Arab Emirates | [314] |
| | Subsidized electricity tariffs | Egypt | [22, 392] |
| | | Iran | [8, 103] |
| | | Kazakhstan | [234] |
| | | Morocco | [341] |
| | | Oman | [19, 20, 314] |
| | | U. Arab Emirates | [20, 314] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| MARKET DISTORTIONS | | | |
| Taxes on wind energy *(4 Countries)* | High taxes on wind energy generation | China | [267, 514, 532] |
| | | Turkey | [412] |
| | Taxes on wind energy generation incomes | China | [287] |
| | | Greece | [162] |
| | | Pakistan | [37] |
| Non-consideration of externalities *(83 Countries)* | Exclusion of externalities in the calculation of energy costs | Australia | [4, 460] |
| | | Brazil | [410] |
| | | Caribbean | [181] |
| | | Canada | [141, 311, 386, 460] |
| | | China | [68, 150, 178, 273, 274, 436] |
| | | Europe | [312] |
| | | France | [141] |
| | | Greece | [347] |
| | | Japan | [460, 461] |
| | | Kazakhstan | [234] |
| | | Lithuania | [435] |
| | | Maldives | [465] |
| | | Pakistan | [56, 377] |
| | | Taiwan | [460] |
| | | United States | [350] |
| | | U. Arab Emirates | [314] |
| | | Vietnam | [342, 343] |
| ECONOMIC AND FINANCIAL | | | |
| Economically not viable *(35 Countries)* | Immaturity of wind technology in terms of generation and cost-effectiveness | Finland | [34] |
| | | Indonesia | [39] |
| | | Japan | [460] |
| | | Philippines | [39] |
| | High initial capital costs | Brazil | [304, 360] |
| | | Bulgaria | [380] |
| | | China | [68, 150, 178, 199, 267, 271, 278, 287, 288, 294, 515, 532] |
| | | Cyprus | [380] |
| | | Czech Rep. | [380] |
| | | Estonia | [380] |
| | | Hungary | [380] |
| | | India | [233] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| ECONOMIC AND FINANCIAL | | | |
| Economically not viable *(35 Countries)* | High initial capital costs | Japan | [323] |
| | | Latvia | [380] |
| | | Lithuania | [149, 380] |
| | | Malta | [380] |
| | | New Zealand | [400] |
| | | Pakistan | [320] |
| | | Poland | [72, 380] |
| | | Romania | [380] |
| | | Slovakia | [380] |
| | | Slovenia | [380] |
| | | Turkey | [339, 380, 412] |
| | | United States | [440] |
| | | Vietnam | [342] |
| | Low electricity prices to remunerate wind energy generation | Algeria | [158] |
| | | Azerbaijan | [468] |
| | | China | [178, 271, 275, 497, 532] |
| | | Denmark | [202] |
| | | Egypt | [158] |
| | | Georgia | [158] |
| | | India | [353, 413] |
| | | Libya | [158] |
| | | Montenegro | [158] |
| | | Norway | [396] |
| | | Pakistan | [37] |
| | | Serbia | [158] |
| | | Syria | [158] |
| | | U. Arab Emirates | [314] |
| Long payback period for wind farm investments *(8 Countries)* | Long-term rate of return | China | [534] |
| | | Japan | [323] |
| | | Jordan | [120] |
| | | Lithuania | [149] |
| | | Malaysia | [392] |
| | | Mexico | [79] |
| | | Russia | [416] |
| | | Sri Lanka | [480] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| ECONOMIC AND FINANCIAL | | | |
| High cost of capital *(86 Countries)* | High interest rates on loans for wind farm development | Brazil | [245] |
| | | Caribbean Region | [487] |
| | | China | [150, 278, 318, 514] |
| | | Greece | [303] |
| | | India | [133, 209, 233, 379, 409] |
| | | Nepal | [439] |
| | | Russia | [66] |
| | | Portugal | [303] |
| | | South Africa | [473] |
| | | Spain | [303] |
| | | Sri Lanka | [480] |
| | | Sub-Sahara Africa | [326] |
| | | Taiwan | [200] |
| | | Tanzania | [387] |
| | | Turkey | [412] |
| | | Ukraine | [456] |
| | | Vietnam | [119] |
| Lack or inadequate access to capital (48 Countries) | Lack of access to capital for financing wind farms | Azerbaijan | [468] |
| | | Caribbean | [181] |
| | | China | [178, 278] |
| | | Greece | [122, 336] |
| | | Eritrea | [175] |
| | | India | [133, 209, 216, 233, 243, 409] |
| | | Nigeria | [6, 38] |
| | | Pakistan | [320, 377] |
| | | Russia | [301] |
| | | Taiwan | [460] |
| | | Turkey | [232, 239] |
| | | Ukraine | [456] |
| | Difficult access to capital for wind farm implementation | Brazil | [31, 46, 101] |
| | | Canada | [194, 460] |
| | | Chile | [46] |
| | | China | [114, 223, 235, 275, 278, 534] |
| | | France | [315] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| ECONOMIC AND FINANCIAL | | | |
| Lack or inadequate access to capital *(48 Countries)* | Difficult access the capital for wind farm implementation | Germany | [428] |
| | | India | [233, 379, 407] |
| | | Italy | [132] |
| | | Maldives | [465] |
| | | Nigeria | [6, 17, 26] |
| | | Sweden | [53] |
| | | Switzerland | [194] |
| | | Taiwan | [460] |
| | | Tanzania | [387] |
| | | Thailand | [399] |
| | | Turkey | [82, 352] |
| | | United States | [58, 65] |
| | | United Kingdom | [75, 113, 428] |
| High up-front capital costs *(15 Countries)* | High initial costs for wind farm implementation | Algeria | [189] |
| | | Azerbaijan | [468] |
| | | Brazil | [304] |
| | | China | [223, 276, 438] |
| | | Greece | [122] |
| | | India | [216, 297, 397, 413] |
| | | Lebanon | [204, 244] |
| | | Nigeria | [26] |
| | | Mexico | [78] |
| | | Pakistan | [37, 41, 42, 207] |
| | | Tanzania | [387] |
| | | Turkey | [239, 339, 412] |
| | | U. Arab Emirates | [314] |
| | | Vietnam | [119] |
| | | Yemen | [18] |
| Lack or limited financial institutions or instruments *(77 Countries)* | Lack of financial institutions | Africa | [483] |
| | | Bulgaria | [380] |
| | | Cyprus | [380] |
| | | Czech Republic | [380] |
| | | Eritrea | [175] |
| | | Estonia | [380] |
| | | Hungary | [380] |
| | | Latvia | [380] |
| | | Lithuania | [380] |
| | | Malta | [380] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| ECONOMIC AND FINANCIAL | | | |
| Lack or limited financial institutions or instruments *(77 Countries)* | Lack of financial institutions | Nepal | [171] |
| | | Pakistan | [320] |
| | | Poland | [380] |
| | | Romania | [380] |
| | | Slovakia | [380] |
| | | Slovenia | [380] |
| | | Turkey | [380, 412] |
| | Limited availability of financial institutions | India | [209] |
| | | Sub-Sahara Africa | [326] |
| | | Taiwan | [200] |
| | Inexistence of specific loan channels for wind farm developments | France | [315] |
| | | Oman | [20] |
| | | Russia | [66] |
| | | Turkey | [239] |
| | | Vietnam | [119] |
| | | Yemen | [18] |
| | Limited existence of specific loan channels for wind farm developments | China | [287, 318] |
| | | Ghana | [394] |
| | | Sri Lanka | [480] |
| INSTITUTIONAL | | | |
| Lack of institutions and mechanism *(70 Countries)* | Lack of specialized public energy entities | Belarus | [376] |
| | | Vietnam | [343] |
| | | Yemen | [18] |
| | Entities with lack of specialized capability | Brazil | [101] |
| | | Eritrea | [175] |
| | | Lebanon | [204] |
| | | Nepal | [171] |
| | | Serbia | [370] |
| | Entities with lack of interest in wind energy | Azerbaijan | [468] |
| | | Bangladesh | [398] |
| | | Botswana | [127] |
| | | China | [298] |
| | | India | [209, 379] |
| | | Indonesia | [183] |
| | | Japan | [324] |
| | | Nepal | [439] |
| | | Nigeria | [6, 16, 17] |
| | | Pakistan | [319] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| INSTITUTIONAL | | | |
| Lack of institutions and mechanism *(70 Countries)* | Entities with lack of interest in wind energy | Sweden | [477] |
| | | Taiwan | [509] |
| | | Africa | [483] |
| | Public energy entities not encouraging coordination and cooperation between them, wind developers and other stakeholders | China | [137, 150, 230, 273, 275, 403, 514] |
| | | Finland | [217] |
| | | Greece | [336, 355] |
| | | India | [216, 217, 243] |
| | | Nepal | [171] |
| | | Netherlands | [11] |
| | | Pakistan | [320, 321, 377] |
| | | Serbia | [370, 391] |
| | | Turkey | [124, 239, 412] |
| Lack of a legal/regulatory framework *(27 Countries)* | Regulations unfavourable to planning consent for wind farms | Australia | [148, 176, 300] |
| | | Denmark | [335] |
| | | France | [337] |
| | | Germany | [75] |
| | | Greece | [122, 347, 355] |
| | | Netherlands | [10, 11, 452] |
| | | New Zealand | [242, 400] |
| | | Poland | [72, 206, 419] |
| | | Spain | [452] |
| | | Serbia | [391] |
| | | Sweden | [53, 417, 477] |
| | | Turkey | [339, 352] |
| | | United States | [155, 440, 481] |
| | | United Kingdom | [75, 113, 169, 433, 452] |
| | Time-consuming procedures to get construction and grid connection approvals | Brazil | [46, 113] |
| | | Chile | [46] |
| | | China | [276, 392, 534] |
| | | Greece | [226, 347, 355] |
| | | India | [209, 297, 413] |
| | | Italy | [411] |
| | | Mexico | [24] |
| | | Russia | [301] |
| | | Spain | [107, 161] |
| | | Turkey | [124, 239, 352] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| INSTITUTIONAL | | | |
| Lack of a legal/regulatory framework | Time-consuming procedures to get construction and grid connection approvals | United States | [58] |
| *(27 Countries)* | Price rules inadequate to remunerate wind generation | China | [114, 289] |
| | | Nigeria | [327] |
| | | Norway | [73] |
| | | Taiwan | [460] |
| | | Turkey | [239] |
| Problems in realising financial incentives | Collect the certified emission reduction from the clean development mechanism | Brazil | [444] |
| | | China | [444] |
| | | India | [444] |
| | Collect electricity billing subsidies | China | [296, 318] |
| *(4 Countries)* | Reach the tax benefits application deadlines | India | [209] |
| | Collect tax reductions to import wind equipment | Ukraine | [456] |
| Unstable macroeconomic environment | Uncertain economic growth | India | [209] |
| | | United States | [58] |
| | High inflation rate | Brazil | [245] |
| *(6 Countries)* | | Greece | [227] |
| | | Russia | [301] |
| | Unstable currency | Brazil | [31] |
| | | New Zealand | [400] |
| Lack of involvement of stakeholders in decision making | Lack of stakeholder integration and cooperation | China | [68, 197] |
| | | Greece | [347] |
| | | Japan | [323] |
| | | Netherlands | [11] |
| | | Norway | [448] |
| *(7 Countries)* | | Turkey | [82] |
| Clash of interests | Powerful lobbying against wind farms from dominant energy utilities | Australia | [460] |
| | | Bulgaria | [380] |
| *(26 Countries)* | | Canada | [140, 460] |
| | | Cyprus | [380] |
| | | Czech Republic | [380] |
| | | Estonia | [380] |
| | | France | [140] |
| | | Germany | [428, 452] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| INSTITUTIONAL | | | |
| Clash of interests *(26 Countries)* | Powerful lobbying against wind farms from dominant energy utilities | Greece | [347] |
| | | Hungary | [380] |
| | | Japan | [305, 324, 460] |
| | | Latvia | [380] |
| | | Lithuania | [380] |
| | | Malta | [380] |
| | | Norway | [292] |
| | | Poland | [380] |
| | | Romania | [380] |
| | | Slovakia | [380] |
| | | Slovenia | [380] |
| | | Taiwan | [460] |
| | | Turkey | [380] |
| | Powerful lobbying from environmental conservation institutions | Germany | [70, 433] |
| | | Netherlands | [70, 433] |
| | | United Kingdom | [70, 433] |
| | Powerful lobbying from tourism companies | Greece | [347] |
| Lack of R&D culture *(24 Countries)* | Insufficient efforts to develop wind R&D | Africa | [483] |
| | | Azerbaijan | [468] |
| | | Australia | [460] |
| | | Brazil | [304, 345, 410] |
| | | Bosnia & Herze. | [536] |
| | | Canada | [460] |
| | | China | [137, 138, 196, 213, 223, 230, 235, 247, 260, 274, 275, 278, 282, 287, 317, 437, 438, 464, 494, 496, 504, 505, 527, 528, 531, 535] |
| | | Finland | [34] |
| | | Germany | [346] |
| | | Greece | [347] |
| | | India | [209, 233, 297, 397, 407] |
| | | Iran | [8] |
| | | Italy | [132] |
| | | Japan | [323, 460] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| INSTITUTIONAL | | | |
| Lack of R&D culture *(24 Countries)* | Insufficient efforts to develop wind R&D | Malaysia | [144, 392] |
| | | Mexico | [24, 78] |
| | | Nepal | [171] |
| | | Nigeria | [16, 17, 26, 38] |
| | | Norway | [73, 292] |
| | | Oman | [19, 20] |
| | | Pakistan | [33, 37, 41, 320, 321] |
| | | South Africa | [473] |
| | | Taiwan | [460] |
| | | Thailand | [399] |
| | | Turkey | [82, 412] |
| | | Vietnam | [119] |
| TECHNICAL | | | |
| Lack of standard, codes and certifications *(12 Countries)* | Lack of standards for selection/import of wind turbines | Canary Islands | [77] |
| | | India | [209, 407] |
| | Lack of wind turbine quality standards | China | [223, 274, 287, 317, 479, 494, 504] |
| | | Eritrea | [175] |
| | Lack of appropriate standards for the implementation of a WE industry | Lebanon | [244] |
| | | Serbia | [252] |
| | Lack of appropriate standards for the promotion of innovation in the WE industry | Brazil | [345] |
| | | China | [318, 436, 505] |
| | | Turkey | [239] |
| | | United States | [142, 440] |
| | Lack of technical grid codes standards for WE integration | China | [137, 403, 436, 518] |
| | | Ireland | [49] |
| | | Pakistan | [377] |
| | | Taiwan | [84, 281] |
| Lack of skilled personnel *(74 Countries)* | Shortage of wind energy specialized personnel | Africa | [483] |
| | | Azerbaijan | [468] |
| | | Botswana | [127] |
| | | Brazil | [304] |
| | | Canada | [311] |
| | | China | [179, 247, 275, 302, 438, 479, 492, 496, 527, 530, 534] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| TECHNICAL | | | |
| Lack of skilled personnel *(74 Countries)* | Shortage of wind energy specialized personnel | India | [209, 297] |
| | | Iran | [8] |
| | | Lebanon | [244] |
| | | Libya | [325] |
| | | Mexico | [24, 78] |
| | | Morocco | [255] |
| | | Nepal | [171, 439] |
| | | Nigeria | [6, 15, 16] |
| | | Oman | [19] |
| | | Palestine | [5] |
| | | Pakistan | [33] |
| | | Russia | [301] |
| | | Serbia | [370] |
| | | South Africa | [404, 473] |
| | | Thailand | [399] |
| | | Turkey | [82, 339] |
| | | United Kingdom | [145] |
| | | Ukraine | [456] |
| | | Vietnam | [119] |
| Lack of O&M facilities *(8 Countries)* | Insufficient availability of O&M facilities | China | [438, 527] |
| | | India | [209] |
| | | Japan | [323] |
| | | Nepal | [439] |
| | | Nigeria | [38] |
| | | Pakistan | [320] |
| | | Taiwan | [84] |
| | | Turkey | [82] |
| System constraints *(52 Countries)* | Weak grid infrastructure | Australia | [300] |
| | | Bangladesh | [398] |
| | | Brazil | [98, 304] |
| | | Bulgaria | [371] |
| | | Canada | [191, 392] |
| | | China | [43, 129, 131, 235, 270, 275, 277, 286, 294, 296, 302, 403, 437, 464, 474, 476, 479, 502, 514, 518, 521, 523, 525-527, 532] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| TECHNICAL | | | |
| System constraints *(52 Countries - these ones have insufficient transmission infrastructure)* | Weak grid infrastructure | Caribbean | [487] |
| | | Germany | [250, 346, 466] |
| | | Ghana | [394] |
| | | Greece | [122, 177, 226-229, 238, 347, 355, 371] |
| | | India | [209, 212, 233, 413] |
| | | Ireland | [49] |
| | | Japan | [323, 324] |
| | | Kazakhstan | [234] |
| | | Morocco | [255] |
| | | Nigeria | [15] |
| | | Norway | [62] |
| | | Pakistan | [41, 319, 373, 377] |
| | | Philippines | [39] |
| | | Serbia | [47, 252] |
| | | Scotland | [93] |
| | | Spain | [46, 61, 107, 250, 428] [316] |
| | | Sri Lanka | [480] |
| | | Turkey | [124, 339] |
| | | Thailand | [87, 281] |
| | | United States | [30, 58, 108, 142, 143, 160, 414, 511] |
| | | United Kingdom | [250] |
| | | Ukraine | [456] |
| | | Yemen | [18] |
| | Wind curtailment | China | [81, 129, 164, 193, 235, 272, 286, 293, 294, 296, 358, 403, 437, 479, 491, 495, 500, 503, 505, 520] |
| | | Denmark | [125] |
| | | Germany | [250] |
| | | Greece | [228] |
| | | India | [209] |
| | | Spain | [46, 125] |
| | | United States | [58, 108, 143] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| TECHNICAL | | | |
| Unreliable product *(12 Countries)* | Lack of quality in wind turbine manufacturing processes | India | [209, 407] |
| | | China | [131, 178, 179, 186, 193, 196, 235, 278, 289, 293, 302, 318, 403, 436, 437, 478, 488, 494, 495, 504, 521, 524, 527, 532, 534] |
| | Wind turbines running in underproductive regimes | Canary Islands | [77] |
| | | China | [247, 275, 505] |
| | | Finland | [472] |
| | | Greece | [226, 228, 347] |
| | | Japan | [323] |
| | | India | [209, 212, 413] |
| | | Lebanon | [158] |
| | | Macedonia | [158] |
| | | Malaysia | [25] |
| | | Moldova | [158] |
| | | Sri Lanka | [480] |
| | | Thailand | [83, 399] |
| SOCIAL | | | |
| Lack of consumer acceptance *(91 Countries)* | Wind energy technology reported as popularly unknown | India | [297, 379] |
| | | Iran | [8] |
| | | Lebanon | [204, 244] |
| | | Mexico | [79] |
| | | Morocco | [255] |
| | | Nepal | [439] |
| | | Nigeria | [16, 17] |
| | | Pakistan | [33, 320, 377] |
| | | South Africa | [404] |
| | | Sub-Sahara Africa | [326] |
| | | Taiwan | [509] |
| | Consumers with insufficient information about wind energy benefits | Brazil | [410] |
| | | Bulgaria | [380] |
| | | China | [273, 508] |
| | | Cyprus | [380] |
| | | Czech Republic | [380] |
| | | Estonia | [380] |
| | | Greece | [237, 355] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| SOCIAL | | | |
| Lack of consumer acceptance *(91 Countries)* | Consumers with insufficient information about wind energy benefits | Hungary | [380] |
| | | Italy | [80, 132] |
| | | Latvia | [380] |
| | | Lithuania | [236, 380, 435] |
| | | Maldives | [465] |
| | | Malta | [380] |
| | | Mexico | [78] |
| | | Serbia | [370, 391] |
| | | Turkey | [124] |
| | | Poland | [380] |
| | | Romania | [380] |
| | | Serbia | [252] |
| | | Slovakia | [380] |
| | | Slovenia | [21, 380] |
| | | Turkey | [82, 380] |
| | Misinformation about wind energy benefits | Australia | [97] |
| | | Bangladesh | [23] |
| | | Canada | [386] |
| | | Germany | [455] |
| | | Greece | [122, 347] |
| | | Iran | [103] |
| | | Kyrgyzstan | [284] |
| | | United Kingdom | [52, 433] |
| | Public opinion against wind energy | Greece | [347] |
| | | Japan | [305] |
| | | Spain | [32] |
| | | Turkey | [257, 339] |
| | | United Kingdom | [69, 369, 433] |
| | Public resistance to the construction of new transmission lines | Germany | [64, 333] |
| | | Greece | [226] |
| | | Japan | [194] |
| | | Norway | [1] |
| | | Switzerland | [194] |
| | | United States | [142, 143] |
| | | United Kingdom | [1] |
| Lack of social acceptance *(25 Countries)* | Local community opposition to wind farms | Australia | [76, 92, 97, 148, 168, 195, 460] |
| | | Austria | [401] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| SOCIAL | | | |
| Lack of social acceptance *(25 Countries)* | Local community opposition to wind farms | Brazil | [67, 410] |
| | | Canada | [48, 135, 210, 211, 392, 420, 460, 469] |
| | | Czech Republic | [54] |
| | | Denmark | [202, 312, 328, 425] |
| | | Finland | [96] |
| | | France | [123, 338] |
| | | Germany | [70, 266, 383] |
| | | Greece | [347] |
| | | Italy | [432] |
| | | Japan | [323, 331] |
| | | Mexico | [201] |
| | | Netherlands | [11, 70, 113] |
| | | New Zealand | [167, 242] |
| | | Norway | [62, 73, 390, 396] |
| | | Poland | [72] |
| | | Spain | [61, 105, 112, 329, 368, 452] |
| | | Sweden | [29, 111, 214, 315, 417] |
| | | United States | [7, 142, 170, 261, 334, 350, 375] |
| | | United Kingdom | [13, 70, 113, 190, 218, 220, 291, 430, 450, 453] |
| | | Wales | [290] |
| OTHER BARRIERS | | | |
| Uncertain governmental policies *(114 Countries)* | Lack of support schemes | Afghanistan | [126] |
| | | Azerbaijan | [468] |
| | | Bangladesh | [398] |
| | | Belarus | [376] |
| | | Canada | [139, 221, 311] |
| | | Caribbean | [181] |
| | | Colombia | [94] |
| | | Ghana | [394] |
| | | Greece | [347] |
| | | Iran | [8, 103, 443] |
| | | Kazakhstan | [234] |

| Barrier | | Country/Region | References |
|---|---|---|---|
| OTHER BARRIERS | | | |
| Uncertain governmental policies *(114 Countries)* | Lack of support schemes | Lebanon | [204] |
| | | Libya | [325] |
| | | Lithuania | [236, 435] |
| | | Malaysia | [392] |
| | | Maldives | [465] |
| | | Morocco | [255] |
| | | Nepal | [171, 439] |
| | | New Zealand | [242, 400] |
| | | Nigeria | [6, 16, 17, 26, 327] |
| | | Oman | [19, 20] |
| | | Pakistan | [33, 37, 319-321] |
| | | Palestine | [5] |
| | | Russia | [66] |
| | | Serbia | [446] |
| | | South Africa | [404] |
| | | Sub-Sahara Africa | [326] |
| | | Taiwan | [509] |
| | | Tanzania | [387] |
| | | Turkey | [82, 180, 232, 239] |
| | | United States | [58] |
| | | U. Arab Emirates | [314] |
| | | Vietnam | [119, 343] |
| | | Yemen | [18] |
| | Support schemes with inadequate designs | Australia | [4, 300, 460] |
| | | Argentina | [378] |
| | | Brazil | [46, 113, 304] |
| | | Bosnia & Herze. | [536] |
| | | Canada | [460] |
| | | Chile | [46] |
| | | China | [68, 137, 144, 150, 178, 197, 230, 271, 273, 276-278, 287, 288, 436, 438, 476, 489, 491, 497, 514, 517, 522, 523, 525] |
| | | Denmark | [202] |
| | | Estonia | [96] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| OTHER BARRIERS | | | |
| Uncertain governmental policies *(114 Countries)* | Support schemes with inadequate designs | France | [140, 315] |
| | | Germany | [118] |
| | | India | [216, 233, 243, 297, 413] |
| | | Indonesia | [183] |
| | | Japan | [305, 323, 324, 392, 460, 461] |
| | | Latvia | [96] |
| | | México | [24, 78, 79, 361] |
| | | Norway | [62] |
| | | Poland | [72, 206] |
| | | Spain | [40, 203, 205] |
| | | Sweden | [417, 477] |
| | | Taiwan | [283, 408, 460] |
| | | United States | [182, 215, 263, 482] |
| | | United Kingdom | [113, 428] |
| | Reduction of support schemes | Australia | [231, 459] |
| | | Austria | [152] |
| | | Germany | [9, 452] |
| | | Greece | [122] |
| | | India | [209] [55] |
| | | Indonesia | [39] |
| | | Philippines | [39] |
| | | Romania | [117, 162] |
| | | United Kingdom | [74, 128] |
| | Interruption of support schemes | Hungary | [162] |
| | | India | [212] |
| | | Latvia | [96] |
| | | Sweden | [477] |
| | | United States | [58, 59, 102, 182, 269, 350, 427, 481] |
| | Removal of support schemes | Czech Republic | [162] |
| | | Denmark | [313, 425, 452] |
| | | Portugal | [162, 359] |
| | | Spain | [91, 162] |

| **Barrier** | | **Country/Region** | **References** |
|---|---|---|---|
| OTHER BARRIERS | | | |
| Lack of infrastructure *(109 Countries – including the ones with grid system constrain)* | Insufficient transmission infrastructure | Australia | [300, 459] |
| | | Brazil | [31, 245, 304] |
| | | Central Africa | [116] |
| | | China | [130, 178, 184, 193, 230, 271, 275, 289, 436, 476, 479, 491, 503, 505, 531, 532] |
| | | Eritrea | [175] |
| | | Germany | [346] |
| | | Greece | [122, 177, 347] |
| | | India | [233, 297] |
| | | Iran | [8] |
| | | Japan | [254, 323] |
| | | Middle East | [519] |
| | | Nepal | [439] |
| | | Nigeria | [327] |
| | | Palestine | [5] |
| | | Pakistan | [373, 406] |
| | | Russia | [66] |
| | | Sub-Sahara Africa | [326] |
| | | South Africa | [404] |
| | | Thailand | [87] |
| | | Turkey | [180] |
| | | United States | [30, 142, 143, 414, 440, 481, 511] |
| | | Vietnam | [343] |
| | Limited road access to windy sites | Brazil | [410] |
| | | China | [196] |
| | | Caribbean | [487] |
| | | Iran | [8] |
| | | Nigeria | [6] |
| | | Pakistan | [373, 406] |
| | | Vietnam | [119] |

# APPENDIX B

Table 2.4 – Barriers to wind farm implementation identified in the review according the level of economic development

| **Barriers** | **Countries** | **Least Developed** | **Developing** | **In transition** | **Developed** |
|---|---|---|---|---|---|
| MARKET FAILURES | | | | | |
| High controlled energy sector | 11 | 0% | 45% | 18% | 36% |
| Lack of information and awareness | 91 | 5% | 85% | 3% | 7% |
| Restricted access to technology | 7 | 0% | 100% | 0% | 0% |
| Lack of competition | 10 | 0% | 10% | 10% | 80% |
| High transaction costs | 10 | 0% | 30% | 0% | 70% |
| Poor market infrastructure | 93 | 37% | 53% | 3% | 8% |
| MARKET DISTORTIONS | | | | | |
| Favourable treatment to conventional energy | 25 | 4% | 52% | 12% | 32% |
| Taxes on wind energy | 4 | 0% | 75% | 0% | 25% |
| Non-consideration of externalities | 83 | 0% | 54% | 1% | 46% |
| ECONOMIC/FINANCIAL | | | | | |
| Economically not viable | 35 | 3% | 34% | 9% | 54% |
| Long-payback period to wind farm investments | 8 | 0% | 63% | 13% | 25% |
| High cost of capital | 86 | 41% | 53% | 2% | 3% |
| Lack or inadequate access to capital | 48 | 0% | 69% | 6% | 25% |
| High up-front costs | 15 | 0% | 87% | 7% | 7% |
| Lack or limited financial institutions or instruments | 77 | 45% | 27% | 1% | 17% |
| INSTITUTIONAL | | | | | |
| Lack of institutions and mechanisms | 70 | 50% | 40% | 3% | 7% |
| Lack of a legal/regulatory framework | 27 | 0% | 30% | 7% | 63% |
| Problems in realising financial incentives | 4 | 0% | 75% | 25% | 0% |
| Unstable macroeconomic environment | 6 | 0% | 50% | 0% | 50% |
| Lack of involvement of stakeholders in decisi. making | 7 | 0% | 29% | 14% | 57% |

| **Barriers** | **Countries** | **Least Developed** | **Developing** | **In transition** | **Developed** |
|---|---|---|---|---|---|
| INSTITUTIONAL | | | | | |
| Clash of interests | 26 | 0% | 8% | 0% | 92% |
| Lack of R&D culture | 24 | 4% | 58% | 4% | 33% |
| TECHNICAL | | | | | |
| Lack of standard, codes and certifications | 12 | 0% | 67% | 8% | 25% |
| Lack of skilled personnel | 74 | 45% | 43% | 5% | 7% |
| Lack of O&M facilities | 8 | 13% | 75% | 0% | 13% |
| System constraints | 52 | 6% | 63% | 6% | 25% |
| Unreliable product | 12 | 0% | 50% | 17% | 33% |
| SOCIAL | | | | | |
| Lack of consumer acceptance | 91 | 38% | 31% | 3% | 27% |
| Lack of social acceptance | 25 | 0% | 12% | 0% | 88% |
| OTHER BARRIERS | | | | | |
| Uncertain policies | 114 | 32% | 40% | 4% | 23% |
| Lack of infrastructure | 109 | 34% | 57% | 1% | 8% |

* Table created based on the country classification of economic development proposed by the United Nations [458].

# APPENDIX C

Table 2.5 – Barriers to wind farm implementation identified in this SLR (in the past decade) according the level of wind energy diffusion

| **Barriers** | **Countries** | **Recent** | **Advanced** |
|---|---|---|---|
| MARKET FAILURES | | | |
| High controlled energy sector | 9 | 67% | 33% |
| Lack of information and awareness | 77 | 96% | 4% |
| Restricted access to technology | 6 | 83% | 17% |
| Lack of competition | 10 | 30% | 70% |
| High transaction costs | 8 | 38% | 63% |
| Poor market infrastructure | 63 | 95% | 5% |
| MARKET DISTORTIONS | | | |
| Favourable treatment to conventional energy | 23 | 83% | 17% |
| Taxes on wind energy | 4 | 75% | 25% |
| Non-consideration of externalities | 13 | 62% | 38% |
| ECONOMIC/FINANCIAL | | | |
| Economically not viable | 24 | 79% | 21% |
| Long-payback period to wind farm investments | 6 | 83% | 17% |
| ECONOMIC/FINANCIAL | | | |
| High cost of capital | 58 | 93% | 7% |
| Lack or inadequate access to capital | 23 | 61% | 39% |
| High up-front costs | 15 | 87% | 13% |
| Lack or limited financial institutions or instruments | 57 | 96% | 4% |
| INSTITUTIONAL | | | |
| Lack of institutions and mechanisms | 15 | 79% | 21% |
| Lack of a legal/regulatory framework | 25 | 52% | 48% |
| Problems in realising financial incentives | 4 | 75% | 25% |
| Unstable macroeconomic environment | 2 | 100% | 0% |
| Lack of involvement of stakeholders in decision making | 6 | 50% | 50% |
| Clash of interests | 7 | 57% | 43% |
| Lack of R&D culture | 22 | 77% | 23% |
| TECHNICAL | | | |
| Lack of standard, codes and certifications | 7 | 71% | 29% |
| Lack of skilled personnel | 20 | 85% | 15% |
| Lack of O&M facilities | 7 | 71% | 29% |
| System constraints | 24 | 50% | 50% |
| Unreliable product | 11 | 64% | 36% |
| SOCIAL | | | |
| Lack of consumer acceptance | 78 | 86% | 14% |

| **Barriers** | **Countries** | **Recent** | **Advanced** |
|---|---|---|---|
| SOCIAL | | | |
| Lack of social acceptance | 25 | 44% | 56% |
| OTHER BARRIERS | | | |
| Uncertain governmental policies | 104 | 87% | 13% |
| Lack of infrastructure | 82 | 90% | 10% |

* Wind energy diffusion classified as recent, for countries with less than 1 GW of wind capacity installed at the end of 2008 (past decade), or advanced, for countries with or more than 1 GW of wind capacity installed at the end of 2008 (past decade) [172]. Considering 2008 as the point of departure to qualify the level of wind energy diffusion, this appendix considered the barriers identified by articles published since 2008 (see Figure 2.1).

# APPENDIX D

Table 2.6 – Occurrence of categories of barriers to onshore wind energy implementation per region/country

| **Region/Country** | **Barrier categories and number of barriers according to the framework of Painuly [354]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Market Failures (7) | Market Distortions (4) | Economic and Financial (9) | Institutional (9) | Technical (6) | Social (2) | Uncertain policies (1) | Environmental (1) | Risk perception (1) | Infrastructure (1) |
| AFRICA | 1 | | 1 | 1 | 1 | | | | | |
| CENTRAL AF. | | | | | | | | | | 1 |
| SAHARAN AF. | 2 | | 2 | | | 1 | 1 | | | 1 |
| Algeria | | | 1 | | | | | | | |
| Botswana | 1 | | | 1 | 1 | | | | | |
| Egypt | 1 | 1 | 1 | | | | | | | |
| Eritrea | | | 2 | 1 | 1 | | | | | 1 |
| Ghana | | | 1 | | 1 | | 1 | | | 1 |
| Libya | | | 1 | | 1 | | 1 | | | |
| Morocco | 1 | 2 | | | 2 | 1 | 1 | | | 1 |
| Nigeria | 3 | 1 | 3 | 3 | 3 | 1 | 1 | | | 1 |
| South Africa | 4 | | 1 | 1 | 1 | 1 | 1 | | | 1 |
| Tanzania | | | 3 | | | | 1 | | | |
| ASIA | | | | | | | | | | |
| Bangladesh | 2 | | | 1 | 1 | 1 | 1 | | | 1 |
| Cambodia | 1 | | | | | | | | | |
| China | 6 | 3 | 4 | 5 | 5 | 1 | 1 | | | 1 |
| India | 3 | | 5 | 5 | 5 | 2 | 1 | | | 1 |

| **Region/Country** | **Barrier categories and number of barriers according to the framework of Painuly [354]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Market Failures (7) | Market Distortions (4) | Economic and Financial (9) | Institutional (9) | Technical (6) | Social (2) | Uncertain policies (1) | Environmental (1) | Risk perception (1) | Infrastructure (1) |
| Indonesia | 1 | | 1 | 1 | | | 1 | | | |
| Japan | 4 | 2 | 2 | 4 | 3 | 2 | 1 | | | 1 |
| Kazakhstan | | 2 | | | 1 | | 1 | | | |
| Kyrgyzstan | | | | | | 1 | | | | |
| Laos | 1 | | | | | | | | | |
| Malaysia | 1 | 1 | 1 | 1 | 1 | | 1 | | | |
| Maldives | 2 | 1 | 1 | | | 1 | 1 | | | |
| Nepal | 1 | 1 | 2 | 3 | 2 | 1 | 1 | | | 1 |
| North Korea | 1 | | | | | | | | | |
| Pakistan | 3 | 3 | 4 | 2 | 4 | 1 | 1 | | | 1 |
| Philippines | | | 1 | | 1 | | 1 | | | 1 |
| Sri Lanka | 2 | | 3 | | 2 | | | | | 1 |
| Taiwan | 2 | 2 | 2 | 4 | 2 | 1 | 1 | | | |
| Thailand | 2 | | 1 | 1 | 3 | | | | | 1 |
| Vietnam | 3 | 1 | 4 | 2 | 1 | | 1 | | | 1 |
| C. AMERICA | | | | | | | | | | |
| Caribbean | 1 | 1 | 1 | | 1 | | | | | 1 |
| N. AMERICA | | | | | | | | | | |
| Canada | 1 | 2 | 1 | 2 | 1 | 2 | 1 | | | 1 |
| Mexico | 2 | | 2 | 2 | 1 | 2 | 1 | | | |
| United States | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | | 1 |

| **Region/Country** | **Barrier categories and number of barriers according to the framework of Painuly [354]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Market Failures (7) | Market Distortions (4) | Economic and Financial (9) | Institutional (9) | Technical (6) | Social (2) | Uncertain policies (1) | Environmental (1) | Risk perception (1) | Infrastructure (1) |
| S. AMERICA | | | | | | | | | | |
| Argentina | | | | | | | 1 | | | |
| Brazil | 2 | 2 | 4 | 5 | 3 | 2 | 1 | | | 1 |
| Chile | | | 1 | 1 | | | 1 | | | |
| Colombia | | | | | | | 1 | | | |
| EUROPE | | 1 | | | | | | | | |
| Austria | 1 | | | | | 1 | 1 | | | |
| Azerbaijan | | | 3 | 2 | 1 | | 1 | | | |
| Belarus | 1 | | | 1 | | | 1 | | | |
| Bosnia & Herze. | 2 | | | 1 | | | 1 | | | |
| Bulgaria | | | 2 | 1 | 1 | 1 | | | | 1 |
| Canary Islands | | 1 | | 1 | 1 | | | | | |
| Cyprus | | | 2 | 1 | | 1 | | | | |
| Czech Republic | | | 2 | 1 | | 2 | 1 | | | |
| Denmark | | | 1 | 1 | | 1 | 1 | | | 1 |
| Estonia | | | 2 | 1 | | 1 | 1 | | | |
| Finland | 1 | | 1 | 2 | 1 | 1 | | | | |
| France | | | 1 | 1 | | | | | | |
| Georgia | | | 1 | | | | | | | |
| Germany | | | 1 | 3 | 1 | 2 | 1 | | | 1 |
| Greece | 3 | 3 | 3 | 7 | 2 | 2 | 1 | | | 1 |

| **Region/Country** | **Barrier categories and number of barriers according to the framework of Painuly [354]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Market Failures (7) | Market Distortions (4) | Economic and Financial (9) | Institutional (9) | Technical (6) | Social (2) | Uncertain policies (1) | Environmental (1) | Risk perception (1) | Infrastructure (1) |
| Hungary | | | 2 | 1 | | 1 | 1 | | | |
| Ireland | | | | | 1 | | | | | 1 |
| Italy | 2 | | 1 | 2 | | 2 | | | | |
| Latvia | | | 2 | 1 | | 1 | 1 | | | |
| Lithuania | | | 3 | 1 | | 1 | 1 | | | |
| Macedonia | | | | | 1 | | | | | |
| Malta | 1 | | 2 | 1 | | 1 | | | | |
| Moldova | | | | | 1 | | | | | |
| Montenegro | | | 1 | | | | | | | |
| Netherlands | 1 | | | 4 | | 1 | | | | |
| Norway | 2 | | 1 | 4 | 1 | 2 | 1 | | | 1 |
| Poland | 1 | | 2 | 2 | | 2 | 1 | | | |
| Portugal | | | 1 | | | | 1 | | | |
| Romania | | | 2 | 1 | | 1 | 1 | | | |
| Russia | 5 | 1 | 4 | 2 | 1 | | 1 | | | 1 |
| Scotland | | | | | | | | | | 1 |
| Serbia | 2 | 1 | 1 | 2 | 3 | 1 | 1 | | | 1 |
| Slovakia | | | 2 | 1 | | 1 | | | | |
| Slovenia | | | 2 | 1 | | 1 | | | | |
| Spain | 1 | | 1 | 1 | 1 | 2 | 1 | | | 1 |
| Sweden | 1 | 1 | 1 | 2 | | 1 | 1 | | | |

| **Region/Country** | **Barrier categories and number of barriers according to the framework of Painuly [354]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Market Failures (7) | Market Distortions (4) | Economic and Financial (9) | Institutional (9) | Technical (6) | Social (2) | Uncertain policies (1) | Environmental (1) | Risk perception (1) | Infrastructure (1) |
| Switzerland | | | 1 | | | 1 | | | | |
| Turkey | 2 | 2 | 5 | 6 | 4 | 1 | 1 | | | 1 |
| Ukraine | | | 2 | 1 | 2 | | | | | 1 |
| United King. | 3 | | 1 | 3 | 2 | 2 | 1 | | | 1 |
| Wales | | | | | | 1 | | | | |
| MID. EAST | | | | | | | | | | 1 |
| Arabian Penins. | 1 | | | | | | | | | |
| Afghanistan | | | | | | | 1 | | | |
| Iran | 1 | 1 | | 1 | 1 | 1 | 1 | | | 1 |
| Iraq | 1 | | | | | | | | | |
| Jordan | | | 1 | | | | | | | |
| Lebanon | 2 | | 1 | 1 | 3 | 1 | 1 | | | |
| Oman | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| Palestine | | | | | 1 | | 1 | | | 1 |
| Syria | | | 1 | | | | | | | |
| United Arab Emirates | | 2 | 2 | | | | 1 | | | |
| Yemen | | | 2 | 1 | 1 | | 1 | | | 1 |
| PACIFIC | | | | | | | | | | |
| Australia | 2 | 2 | | 3 | 1 | 2 | 1 | | | 1 |
| New Zealand | 1 | 1 | 1 | 2 | | 1 | 1 | | | |

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# 3 BARRIERS TO ONSHORE WIND FARM IMPLEMENTATION IN BRAZIL

## 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 where identified, three of which with particular relevance: poor transmission infrastructure, unattractive financial loans and unstable macroeconomic environment. Furthermore, the data collected suggests a serious risk of Brazil's WE sector stop 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.

## KEYWORDS

Renewable energy; Wind energy; Wind farms implementation; Barriers to implementation

## 3.1 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 [98]. Moreover, the expansion of WE around the world has been regarded as important to meet a rising energy demand and ensuring security of supply [22].

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 [91]. 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 [46] to 12770 MW [3, 55]. 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 [3], have presented low levelized costs of electricity and high capacity factors [27]. 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 WE Brazilian, had mentioned these barriers [11, 15, 20, 23, 30, 33, 44, 65, 82, 89, 93, 102, 107]. In addition, the only study which had included field 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 [82].

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 [91] 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 and general to the Brazilian industrial development, 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 [91]. 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.

## 3.2 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 [79, 97]. Among the options to expand the energy matrix and re-establish security of supply [64], WE emerged as a reliable option in Brazil, especially in the Northeast region, due to its excellent wind conditions [8, 29, 32, 71, 93]. Supported by a public auctioning system, the WE capacity installed in the country grew 37 times in the past decade, reaching 12770 MW at the end of 2017 (see Figure 3.1). Currently, Brazil occupies the eighth position among the top 10 nations with higher installed WE capacity [55].

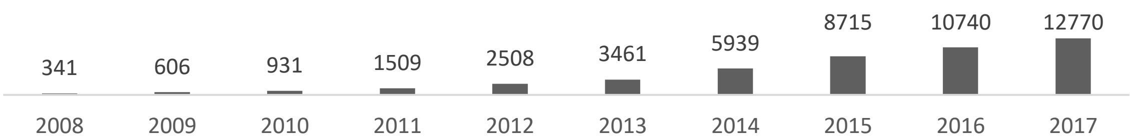


Figure 3.1 – Evolution of the Brazilian cumulative installed WE capacity (MW/year) [46-55].

Using the currently WE installed 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) [3]. This installed capacity still represents a small portion (7.8%) in Brazil’s total electricity installed generating capacity, which is dominated by the Non-renewable (17.2%) and Hydropower (63.8 %) [39].

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% [2, 3, 27], much higher than country average across the world [59]. Consequently, even facing barriers with an impact on development costs, the levelized cost of WE in the region has reached 0.035 USD/kWh [27], a value much lower than those observed in others parts of the world [60].

In fact the WE future seems promising in the region, either for expanding electricity generation or replacing the other main sources of generation, since wind farms have been negotiating electricity with competitive tariffs in comparison with thermoelectric plants and lately also with hydropower plants [10], and have their generation reliably foreseen and quantified (due to the existence of strong and stable trade winds - suitable for a wide integration on the grid). In the current scenario of high hydroelectric availability losses (due the frequent occurrence of droughts) a supply alternative is urgently required [26].

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 3.1).

| **Barriers** | | **Studies** |
|---|---|---|
| MARKET FAILURES (MF) | | |
| Lack of information and awareness | Lack of recent, detailed and accurate wind data | [82, 89, 93] |
| Poor market infrastructure | Underdeveloped home wind industry | [11, 23, 33, 44] |
| MARKET DISTORTIONS (MD) | | |
| Favourable treatment to conventional energy | Subsidies to conventional energy generation | [82] |
| Non-consideration of externalities | Exclusion of externalities in the calculation of energy costs | [28, 102, 111] |
| ECONOMIC AND FINANCIAL (EF) | | |
| High cost of capital | High interest rates on loans for wind farm development | [65] |
| Lack or inadequate access to capital | Difficult access to capital for wind farm implementation | [11, 15, 30] |
| High up-front capital costs | High initial costs for wind farm implementation | [82, 93] |

| **Barriers** | | **Studies** |
|---|---|---|
| INSTITUTIONAL (I) | | |
| Lack of institutions and mechanism | Entities with lack of specialized capability | [30] |
| Lack of a legal/regulatory framework | Time-consuming procedures to get construction and connection approvals | [15, 33] |
| Problems in realising financial incentives | Collect the certified emission reduction from the clean development mechanism | [107] |
| Unstable macroeconomic environment | High inflation rate | [65] |
| | Unstable currency | [11] |
| Lack of R&D culture | Insufficient efforts to develop wind R&D | [82, 89, 102] |
| TECHNICAL (T) | | |
| Lack of standard, codes and certifications | Lack of appropriate standards for the promotion of innovation in the WE industry | [89] |
| Lack of skilled personnel | Shortage of WE specialized personnel | [82] |
| System constraints | Weak grid infrastructure | [23, 82] |
| SOCIAL (S) | | |
| Lack of consumer acceptance | Consumers with insufficient information about WE benefits | [102] |
| Lack of social acceptance | Local community opposition to wind farms | [20, 102] |
| OTHER BARRIERS (OB) | | |
| Uncertain governmental policies | Support schemes with inadequate designs | [15, 33, 82] |
| Lack of infrastructure | Insufficient transmission infrastructure | [11, 65, 82] |
| | Limited road access to windy sites | [102] |

Table 3.1 – Barriers to onshore wind energy implementation in Brazil found in the literature according the categories provided by Painuly [91].

Even though 21 barriers are mentioned across these studies, except for Martins and Pereira [74] none of these studies have collected information through interactions with multiple stakeholders to reliably identify the existence of these obstacles [91]. 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 [38, 70, 94, 95, 116, 122]

## 3.3 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 its charateristics of allowing 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 [118] – implementation processes involving a large number of critical actors and factors [76]. Moreover, the lack of detailed and updated preliminary research about onshore wind farms implementation in developing countries (such as Brazil) leads to the need of exploring the distinct phenomena [86] which corroborated this choice. Futhermore, when comparing with other qualitative methods, case research is a suitable method to use when there is an intention to combine an existing theoretical framework as a basis for the analysis of results (such as the one proposed by Painuly [91]) with an in-depth exploration of the phenomena (the implementation of onshore wind farms) [118].

### 3.3.1 STAKEHOLDER INTERVIEWS

To identify the barriers to onshore wind farm implementation in Brazil, information was collected through interviews with several stakeholders from the Brazilian WE sector. The interviews were complemented with a literature review and site visits, as recommended by Painuly [91] 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 [91], as well as the wide adoption of a stakeholder perspective in other studies with similar objectives [24, 80, 95, 112, 122]. The interviewed stakeholders included wind developers, engineers & consultants, manufacturers, support agents, public administrators, and researchers (see Table 3.2).

| **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 thank 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 3.2 – Stakeholder category descriptions.

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 [1]. 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 recognized. 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 [91] (see Table 3.3). 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 barriers mentioned and explain which were of higher relevance in the development of onshore wind farms in Brazil. The interviews were supported by a protocol that guided the interviewer to conduct the open questions, as well as to identify the stakeholder profiles.

| **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 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. |

Table 3.3 – Barriers to renewable energy implementation [91].

### 3.3.2 DATA COLLECTION AND ANALYSIS

Between August and December 2016, 41 interviews were performed with relevant stakeholders from the Brazilian WE sector. Of 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 the barriers to renewable energy implementation [91], which ensured reliability [118]. This research used an informed consent 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 [36], as well as a first analysis of the collected data and the improvement of the subsequent interviews [14, 105].

The interviews lasted from 10 minutes to 1 hour and 36 minutes, with an average of 40 minutes and a total of approximately 27 hours and 41 minutes, resulting in 345 pages of text transcribed verbatim [118]. The sample was large enough to reach theoretical saturation [35, 105].

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 3.4), some of them with experience in more than one state.

| **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 |

Table 3.4 – Interviewed stakeholders per category and range of experience.

The qualitative data collected in the 41 interviews were analysed using a qualitative content analysis method [101], with category construction and coding frame [69, 88] considering, respectively, 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 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 [105]. 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 [14, 35]. The descriptive and simultaneous coding was performed using appropriate analysis software (Qiqqa).

## 3.4 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 barriers transcend the following sector affecting the whole Brazilian industrial development (see table 3.5), i.e., having a general impact on the industry of the country.

| **Barriers (B)** | **Scope of Impact** | **Stakeholders RE** | | | |
|---|---|---|---|---|---|
| | | BRA (41) | RN (28) | BA (20) | CE (25) |
| MARKET (M) | | | | | |
| (M.1) Underdeveloped home wind industry *(specific)* | National | 39% | 32% | 45% | 36% |
| (M.2) Restricted access to wind turbine technology *(specific)* | National | 27% | 29% | 35% | 24% |
| (M.3) Lack of information about the wind potential *(specific)* | State | 12% | 11% | 0% | 8% |
| ECONOMIC AND FINANCIAL (EF) | | | | | |
| (EF.4) Inadequate access to capital *(general)* | National | 83% | 79% | 95% | 88% |
| (EF.5) High cost of capital *(recent and general)* | National | 29% | 25% | 40% | 24% |
| (EF.6) Insufficient financial institutions *(general)* | National | 24% | 21% | 30% | 16% |
| INSTITUTIONAL (I) | | | | | |
| (I.7) Unstable macroeconomic environment *(recent and general)* | National | 78% | 56% | 41% | 46% |
| *Inadequate regulations* | | | | | |
| (I.8) Environmental licence *(general)* | State | 66% | 64% | 70% | 64% |
| (I.9) Land regularization *(general)* | State | 56% | 46% | 50% | 56% |
| (I.10) Archeological licence *(general)* | National | 51% | 46% | 70% | 52% |

| Barriers (B) | Scope of Impact | Stakeholders RE | | | |
|---|---|---|---|---|---|
| | | BRA (41) | RN (28) | BA (20) | CE (25) |
| (I.11) Lack of R&D culture *(general)* | National | 32% | 43% | 25% | 20% |
| *Lack of governmental institutions and mechanisms* | | | | | |
| (I.12) Lack of state public institutions capacity *(general)* | State | 27% | 25% | 30% | 20% |
| (I.13) Lack of governmental cooperation *(general)* | National | 20% | 18% | 5% | 16% |
| (I.14) Inadequate state secretary of energy *(specific)* | State | 10% | 14% | 0% | 8% |
| TECHNICAL (T) | | | | | |
| (T.15) Grid system capacity limitation *(recent and specific)* | State | 100% | 100% | 100% | 100% |
| (T.16) Lack of skilled personnel *(specific)* | National | 56% | 46% | 65% | 52% |
| (T.17) Insufficient of O&M services *(specific)* | National | 51% | 46% | 45% | 48% |
| (T.18) Insufficient quality of wind turbines and blades *(specific)* | National | 12% | 18% | 5% | 4% |
| SOCIAL (S) | | | | | |
| (S.19) Local community opposition *(specific)* | State | 59% | 57% | 35% | 56% |
| OTHER BARRIERS (OB) | | | | | |
| *Poor infrastructure* | | | | | |
| (OB.20) Transmission *(recent and specific)* | State | 100% | 100% | 100% | 100% |
| (OB.21) Roads *(general)* | State | 68% | 75% | 75% | 56% |
| (OB.22) Communication *(general)* | State | 17% | 18% | 20% | 7% |
| *Uncertain governmental policies* | | | | | |
| (OB.23) Auctions occurrence uncertainty *(recent and specific)* | National | 63% | 57% | 60% | 60% |
| Environmental | | | | | |
| (OB.24) Competition for land *(recent and specific)* | State | 29% | 29% | 25% | 20% |

Table 3.5 – Percentage of responses according to stakeholder range of experience.

The interviews also revealed patterns of perception for the identified barriers according to stakeholder category (see Table 3.6).

| 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% |
| *Inadequate regulations* | | | | | | |
| (I.8) Environmental license | 69% | 82% | 50% | 50% | 100% | 40% |
| (I.9) Land regularization | 85% | 73% | 50% | 13% | 0% | 40% |
| (I.10) Archeological license | 69% | 55% | 50% | 38% | 100% | 0% |

| **Barriers** **Stakeholder Category** | **D (13)** | **EC (11)** | **M (2)** | **Sa (8)** | **Pa (2)** | **R (5)** |
|---|---|---|---|---|---|---|
| (I.11) Lack of R&D culture | | | | | | |
| *Lack of governmental institutions and mechanisms* | | | | | | |
| (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 of 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) | | | | | | |
| *Poor infrastructure* | | | | | | |
| (OB.20) Transmission | 100% | | | | | |
| (OB.21) Roads | 77% | 45% | 100% | 63% | 50% | 100% |
| (OB.22) Communication | 31% | 0% | 0% | 13% | 0% | 40% |
| *Uncertain governmental policies* | | | | | | |
| (OB.23) Auctions occurrence uncertainty | 85% | 64% | 50% | 38% | 50% | 60% |
| Environmental | | | | | | |
| (OB.24) Competition for land | 38% | 18% | 50% | 38% | 0% | 20% |

Table 3.6 – Barrier perception according to stakeholder category.

At the end of the interviews the participants indicated which barriers had particular relevance in the development of onshore wind farms (see Figure 3.2)

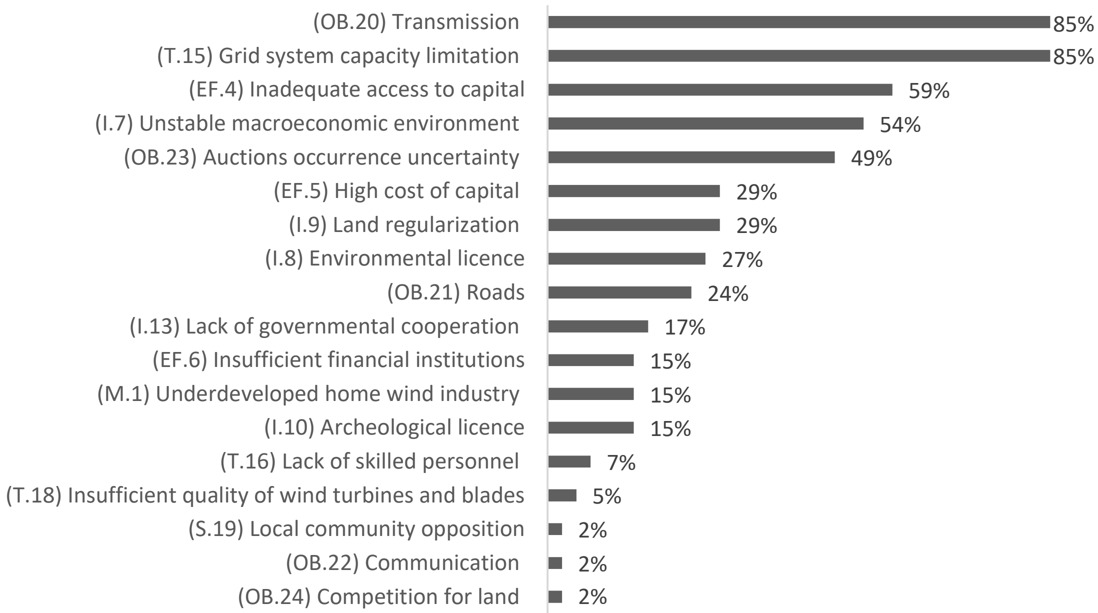


Figure 3.2 – Main barriers to onshore wind farm implementation in Brazil according the stakeholders' perception.

### 3.4.1 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."

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, the 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.

### 3.4.2 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 frequently are 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 70-80% 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 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.

### 3.4.3 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 reduced due the reduction in fiscal revenue, which consequently decreased the availability of public resources for investments of this magnitude.

These 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 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 licencing, 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.

### 3.4.4 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 farms 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. According 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.

### 3.4.5 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 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 the 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.

### 3.4.6 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, especially 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 is 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 of 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.

## 3.5 DISCUSSION

The very promising and distinguished future of WE in Brazil became true [40]. 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 of which with general impact on the overall Brazilian industry development 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 industries); unstable macroeconomic environment (another general problem) and its main consequence, the auction uncertainty (this a specific problem for the Brazilian wind sector); and, the poor transmission infrastructure and its currently grid system constraints (also a specific problem of the Brazilian wind sector). In general, the barriers interference 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 grow 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 those electromechanical inside of the nacelle, has acted as a factor inhibiting the reduction of the high WE development costs [119], which is important to enable the competitiveness and the growth of the contribution of WE to the Brazilian energy matrix [75]. However, this dependence is reducing because the BNDES Finame (the most important public funding channel used by wind developers in Brazil to finance machines and equipments) has evolved in terms of access rules, requiring that the wind turbines sitting on the Brazilian wind farms are, at least, partly composed of high-tech components produced locally, which naturally increased the establishment and expansion of foreign manufacturers in the country and stimulated the emergence of the national ones [110]. However, the sum of governmental taxes applied to the local turbine production of 26.5% in comparison with 14% applied to imported turbines, is slowing down the consolidation and development of Brazilian wind industry [4]. In addition, it is important to highlight the need that this supply chain, especially the manufactures and assemblers of large and weighty wind components, and the subcomponent suppliers, expand in the direction of the Northeast region, closest to the wind sites, seeking for reducing the chain geographic dispersion and consequently the current logistical difficulties [1].

Moreover, the resistance of turbine manufacturers to cooperate jeopardizes 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 fundamental knowledge to the local wind technology development [56]. 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 [99].

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 [16, 21, 102, 120], and their availability is important to speed up RES developments [78, 85]. 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 can be considered the main barrier to wind farm implementation in the country recently, which is also more generally a main barrier to the development of current national industry. 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 [42, 100], 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 [19, 78].

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 [18, 61]. The auctions are planned based on short-term demand previsions informed by the electricity retailers of the state, via the federal government. In these previsions, retailers have a conservative perspective and do not consider a possible economic growth recovery and a consequent electricity consumption raise that would ratify the snapshot effect of the recent economic crisis on the WE auctions occurrence. Besides the interference of such economic crisis in the regulated market and its auctions periodicity, the free market and its electricity consumers (usually large industry and retail companies) – a growing alternative for wind developers to achieve PPAs – exhibit resistance to accept medium-long term electricity supply contracts in times of economic recession and correspondent uncertainty of revenue.

Nevertheless, the occurrence of auctions to contract large wind farms should be independent of the national electricity consumption growth, since the main electricity source in Brazil (hydropower) suffers frequent losses of capacity due to droughts, and its usual alternative (thermoelectric supply) generates electricity with a tariff that is much higher in comparison with WE. In fact, the expansion of WE in the country is recommended to diversify the current energy matrix not only justified by its low tariffs, but also by its increasing ability in predict when and how much WE can be generated, ensuring the security of supply [26, 27].

Furthermore, the implementation of onshore wind farms in the country can be stimulated by making the current free electricity market legislation [9] more flexible. Namely by decreasing the contract power limit (currently of 500 kW), providing consumers that require less power, particularly Brazilian small and medium-sized enterprises (SMEs), the chance to buy electricity direct from wind farms at more competitive tariffs. Other alternative to be considered to keep encouraging the implementation of WE in the country, is liberalizing the retailing market. In this scenario, households can choose which retailer they want to buy electricity from, as already occurs in several European countries. Such liberalized market provides end-consumers the opportunity to select a retailer that sells, for instance, a greener and more affordable electricity – as is the case of Brazilian Northeast WE nowadays. The need to apply alternatives to reinstate the implementation of onshore wind farms in a growing basis is also important to drive a market demand fundamental to drive the national WE supply chain development [56].

The reported difficulties with environmental and archaeological licencing 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 [34].

The lack of R&D culture in the country has contributed to the current status of underdevelopment of the home wind industry [75, 81, 99, 125], leaving onshore wind farm developers in the country dependent on imports [58, 66, 114, 123, 124], 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 licences 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 farms implementation across the country [37, 75, 108].

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 [43, 62, 68, 121]. 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 [42, 58, 67]. In addition, it its remarkable that this lack of skilled personnel with high expertise in wind technology hinders the whole expansion of local industrial WE cluster, fundamental to keep reducing the dependence on foreign technology [56]. The need to adapt turbine technology to local wind conditions, in order to avoid downtimes and increase the capacity factor and lifetime [99, 119], 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 [6, 7, 41, 87, 109]. 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 [17, 92, 117], and their disruption by wind turbines is believed to hamper tourism activities [70, 103]. Local resistance was also observed in inland areas, as a result 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 [57, 106]. 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 [73]. 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 [104]. 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 the shutdown of 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 [91], 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 [16], as well as a need recognized by the local government to establish alternatives to electricity generation from conventional sources [74, 108]. 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 [16, 45, 84, 113], providing wind farms an opportunity to commercialize their generation in the local energy market [5, 30, 31, 72, 77, 90, 100]. Although the existence of the identical selling opportunity reported by the participants, it is important to note that the current support scheme impedes appropriate evaluation and does not consider the social, environmental and transmission externalities, which provides the conventional sources with a cost-advantage in the country [28].

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 [13, 25]. 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 [30, 63, 96]. 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 [12, 83, 115], 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.

## 3.6 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 clarified that 12 barriers not only hinders wind farm implementation, but may also affect all kinds of Brazilian industrial development efforts.

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 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 were considered the barrier with the second highest impact, which is one of the 12 barriers with overall impact on Brazilian industrial development. 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 was considered the barrier with the third highest impact, due to its direct relation with the uncertainty in the auctions. Again, the unstable macroeconomic environment impacts generally the Brazilian industry development, while the uncertainty in the periodicity of auctions is something specific from 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 capacity available from the hydropower plants and the selected alternative of use thermoelectric generation to compensate these hydro generation losses, may be replaced by the currently tariff-competitive and predictable WE generation, providing an important motivation for the government to keep promoting auctions even when the economy does not suggest an electricity consumption increase.

Furthermore, the free market provides another important alternative to stimulate the implementation of onshore wind farms in the country, by reviewing current legislation, which restricts the participation of several potential consumers. Changing policies may allow attract a larger consumer base to this market, which naturally will select WE – one of the electricity source most tariff-competitive in the country nowadays. In addition, the liberalization of the retail market is another interesting option 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 monopolist state retailers, and a possible lack of political will, may be powerful impediments to this market opening. Thus, a scenario where the household consumer can decide to buy electricity from a retailer that sells greener and lower tariff energy can take a long time to occur.

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 utilisation in Brazil, all the interviewees revealed optimist, believing a turnaround of the economy to be soon on its way, and the growth in electricity consumption to be resumed, leading periodic energy auctions to be restored, as well as competitive public funding and transmission infrastructure reinforcements.

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, twelve recommendations emerged from the analysis of the interviews, focused on establishing development stability and consequentely 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. Such legislation should ensure 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 reducing promptly the use of expansive thermoelectric plants and gradually the dependence on hydroelectric power;

(iv) Make the current free market legislation flexible, to allow attract and retain more consumers, namely SMEs;

(v) Liberalize the retail electricity market, creating the conditions to emerge the opportunity for household consumers to choose a retailer that supplies the green and tariff-competitive WE;

(vi) Review the incentives to WE, taking especially into consideration the externalities of all energy sources;

(vii) Implement federal legislation to standardize and simplify the processes of land regularization, and environmental and archaeological licencing, required for wind farm development, improving efficiency while still addressing environmental and archaeological concerns;

(viii) 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;

(ix) 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;

(x) Expand technical training programs in the Federal Institutes of Education, Science and Technology in partnership with local universities, foreign technology institutes, *Serviço Nacional de Aprendizagem Industrial* (SENAI), turbine manufacturers and wind developers, to attend to the local wind industry needs for skilled human resources;

(xi) Create WE technology parks, led by the state's research foundations, in partnership with turbine manufacturers, federal universities, foreign technology institutes and ABEEólica, to promote wind technology R&D efforts that promote the national production of high-tech content for wind turbines, blades and towers;

(xii) 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. This update should prioritize windy sites, taking into consideration existing infrastructures (roads, transmission lines and communication services) and be 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.

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# 4 Overcoming barriers to onshore wind farm implementation in Brazil


## Abstract

The fast and expressive wind energy (WE) diffusion observed in Brazil is being hampered by several barriers, and the Brazilian government, in particular, is failing at offering propitious conditions for implementing onshore wind farms in the country. Even so, the onshore wind farms implemented in the country have reached expressive capacity factors and very low levelized cost of electricity. This study aims to identify how wind developers plan their onshore wind farms to overcome the existing barriers. Based on forty-one interviews performed with relevant stakeholders of the Brazilian WE sector, this study identified for each of twenty-four previously identified existing barriers at least one overcoming effort performed by developers. Although most barriers may be overcome directly by developer initiatives, the obstacles with higher impact on the implementation of onshore wind farms, namely the unstable macroeconomic environment, the poor transmission infrastructure and the inadequate access to capital, depend on governmental actions to be addressed.



## Keywords

Renewable energy; Wind energy; Wind farms implementation; Barriers to implementation


## 4.1 Introduction

Current estimates suggest that wind energy (WE) is the renewable energy source (RES) responsible for driving the future expansion and diversification of electricity generation across the world, especially in developing regions [30]. The choice for WE is a result of its capacity for generating large amounts of electricity at competitive costs [13, 56, 61]. However, worldwide WE diffusion has been constrained by several barriers (see Chapter 2) that affect its cost-competitiveness [52, 55]. Identifying which barriers hinder the implementation of onshore wind farms and consequently verifying how it is possible to overcome them, becomes therefore essential to increase WE investment [10, 18, 57].

Among the nations that are promoting WE utilization across the globe, Brazil has been noted for observing a rapid and expressive implementation of onshore wind farms. From 2008 to 2017 the national WE installed capacity grew 37 times, reaching 12.770 MW [25, 35]. As a result of 508 onshore wind farms in operation, Brazil generated 40.46 TWh of wind power in 2017, placing definitively and expressively that source in the Brazilian energy matrix [3]. As also observed worldwide, the implementation of onshore wind farms in Brazil has been constrained by various barriers (see chapter 3). Despite this implementation being hampered by various obstacles, the wind farms in the country are considered to be successfully implemented as they present impressive capacity factors [3] and a very low levelized cost of electricity generation [15].

Considering that good planning increases the chances of project implementation success [21, 40], it is assumed that onshore wind farms in Brazil have been planned with the capability to overcome, or at least mitigate the interference caused by the barriers. Thus, the efforts applied by the local wind developers to address these barriers may serve as reference to others experiencing similar problems. The purpose of this study is to contribute to facilitate the continuity of the increasing onshore wind farm implementation across the world, especially in developing economies such as Brazil, through the answer to the following research question: "how do wind developers plan their wind farm projects to overcome these barriers?". This paper identifies the efforts made by local developers at project planning stage with the intention to address existing barriers to onshore wind farm implementation in Brazil.

It is only possible to develop a study with this purpose based on knowledge about all the existing barriers to onshore wind farm implementation. Diogenes *et al.* (see chapter 3) recently performed a reliable identification of all the barriers to onshore wind farm implementation in Brazil, which was not available from previous studies [5, 8, 9, 14, 17, 20, 24, 42, 47, 51, 53, 60, 63], thus creating the opportunity to perform this study.

Starting with this introduction, this paper additionally includes six sections. The second section describes the case study selected, presenting each of the twenty-four barriers to onshore wind farm implementation in Brazil. The third section introduces the steps to plan onshore wind farms. The fourth section details the methodology used, mentioning how the interviews and the data analysis were performed. The fifth section details the efforts applied at each wind farm planning phase by the local wind developers to overcome each barrier. Then, the application of these efforts is briefly discussed. This study concludes stressing which barriers it has been possible to overcome at the wind farm planning level and which still depend on regulatory or other governmental efforts to be addressed.

## 4.2 LARGE-SCALE WIND ENERGY IMPLEMENTATION: 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 diminish its high dependence on hydropower [46, 58].

Among the options to expand the energy matrix and consecutively re-establish security of supply [41], WE emerged as a reliable option in Brazil, especially in the Northeast region due its excellent wind conditions [4, 16, 19, 44, 53].

As a consequence of the deployed public auction system, the installed capacity of WE in the country increased 37 times in the past decade, reaching 12.770 MW in the end of 2017 (see Figure 4.1). Currently, Brazil occupies the eighth position among the top 10 nations with more WE capacity installed [35].

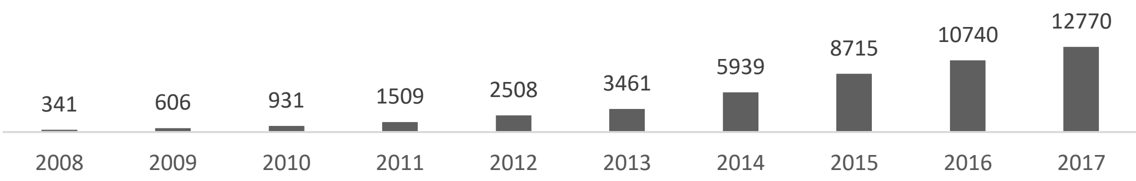


Figure 4.1 – Evolution of the Brazilian WE cumulative installed capacity (MW/year) [25-29, 31-35].

From the current installed capacity, the country generated 40.46 TWh of electricity, 33.99 TWh (i.e., approximately 84% of the generation) 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) [3] – approximately 77% of the generation in the Northeast region. Associated with this fast and expressive national WE growth, the wind farms located in the Northeast region have been continuously reported as having an outstanding average capacity factor above 40% [2, 3, 15], much higher than the average found across countries worldwide, which varies between 18 and 32% [36]. Consequently, even facing barriers that affect implementation costs, the levelized cost of WE in the region has reached 0.035 USD/kWh [15], much lower than the costs of WE generation observed in other regions of the world, which reaches up to 0.12 USD/kWh [37]. These barriers were recently identified and described by Diogenes *et al*. (see Chapter 3). According to the authors, there are currently twenty-four barriers hindering the implementation of onshore wind farms in Brazil (see Table 4.1).

| **Barriers** | **Description** | **Implications on the wind farm implementation/operation** |
|---|---|---|
| MARKET | | |
| 1. Underdeveloped home wind industry | The national wind industry is underdeveloped, relying on the import of core materials and components, especially those required to assemble and further maintain the wind turbines. | Due to the time-consuming process of importing core components, wind turbines can spend long periods out of operation during maintenance. As the manufacturers are not Brazilian companies, supply contracts are usually made in U.S. Dollars and subject to local currency variation. |
| 2. Restricted access to wind turbine technology | Turbine manufacturers established in Brazil resist transferring technology to support the construction and further O&M (operation and maintenance) of the wind farms. | To construct made-to-measure foundations and towers, as well as perform O&M internally, wind developers need access to core technological information from the manufacturer. The construction and the adequacy of O&M schedules may be compromised and dependent on the manufacturer. |
| 3. Lack of information about wind potential | The region or state wind resource maps developed by the public electric utilities are outdated. | It becomes difficult to prospect new sites to implement wind farms without such information. |
| ECONOMIC AND FINANCIAL | | |
| 4. Inadequate access to capital | The public development banks (PDBs) have been strict in loan approval. When approved, the loans frequently are delivered late. | These conditions create serious difficulties for wind developers to cope with the high up-front costs required in the implementation of wind farms. |
| 5. High cost of capital | It is expensive to raise financial resources to fund wind farms in Brazil, even from PDBs. The PDBs have decreased the equity ratio offered, from 80%, 70% to not more than 50%. | |
| 6. Insufficient financial institutions | The main PDB, *Banco Nacional de Desenvolvimento Econômico e Social* (BNDES), is insufficient to fund the implementation of wind farms in the country. | |

| Barriers | Description | Implications on the wind farm implementation/operation |
|---|---|---|
| INSTITUTIONAL | | |
| 7. Unstable macroeconomic environment | The current economic crisis in Brazil. | The economic crisis is causing a reduction in the demand for electricity, decreasing the need for WE auctions. The economy deceleration is limiting the main sources of tax collection, as well as the loan capacity of the PDBs, forcing them to reduce the equity ratio and increase the interest rates. Uncertainty about the economic recovery causes fluctuation in the value of the local currency in relation with the U.S. Dollar, affecting supply contract prices. Public investments in infrastructure reinforcement have been reduced due the drop in tax collection, which consequently decreased the availability of public resources for infrastructure investments. |
| *Inadequate regulations* | | |
| 8. Environmental license<br>9. Land regularization<br>10. Archaeological license | Bureaucracy and complexity in applying and obtaining land regularizations and environmental/archaeological licenses. | The completion of the processes to obtain regularizations and licenses is time-consuming, making it difficult for wind developers to meet energy auction deadlines. In addition, subsequent environmental and archaeological inspections may block wind farm implementations. |
| 11. Lack of R&D culture | Lack of R&D efforts to promote national wind technology. | Without national R&D efforts, the home wind supply chain will continue underdeveloped and dependent of foreign technology. Thus, supply contracts will always be made in U.S. Dollar, keeping subject to the local currency variation. |
| *Lack of governmental institutions and mechanisms* | | |
| 12. Lack capacity from state public institutions | The limited capacity of skilled personnel in public intuitions responsible for emitting land regularizations and environmental/archaeological licenses. | Due to the limited number of skilled personnel available, when multiple wind farm regularizations/licenses are requested, the processes end up being time-consuming. This makes it difficult for wind developers to meet energy auction deadlines. |

| Barriers | Description | Implications on the wind farm implementation/operation |
|---|---|---|
| INSTITUTIONAL | | |
| *Lack of governmental institutions and mechanisms* | | |
| 13. Lack of governmental cooperation | Public agencies and institutions do not cooperate with wind developers, namely to inform in advance about regulatory changes. | The governmental agencies do not provide wind developers flexibility to adapt ongoing wind farm implementations to the new rules. |
| 14. Inadequate state secretary of energy | Existing cases of lack of support to wind farm implementations from specific state government entities with responsibility for the energy sector. | The lack of state support slows down regularizations and licenses processes, the mobilization of local populations to avoid their potential opposition, as well as the reinforcement of the local infrastructure. |
| TECHNICAL | | |
| 15. Grid system limitation | The grid system features major capacity constraints. | Lack of capacity to integrate new wind farms in the grid, blocking wind farm projects enrolment in the energy auctions. |
| 16. Lack of skilled personnel | With the exception of civil construction of wind farms, the rest of the national wind supply chain faces shortage of skilled workers, especially in technical skills. | The current need for maintenance/repowering of a large number of wind farms hurts O&M services even more due to the lack of personnel. |
| 17. Insufficient O&M services | Insufficient availability of O&M services. | Turbines may present underperformance or even break due the lack of proper and continuous maintenance. |
| 18. Insufficient quality of wind turbines and blades | The foreign wind turbines and blades need adaptation to the Brazilian wind conditions. Especially in the Northeast region, this wind regime is more consistent and powerful, requiring technology adaptation, especially in terms of O&M schedules | Turbines and blades may break due the lack of proper O&M schedule adaptation to local wind conditions. |

| **Barriers** | **Description** | **Implications on the wind farm implementation/operation** |
|---|---|---|
| SOCIAL | | |
| 19. Local community opposition | The implementation of wind farms in some country states may face local community opposition. The opposition found in shoreline areas is different from those areas located far from the coast. | Shoreline communities have argued that onshore wind farm implementations affect the beach landscape, as well as their economic activities. In opposition, the communities far from the coast have used wind farm implementations as opportunities to claim local infrastructure improvements. When these concerns and counterparts are not addressed, local opposition may emerge, delaying wind farm implementations. |
| OTHER BARRIERS | | |
| *Poor infrastructure* | | |
| 20. Transmission | Low availability of substations and high voltage lines. | Unavailability of transmission lines and substations close to windy sites restricts the development of wind farm projects. |
| 21. Roads | Roads usually are not two-lane. | Lack of large roads to facilitate the transportation of wind turbines components. |
| 22. Communication | Poor broadband internet connection. | Internet access limited to send all wind farm information in real time. |
| *Uncertain governmental policies* | | |
| 23. Auction occurrence uncertainty | Auction occurrence uncertainty has affected wind developers' investment schedules. This uncertainty is exacerbated by inadequate energy expansion planning. | This uncertainty has stopped the growing implementation of new wind farms. In addition, this barrier has led the local wind supply chain to foresee production capacity idleness, putting at risk the structure of the national WE supply chain. |
| *Environmental* | | |
| 24. Competition for land | The best wind areas are already occupied by wind farms or face high valorization. | Land overvaluation, due to tourism activities, makes it difficult for wind developers to prospect new areas to implement wind farms. |

Table 4.1 – Barriers to implement onshore wind farms in Brazil (see chapter 3).

Among these barriers, Diogenes *et al*. (see Chapter 3) observed that three had a greater interference on the implementation of onshore wind farms in the Northeast of Brazil: poor transmission infrastructure, unattractive financial loans, and unstable macroeconomic environment.

Poor transmission infrastructure has been recognized as the barrier with the highest impact, due to the current grid capacity limitation which makes it impossible to connect new wind farms in some Brazilian states, and due to the current low availability of substations and high voltage lines close to potential windy sites. The inadequate access to capital was considered the second main barrier, due to the incapacity of many wind developers to cope with the high up-front costs inherent to wind farms implementations alone. Finally, the unstable macroeconomic environment is considered the third main barrier to wind farm implementation in Brazil, due to its direct relation with auction occurrence, as well as with the variation of the U.S. Dollar relative to the Brazilian Real and the governmental financial heath required to perform infrastructure improvements and offer competitive loans.

## 4.3 PLANNING THE ONSHORE WIND FARM IMPLEMENTATION

Considering the guides proposed by the American Wind Energy Association (AWEA) [6], the Renewable Energy Alaska Project (REAP) [54], the Irish Wind Energy Association (IWEA) [38], the Clean Energy Council (CEC) [12], the Ministry of New and Renewables Energy of the Indian Government (MNRE) [49], and the Canadian Wind Energy Association (CanWEA) [11], the planning process for an onshore wind farm implementation may be decomposed in the following twelve steps:

(i) Perform a wind resource assessment, ensuring the existence of good wind conditions to generate electricity at profitable levels;

(ii) Verify grid capacity, ensuring connection and electricity transmission;

(iii) Select the site and define its utilization, establishing land use contracts and verifying the existence of adequate access to infrastructure on site;

(iv) Verify the site viability for project implementation, according to social, environmental, and geological conditions;

(v) Verify technical and operational viability, confirming the availability and reliability of wind turbines, components, specialized labor and other resources required for the project implementation, and subsequently propose a layout with optimized infrastructure micrositing (towers, wind turbines, sub-stations, etc.);

(vi) Get permissions and licenses, legitimizing the project implementation according to socio-environmental laws and guidelines;

(vii) Prove the techno-economic viability, verifying cost and performance criteria, and the existence of suitable turbines, components and management tools;

(viii) Ensure operation and maintenance (O&M), confirming that during the wind lifespan, it will not face technical failures (interruptions, obsolescence of turbines and components, etc.);

(ix) Collect funding resources, internally with the project owner, or externally with financial institutions, to overcome the high up-front implementation costs;

(x) Find buyers for the generated electricity, establishing power purchase agreements (PPAs) and consequently enable the project's economic viability;

(xi) Develop a decommissioning plan, ensuring that after project's lifespan, the wind farm infrastructure will be removed in a cost-efficient and environmentally friendly way;

(xii) Check the possibility of implementing the project in a hybrid system, together with other renewable energy technology or storage systems, ensuring the efficient utilization of available transmission infrastructure (intermittency reduction).

Among these twelve steps, the first eight are common in the six methods (see Table 4.2).

| **Methods** | **Steps** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) | (vii) | (viii) | (ix) | (x) | (xi) | (xii) |
| AWEA [6] | x | x | x | x | x | x | x | x | x | x | | |
| REAP [54] | x | x | x | x | x | x | x | x | x | | | |
| IWEA [38] | x | x | x | x | x | x | x | x | x | x | x | |
| CEC [12] | x | x | x | x | x | x | x | x | | | | |
| MNRE [49] | x | x | x | x | x | x | x | x | | | x | x |
| CanWEA [11] | x | x | x | x | x | x | x | x | x | | | |

Table 4.2 – Steps to develop wind farm projects.

Despite a relatively high commonality, it should be noted that some methods do not consider the action of collecting funding resources as a step to develop wind farm projects. Furthermore, most methods do not include the processes of finding buyers, developing the decommissioning plan, and especially the analysis of the possibility of using hybrid systems. Whatever the steps used by the wind developer, the existing barriers start to interfere on the wind farm implementation since the planning phase [52, 55]. Thereby, efforts to overcome these barriers need to begin preferably at that very phase.

## 4.4 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 its charateristics of allowing 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 [64] – implementation processes involving a large number of critical actors and factors [45]. Moreover, the lack of detailed and updated preliminary research about onshore wind farms implementation in developing countries leads to the need of exploring the distinct phenomena [48].

### 4.4.1 STAKEHOLDER INTERVIEW

To identify the barriers to onshore wind farm implementation in Brazil, information was collected through interviews with several stakeholders from the Brazilian WE sector. The interviews were complemented with a literature review and site visits. The focus on stakeholders is justified by their crucial role and utmost interest in identifying efforts to overcome the barriers to RES implementation [52], as is suggested by Kann [39] when identifying initiatives to overcome barriers to wind project financing in Australia. The interviewed stakeholders included developers, engineers & consultants, manufacturers, support agents, public administrators, and researchers (see Table 4.3).

| **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 (M) | Business directors of the main manufacturing companies linked to the local WE supply chain. |
| Support agents (Sa) | Managers of financial, regulatory and think thank 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 4.3 – Stakeholder category descriptions.

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 [1]. In addition, during the 7$^{th}$ edition of Brazil Wind Power - Conference & Exhibition (Aug-Sep '16), the main authorities and the most important executives of the sector were also recognized. Through telephone calls, e-mails and direct contacts, 128 stakeholders were invited and 41 (32%) accepted contribute with the study.

The semi-structured interviews were based on the barriers to implement onshore wind farms in Brazil described by Diogenes *et al.* (see Table 4.1). Participants were asked openly if they knew how the local wind developers overcome these barriers during wind farm project planning. Additionally, at the end of the interviews, they were asked to confirm the efforts mentioned and point out which depended on governmental initiatives. The interviews were supported by a protocol that guided the interviewer to conduct the open questions, as well as to identify the stakeholder profiles.

### 4.4.2 DATA COLLECTION AND ANALYSIS

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

The interviews were based on a protocol organized after detailed awareness of the barriers to onshore wind farm implementation in Brazil (see Table 4.1) and the Steps to develop wind farm projects (see Table 4.2), which ensured reliability [64]. This research ensured confidentially to the information provided by the interviewees thought the informed consent signed by both parties. The interviews were recorded and transcribed using appropriate analysis software (Express Scribe). The transcriptions were performed as closely after the end of the interview as possible, which ensured constant comparison of responses [23], and allowed a first analysis of the collected data and the improvement of the subsequent interviews [7, 62].

The interviews lasted from 10 minutes to 1 hour and 36 minutes, with an average of 40 minutes and a total of approximately 27 hours and 41 minutes, resulting in 345 pages of text transcribed verbatim [64]. The sample was large enough to reach theoretical saturation [22, 62].

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 4.4), some of them with experience in more than one state.

| **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 |

Table 4.4 – Interviewed stakeholders per category and range of experience.

The qualitative data collected in the 41 interviews was analysed using a qualitative content analysis method [59], with category construction and coding frame [43, 50]. For this study, the analysis of the overcoming efforts employed by the interviews was linked to the barriers observed by Diogenes *et al*. (see Table 4.1).

Data was explored iteratively, going back and forth between the qualitative data and theoretical arguments [62]. The analysis was carried out through qualitative association between overcoming efforts and the barriers [7, 22].

In this way it was possible to verify which efforts were used for overcoming each specific barrier, and which were equally used to overcome more than one barrier. Descriptive and simultaneous coding were used and performed using appropriate analysis software (Qiqqa).

## 4.5 OVERCOMING THE BARRIERS

For each of the barriers mentioned by the stakeholders, at least one overcoming effort was also identified as having been performed by the developers at the planning stage of wind farm projects (see Table 4.5).

| **Barrier** | **Overcoming effort** | **S %** | **Planning step where the effort is applied** |
|---|---|---|---|
| MARKET | | | |
| (1) Underdeveloped home wind industry | (a) Select suppliers considering quality as main criteria, ensuring its capacity to provide properly O&M services. | 10% | Step (viii) – Ensure O&M |
| (2) Restricted access to wind turbine technology | (b) Negotiate technology access with manufacturers by guaranteeing loyalty or hire technical staff from the manufactures. | 17% | Step (v) – Verify the technical and operational viability; Step (vii) – Prove the techno economic viability; Step (viii) – Ensure O&M. |
| (3) Lack of information about the wind potential | (c) Installation of anemometric towers across potential windy sites and creation of a private wind data bank. | 10% | Step (i) – Perform the wind resource assessment |
| ECONOMIC AND FINANCIAL | | | |
| (4) Inadequate access to capital, (5) High cost of capital and (6) Insufficient financial institutions. | (d) Use own company financial resources.<br>(e) Bridge loans with private banks.<br>(f) Loans with investment funds. | 46%<br>46%<br>15% | Step (ix) – Collect funding |
| INSTITUTIONAL | | | |
| (7) Unstable macroeconomic environment | (g) Press the government to reinstate auctions on a regular basis, as well as to return to offering competitive public financing and improve the transmission infrastructure. | 27% | Step (ii) – Verify grid capacity; Step (xi) – Collect funding; Step (x) – Find buyers. |
| | (h) Monitor the exchange rate variation, choosing the best time to sign contracts with foreign turbine manufacturers. | 20% | Step (vii) – Prove the techno economic viability |
| *Inadequate regulations* | | | |
| (8) Environmental license | (i) Hire specialized consulting companies or former professionals from licensing agencies to conduct the studies required by these licenses. | 27% | Step (iv) – Verify the site viability; Step (vi) – Get permissions and licenses. |
| (9) Land regularization | (j) Offer financial support to the land owner to start the regularization process. Land renting contracts need to be signed with a purchase option, guaranteeing the land use rights for all the project lifetime. | 17% | Step (iii) – Select the site and define its utilization; Step (vi) – Get permissions and licenses; Step (viii) – Ensure O&M. |
| (10) Archeological license | Overcoming effort (i). | 27% | Step (iv) – Verify the site viability; Step (vi) – Get permissions and licenses. |
| (11) Lack of R&D culture | (l) Establish partnerships with foreign manufacturers to improve the adaptation of the technology to the local winds. | 24% | Step (v) – Verify the technical and operational viability |

| Barrier | Overcoming effort | S % | Planning step where the effort is applied |
|---|---|---|---|
| INSTITUTIONAL | | | |
| *Lack of governmental institutions and mechanisms* | | | |
| (12) Lack of state public institutions capacity, (13) Lack of governmental cooperation and (14) Inadequate state secretary of energy | (m) The wind developers support the existence of an association that has the mission of providing institutional assistance to WE expansion in the country. | 14% | Step (ii) – Verify grid capacity<br>Step (ix) – Collect funding<br>Step (x) – Find buyers |
| TECHNICAL | | | |
| (15) Grid system capacity limitation | (n) Press the government to reinforce the grid. In addition, hire own engineering services to follow the process of line construction. | 37% | Step (ii) – Verify grid capacity |
| (16) Lack of skilled personnel | (o) Seek specialized technical staff from overseas to train their own human resources. | 32% | Step (v) – Verify the technical and operational viability |
| (17) Insufficient of O&M services | Overcoming effort (o). | 24% | Step (viii) – Ensure O&M |
| (18) Insufficient quality of wind turbines and blades | (p) Evaluate in detail site wind conditions and consequently perform several simulations with different types of turbines. | 10% | Step (v) – Verify the technical and operational viability<br>Step (vii) – Prove the techno economic viability |
| SOCIAL | | | |
| (19) Local community opposition | (q) Open dialogue with the local residents to identify and address their concerns and needs. Promote social projects. | 41% | Step (iv) – Verify the site viability |
| OTHER BARRIERS | | | |
| *Poor infrastructure* | | | |
| (20) Transmission | (r) Press the government to expand the transmission coverage. | 37% | Step (ii) – Verify grid capacity |
| (21) Roads | (s) Perform bridge reinforcements and open road accesses. In addition, hire specialized logistics companies to delivery carefully the large wind components. | 20% | Step (iii) – Select the site and define its utilization |
| (22) Communication | (t) Hire communication services based on iridium networks. | 10% | Step (v) – Verify the technical and operational viability |
| *Uncertain governmental policies* | | | |
| (23) Auctions occurrence uncertainty | Overcoming effort (g).<br>(u) Commercialize WE on the free market. | 12%<br>29% | Step (x) – Find buyers |
| *Environmental* | | | |
| (24) Competition for land | (x) Prospect windy sites away from the coastline. | 17% | Step (iii) – Select the site and define its utilization |

Table 4.5 – Overcoming efforts used for each barrier to implement onshore WE farms, percentage of stakeholders (S%) who mentioned each effort and planning step where the effort is applied.

### 4.5.1 MARKET

Regarding the supply barrier caused by the underdeveloped wind supply chain, 10% of the interviewees reported that wind developers address this limitation in the process of supplier selection. According to them, in addition to cost and performance criteria, the developers performed this selection based on quality, searching for information about the manufacturer's capacity to properly provide O&M services, especially the quick replacement of broken components.

Concerning the technology access barrier due to manufacturers' resistance to sharing technical information about their technologies, 17% of the participants mentioned that wind developers overcame this obstacle by ensuring loyalty to the supplier or by hiring technical staff from manufacturers. They reported that developers are willing to establish long and wide supply contracts to persuade the supplier to be open to sharing more details about its technology. In addition, they mentioned that when the supplier is closed to sharing this information, the developers try to hire manufacturer technical staff to access technological experience about wind turbine composition, operation and maintenance, seeking to ensure wind farm optimal functioning. Highlighting the first mentioned overcoming effort, a director of a consulting engineering enterprise stated that the technical cooperation proposed by the wind developers is based on this prerogative:

> "A good partnership will result in new supply contracts in the future".

About the information barrier created by the outdated wind resource maps, 10% of the interviewees argued that wind developers overcame this obstacle through the installation of anemometric towers across several potential windy sites and the consecutive creation of a private wind data bank. They claimed that developers recognize this effort as fundamental to provide reliable and detailed resource information crucial to wind farm project planning. One head of project development on a public energy enterprise referred to such overcoming effort in the following way:

> "I know one wind developer who installed more than 500 anemometric towers across the Northeast region, searching for windy sites. With this detailed information, he concluded that with a certain amount of wind, a certain layout, and a certain machine he would have a particular amount of WE generated".

### 4.5.2 Economic and financial

Regarding the difficulty to obtain loans to fund the implementation of onshore wind farms in the country, created by the three economic and financial barriers recognized, the interviewees mention three overcoming efforts performed by the local wind developers.

For 46% of the participants, this difficulty in obtaining loans is solved by wind developers by requesting bridge loans to private banks, namely for the case of delays in loan payments from the public development banks (PDBs). According to them, the loan contracts with the PDBs are well endorsed by the national financial market, and once a developer's project is approved, it is used as a guarantee for receivables and the private bank anticipates the loan payment charging appropriate interest rates.

The same 46% of the interviewees highlighted that wind developers consider using their own company resources, free of interest rates, as optimal overcoming effort in this situation. However, as most developers have limited financial resources to cover the high wind farms up-front costs, 15% of the respondents argued that the developers seek loans from investment funds, which are more flexible to negotiate equity-ratios and payment schedules. One head of project development at an energy company described this overcoming effort in these terms:

> "As our CEO has direct contact with foreign investment funds, we have a market advantage. The advantage consists in having flexibility to capture financial resources".

### 4.5.3 Institutional

Concerning the institutional barrier caused by the current unstable Brazilian macroeconomic environment, 27% of the interviewees reported that wind developers address this obstacle by pressing the government to reinstate the auctions on a regular basis, as well as return to offering competitive public financing and improve the transmission infrastructure. They claim that wind developers complain about current governmental WE expansion targets based on short-term demand scenarios, which exclude forecasts for future economic growth recovery and rise in electricity consumption. Moreover, concerning the high exchange rate, which is another barrier to the implementation of onshore wind farms in Brazil resulting from this unstable macroeconomic environment, 20% of the participants claimed that wind developers mitigate this obstacle by monitoring the financial market. According to them, the developers understand that following the financial market is fundamental to be able to predict the periods when the value of the local currency in relation to the U.S. Dollar is high and consequently the time is right to sign contracts with foreign suppliers.

Regarding the institutional barriers caused by inadequate regulations, it was mentioned that wind developers overcome these impediments with different efforts. For the case of land regularization, 17% of the interviewees mentioned that developers address this obstacle by offering financial support in advance so that the land owner can start the land regularization process. Once regularized, they propose a land renting contract with a purchase option ensuring the land use rights for the whole project lifetime. For the case of environmental/archaeological licenses, 27% of respondents argued that developers address this difficulty by contracting specialized consultancies or hiring professionals from the licensing agencies to conduct the studies necessary to get the license. The participants mentioned that to avoid potential refusals or interruptions to the implementation of onshore wind farms, developers require these studies to be developed in the most complete versions possible. In addition, the interviewees mentioned that due to the limited capacity of the licensing agencies and the time-consuming nature of these procedures, wind developers do everything they can to obtain these approvals as soon as possible, to be ready to advance and get enrolled in the energy auctions.

Concerning the lack of WE R&D culture in the country, 24% of the participants argued that to overcome this barrier wind developers establish partnerships with the foreign manufacturers to improve the adaptation of the WE technology to local winds, using their wind farms as cases of analysis.

For the institutional barriers caused by the lack of governmental institutions and mechanisms, 14% of the interviewees mentioned that to overcome these barriers wind developers support the existence of a WE association. This association is the *Associação Brasileira de Energia Eólica* (ABEEólica) that represents the stakeholders of the national wind industry, supporting the promotion of WE nationally, which sometimes public institutions fail to do efficiently. A head of project development of an energy company described the significant role of the association in the implementation of onshore wind farms in the region, in the following way:

> "…ABEEólica is very active. They perform several studies, analysis, and go knocking door to door at governments, ministries, agencies, transmission system operators, claiming solutions for the main problems faced by the sector".

### 4.5.4 Technical

Concerning the technical barrier caused by the grid system capacity limitation, 37% of the participants mentioned that wind developers address this obstacle by pressing the government to build more transmission lines. According to them, the developers complain that the grid system needs to be reinforced in advance in areas with more WE potential, and not only in areas where the auctions led to the implementation of new onshore wind farms, enabling the development of new wind farm projects and further participation in the energy auctions. In addition, after the energy auctions, when these transmission lines are being implemented, wind developers hire engineering services to follow the grid reinforcement process and report any possible interference on the wind farm connection.

For the technical barrier created by the lack of skilled personnel and insufficient O&M services, 32% of the interviewees mentioned that wind developers deal with the problem by contracting specialized technical staff from overseas and using them to train their own human resources, especially those able to perform O&M activities. The participants mentioned that those developers who are manufacturer dependent, from the moment that the warranty contract expires on, want to take the O&M control of their wind turbines.

Regarding the technical barrier caused by the insufficient quality of wind turbines and blades, 10% of the interviewees mentioned that wind developers have overcome the problem by evaluating in detail the local wind conditions and, consequently, performing several simulations with different types of turbine. According to them, the developers perform these efforts to select the turbine that better operates under the local wind conditions. A director of a wind farm project development engineering enterprise highlighted the importance of turbine evaluation, noting:

> "Here, in the region, the wind is well-behaved, it does not change direction much, which is ideal. Wind turbines appreciate neither very strong nor very weak winds, but constant winds at a medium speed. So, you need to check which turbine type is best suited to the local wind".

### 4.5.5 SOCIAL

To address the social barrier due to local community opposition, 41% of the interviewees mentioned that wind developers establish an open dialogue with the local residents in both scenarios (shoreline and away from the coast). The participants argued that developers acknowledge that these debates are essential to identify the community concerns and needs, enabling them to promote social projects that deliver benefits to the community and consequently avoid any kind of resistance. A social responsibility director from an energy company described the importance of these social projects, in the following way:

> "Like us, several energy companies with wind farms implemented have carried out social projects, proposing benefits in the short, medium and long-term to these communities, avoiding their resistance".

In addition, the same director indicated how these projects are developed:

> "The PDBs force a part of the loan to be applied in social projects. With this funding and the support of NGOs and private entities, we make our projects come to life".

### 4.5.6 OTHER BARRIERS

Concerning the "other barrier" caused by the poor infrastructure, namely in terms of transmission, roads and communication, it was verified that wind developers overcome these impediments with different efforts. In the case of insufficient transmission lines, 37% of the interviewees mentioned that the overcoming effort is the same performed in the case of grid system capacity limitations, i.e., pressing the government to perform the grid reinforcement. For inadequate roads, 20% of the respondents mentioned that the developers have addressed the problem by hiring specialized logistics companies to carefully deliver the large wind components, as well as carrying out bridge reinforcement works and openings road accesses jointly with other developers with implementations planned in the region. Regarding absent broadband internet connections, 10 % of the participants mentioned that the developers cope with the problem by hiring communication services based on iridium networks.

Regarding the "other barrier" caused by the auctions occurrence uncertainty, 12% of the interviewees reported that wind developers have been trying to overcome the obstacle by pressing the government to provide a stable prevision of the next auctions based on the same prerogatives previously described in the first institutional barrier.

In addition, 29% of the respondents mentioned that wind developers have overcome the absence of regular auctions by choosing the free market to commercialize the electricity to be generated by their wind farms. However, they argued that for this overcome effort to be viable, the developers need to find one or a group of big consumers that are willing to purchase electricity from the wind farm during several years. One head of project development on an energy enterprise highlighted the opportunity to commercialize energy in the free market, commenting that:

> "In a general vision, currently we have here in Brazil big companies looking to generate their own electricity through wind farms".

About the "other barrier" caused by the land overvaluation in the shoreline zones, 17% of the respondents mentioned that wind developers solve the problem taking advantage from the existing new tower heights and prospecting windy sites away from the coastline, which besides being cheaper, face less local resistance. A director from a national energy system operator highlighted this trend, by noting that:

> "The implementation of new wind farms is migrating to areas away of the coastline, where the developers find land at more competitive prices and at the same time exist a better local community acceptance".

## 4.6 DISCUSSION

Among the 24 efforts identified, three were demonstrated to be able to overcome more than one barrier: press the government (for barriers 7, 15, 20 and 23), hire specialized consulting companies or former professionals from licensing agencies (for barriers 8 and 10) and seek specialized technical staff from overseas (for barriers 16 and 17). This happens because each highlighted group of barriers has the same origin, i.e., the government failure to provide appropriate structural conditions for the promotion of WE, limited capacity from licensing agencies, and lack of Brazilian skilled personnel, respectively.

Crossing the composition of the steps to plan onshore wind farms with the overcoming efforts outlined by the interviewees, it is possible to recognize that these actions are implemented in the ten first steps, and that, except for the first, every other step accommodates the execution of more than one overcoming effort (see Figure 4.2). This means that an onshore wind farm plan able to address all the barriers described must be composed of, at least, the steps included in the AWEA [6] and IWEA [38] guides.


Figure 4.2 – Overcoming barriers while wind farm planning steps are executed.

Furthermore, while most of the efforts could be performed by the developer individually, for six – efforts *g*, *m*, *n*, *q*, *r* and *t* (see Table 4.6) – it is important to partner with other developers.

In the case of efforts *m*, *q* and *t*, the high costs associated with the sponsorship of a representative association, the implementation of social projects, and especially the improvement of access infrastructures, makes the partnership a way of reducing implementation costs.

Additionally, concerning efforts *g*, *n* and *r*, the importance of these being applied in partnership is due to the need to press the government to overcome the corresponding barriers. Partnerships increase the likelihood of attempts to influence political decisions towards WE being triumphant.

| **Barrier** | **Implementation of efforts to overcome barriers** |
|---|---|
| MARKET | |
| (1) Underdeveloped home wind industry | By wind developers (effort a) |
| (2) Restricted access to wind turbine technology | By wind developers (effort b) |
| (3) Lack of information about the wind potential | By wind developers (effort c) |
| ECONOMIC AND FINANCIAL | |
| (4) Inadequate access to capital, (5) High cost of capital and (6) Insufficient financial institutions. | By wind developers (effort d, e and f) |
| INSTITUTIONAL | |
| (7) Unstable macroeconomic environment | By wind developers in partnership / Need governmental support (effort g)<br>By wind developers (effort h) |
| *Inadequate regulations* | |
| (8) Environmental license | By wind developers (effort i) |
| (9) Land regularization | By wind developers (effort j) |
| (10) Archeological license | By wind developers (effort i) |
| (11) Lack of R&D culture | By wind developers (effort l) |
| *Lack of governmental institutions and mechanisms* | |
| (12) Lack of state public institutions capacity, (13) Lack of governmental cooperation and (14) Inadequate state secretary of energy | By wind developers in partnership (effort m) |
| TECHNICAL | |
| (15) Grid system capacity limitation | By wind developers in partnership / Need governmental support (effort n) |
| (16) Lack of skilled personnel | By wind developers (effort o) |
| (17) Insufficient of O&M services | By wind developers (effort o) |
| (18) Insufficient quality of wind turbines and blades | By wind developers (effort p) |
| SOCIAL | |
| (19) Local community opposition | By wind developers in partnership (effort q) |
| OTHER BARRIERS | |
| *Poor infrastructure* | |
| (20) Transmission | By wind developers in partnership / Need governmental support (effort r)<br>By wind developers (effort s) |
| (21) Roads | By wind developers in partnership (effort t) |
| (22) Communication | |
| *Uncertain governmental policies* | |
| (23) Auctions occurrence uncertainty | By wind developers in partnership / Need governmental support (effort g)<br>By wind developers (effort u) |
| *Environmental* | |
| (24) Competition for land | By wind developers (effort x) |

Table 4.6 – Implementation of efforts to overcome barriers.

## 4.7 CONCLUSIONS

Based on the twenty-four barriers to implement onshore wind energy in Brazil identified by Diogenes *et al.* (see chapter 3), this study interviewed several stakeholders from the Brazilian WE sector to understand how local wind developers planned their wind farm projects to overcome these obstacles.

The results show that the stakeholders mention at least one overcoming effort performed by wind developers for each barrier. Even with associated costs, these efforts have been able to keep the implementation of onshore wind farms in Brazil cost-competitive, which is fundamental for the local developers to be able to compete in the national energy market and consequently achieve a profit from their investments.

Although most of the barriers may be overcome directly through developers' initiatives (alone or in partnership), the obstacles with higher impacts on the implementation of wind farms in the country, which are the poor transmission infrastructure, the unattractive financial loans, and the unstable macroeconomic environment, depend on governmental efforts to be addressed. Indisputably, to address these barriers, the developers need to operate jointly and with an organized strategy to perform political pressure. In fact, the developers have recognized this and have created ABEEólica to represent them politically.

Notwithstanding the Brazilian economy going through a recession, concerning the evolution of RESs, the national government should focus on long-term planning, namely for the WE expansion, considering medium to long-term scenarios. Although currently wind developers are able to overcome most of the barriers through their own initiatives, energy auctions can be planned and communicated on a regular basis, and as soon as the electricity demand starts to increase again, the government may act where it is not able to act currently, i.e., bringing back PDB loans, practicing cheaper and more flexible interest rates, and reinvesting in the reinforcement of grid infrastructure expansion.

Being aware that worldwide WE will continue to expand, and that wind developers cannot wait for government actions to overcome these barriers, this study may serve as a guide for such developers in developing countries with similar characteristics to Northeast Brazil, to address existing obstacles to the implementation of their onshore wind farms, based on the successful example of Brazilian counterparts described in this work. Moreover, this study may be useful to policy makers who seek a basis on which to reflect about which public policies may assist wind developers in addressing these obstacles in a less costly way.

However, this should be done recognizing the limitations of this study: a limited number of interviews were carried out; among the interviewees, few acknowledged and understood the efforts; non-inclusion of interviewees with sound knowledge about the implementation of onshore wind farms in other Brazilian states and countries; the fact that the identified efforts are only likely to work for the barriers mentioned in this study.

Future studies with the same objective of studying how it is possible to overcome the barriers to onshore wind farm implementation, addressing the abovementioned limitations of this study, are strongly recommended, to address the scarcity of knowledge about the subject. Additionally, these studies will be useful to further compare and discuss the approaches used by wind developers to overcome similar barriers around the world.

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# 5 CONCLUSION

This thesis was broadly motivated by the urgent need to overcome the negative interference of implementation barriers on the development of onshore wind farms around the world, especially in countries experiencing the initial stages of a significant wind energy integration. The main goal of the thesis was to strengthen the current knowledge about the barriers to the implementation of wind farms, as well to recognize how they may be overcome.

To achieve this goal, the research was divided in three parts. In a first part, a SLR was conducted, filling a gap in the literature, to develop a broad overview about which WE implementation barriers can be found, and which countries have faced these hurdles as they seek to expand their WE utilization. The other two parts of the thesis sought to identify which are the existing barriers to WE diffusion, and how they may be overcome, in cases of fast and expressive WE expansion.

The analysis and discussions carried out in the research allowed the verification of the following: even developed countries, with deep RE diffusion experience, currently present barriers to WE expansion; depending on local circumstances, some barriers can hamper wind farm implementation more than others; the WE implementation barriers present in the case of fast and expressive WE expansion are, in general, the same faced by countries with a long history of WE utilization; it is possible for wind developers to mitigate the barriers, in advance, at the wind farm project planning stage; overcoming some of these barriers, however, can be beyond their control and require direct government intervention.

Besides contributing to strengthening the literature about WE implementation barriers, this thesis also provides practical insights for wind developers and policy makers, to improve wind farm planning and energy markets, respectively.

## 5.1 THEORETICAL CONTRIBUTIONS

In terms of theoretical contributions, the three core parts of this thesis (chapters 2, 3 and 4) have contributed to strengthening the existing knowledge about WE implementation barriers, through three potential original research papers (RPs), as follows.

Chapter 2 reviewed systematically studies that addressed world barriers to WE implementation of various natures, providing a general view about which are those barriers, where in the world they have emerged, and which have long historic occurrences and significant impacts on wind farm implementations, and resulting in the first working paper:

- DIOGENES, J.R.F., CLARO, J., COELHO RODRIGUES, J., LOUREIRO, MVM. 2018. Barriers to onshore wind energy implementation: A systematic literature review. *Working Paper*.

The paper brings to the literature, for the first time, a comprehensive literature review on the subject, considering all natures of barriers to implementing onshore WE across the world. All information complied in the following study acts as essential for students, researchers, decision makers and wind developers to better understand the phenomenon under discussion, especially in your first contact with the topic.

Chapter 3, based on interviews with local WE stakeholders, identified and discussed the barriers to implement wind farms in the case of the fast and expressive WE expansion observed in Brazil, resulting in the second working paper:

- DIOGENES, J.R.F., CLARO, J., COELHO RODRIGUES, J. 2018. Barriers to onshore wind farm implementation in Brazil. *Working Paper*.

The paper contributes with an updated and methodologically reliable study regarding the barriers to onshore wind farm implementation in a developing country. The study was developed taking as reference the Brazilian WE sector – the most expressive and fastest case of WE diffusion observed in the emerging world. The knowledge produced strengthens the existing theoretical literature, by providing a clear notion about how the barriers can truly impact WE diffusion.

Chapter 4, based on the implementation barriers described in chapter 3 and on the same interviews with local WE stakeholders, identified the project planning decisions that allowed overcoming existing WE implementation barriers, resulting in the third and final working paper:

- DIOGENES, J.R.F., CLARO, J., COELHO RODRIGUES, J. 2018. Overcoming barriers to onshore wind farm implementation in Brazil. *Working Paper*.

This study is fundamental to advise wind developers, whether in Brazil or in countries with similar barriers to onshore wind farm implementation, regarding the successful project planning practices to overcome, or at least mitigate, the interference caused by these barriers. The present paper, as the previous ones, contributes to address the scarcity of knowledge about the practices towards successful onshore wind farm projects.

Together the three papers provide a rich and embracing theoretical contribution to the subject once the body of knowledge was reviewed and thereafter an applied case study was performed to validate and enlarge such body of knowledge.

## 5.2 PRATICAL IMPLICATIONS

The three parts of this thesis (chapters 2, 3 and 4), may also be useful for wind developers and policy makers, as well other WE sector stakeholders aiming at fostering an improved context for wind farm implementation.

The SLR in chapter 2 provides systematized information for wind developers about which barriers they can face in the implementation of wind farms in specific countries, and in addition, about how the barriers will affect their investment efforts. In addition, data about the historic occurrence of barriers may inform policy makers about countries where barriers were overcome or were not present, potentially enabling the identification of successful policy efforts that could be adapted and applied to other contexts.

Chapter 3, building on the multi-stakeholder interviews, similarly to the previous chapter includes organized information that allows wind developers to anticipate which barriers they may expect to find in emerging RE markets. In addition, policy makers in these emerging markets seeking to expand promptly their WE sector, can take the Brazilian case as model, and in advance develop energy policies that prevent these barriers from occurring.

Chapter 4, also building on the multi-stakeholder interviews, exploits the experience of local wind developers to develop guidelines for developers seeking to implement wind farms in emerging energy markets, as well in the Brazilian market, to plan their projects in such a way that they are able to overcome existing barriers.

## 5.3 LIMITATIONS

Each part of the thesis (chapters 2, 3 and 4) has specific limitations, which are outlined in the following paragraphs.

The main limitations of Chapter 2 are related to the chance that some significant studies were not included in the SLR, because of a failure to match the search and inclusion criteria. The fact that conference papers, as well as other studies which are outside the scope of the Scopus and Web of Science databases, were excluded, also contributes to this limitation.

Chapters 3 and 4 have limitations related to the case research design. The identified barriers and the suggested efforts to overcome them, may not, respectively, be the same or perform well in other emerging energy markets. Each emerging country has specific political, economic, and industry characteristics, which may lead to the presence of WE implementation barriers different from those observed in Brazil. Thereby, the generalizability of the findings from both chapters may be limited.

## 5.4 FUTURE WORK

Seeking to complement and expand the findings of this study, the following research directions are suggested:

- Create systematic literature reviews focused on: drivers to onshore wind energy implementation and efforts to mitigate and overcome WE implementation barriers around the world, from the wind developer and policy maker perspectives;
- Develop multi-stakeholder analysis of the barriers to WE implementation and its overcoming efforts, especially in the promising new RE markets with scarce knowledge in the area (e.g., Africa and Latin America countries);
- Perform quantitative studies seeking to evaluate the level of impact of these barriers as well the level of success of the overcoming efforts.

# APPENDIX (IN PORTUGUESE)

## PROTOCOL USED IN THE CASE RESEARCH

*PROTOCOLO DO ESTUDO DE CASO*

JAMIL RAMSI FARKAT DIÓGENES, *PRODEGI & INESC TEC*

No âmbito do programa doutoral em engenharia e gestão industrial (PRODEGI/FEUP), este estudo de caso que está a ser conduzido, tem como objetivo principal a constituição de uma tese de doutoramento.

O desenvolvimento desta tese é apoiado pelo centro para inovação, tecnologia e empreendedorismo (CITE) do INESC TEC, uma vez que pretende investigar o tema de adoção e implementação de tecnologias. No estudo em questão, trata-se energia eólica *onshore* a tecnologia sob investigação. A escolha da referida tecnologia deu-se pelo facto da continuidade de sua implementação ser dificultada pela existência de barreiras.

Neste sentido, pretende-se verificar quais são essas barreiras, onde elas ocorreram, e como é possível superá-las antecipadamente na fase de planeamento dos projetos eólicos. Uma vez alcançado objetivo descrito, o referido estudo contribuirá para a renovação da geração de eletricidade e consequentemente para descarbonizar a economia global. É importante ressaltar que consultas preliminares a literatura cientifica indicaram a escassez e a necessidade em desenvolver estudos sobre o tema.

Este protocolo serve de guião para a condução da investigação deste caso de estudo. Podem aqui ser encontradas informações sobre os procedimentos que são esperados utilização no processo de recolha dos dados, as questões principais que se pretendem ver respondidas com as entrevistas e a estrutura base do relatório resultante de cada estudo de caso.

**Procedimentos de recolha de dados**

*Quem entrevistar*

| | |
|---|---|
| Desenvolvedores | Gestores de projetos vinculado às empresas proprietárias ou desenvolvedoras dos projetos eólicos no Brasil. |
| Engenheiros e consultores | Gestores que integram as empresas prestadoras de serviços de engenharia e consultoria ao desenvolvimento de projetos eólicos no Brasil. |

| | |
|---|---|
| Fabricantes | Gestores das empresas que fabricam aerogeradores, pás, torres eólicas e componentes para projetos eólicos brasileiros. |
| Agentes de apoio | Gestores das organizações financeiras, regulatórias e sociais (governamental ou não governamental) que desenvolvem atividades de apoio ao desenvolvimento do setor eólico brasileiro. |
| Administradores públicos | Gestores dos estados e municípios brasileiros que observam projetos eólicos implementados. |
| Investigadores | Doutores que coordenem grupos de investigações que abordem como linha de investigação a difusão da energia eólica no Brasil. |

*Previsão de entrevistas*

No mínimo 30 entrevistados que tenha experiência dentro do setor eólico brasileiro como também nos principais estados geradores da região nordeste (Rio Grande do Norte, Bahia e Ceará). Destas 30 entrevistas, pretende-se a grande maioria seja realizada pessoalmente. Cada entrevista deverá ter no mínimo 10 minutos, sem tempo limite para encerramento.

Em um primeiro *round* de entrevistas será questionado aos participantes sobre a existência das barreiras. Feito isto, um segundo *round* é executado, buscando verificar se os entrevistados reconhecem como essas barreiras podem ser superadas. É esperado que a maior parte dos dados recolhidos seja proveniente das entrevistas conduzidas com base nas questões apresentadas.

*Preparação das visitas/entrevistas*

As visitas/entrevistas estão sujeitas à disponibilidade dos entrevistados. Os entrevistados deverão ser informados antecipadamente sobre o propósito da entrevista, que só decorrerá com seu consentimento. Um termo de consentimento, que garante que os entrevistados possuem toda a informação sobre a sua participação no estudo e que nele participam de forma voluntária e confidencial, é incluído em anexo. Antes da entrevista, será feita uma breve apresentação dos objetivos da investigação, bem como das instituições que apoiam o seu desenvolvimento.

**Estrutura do relatório do estudo de caso**

1. Introdução geral ao estudo;

2. Registo das entrevistas (data, local, tempo de duração e perfil do entrevistado,);

3. Resultados preliminares.

# INFORMED CONSENT

**Termo de Consentimento – Participação em Investigação**

**TESE DOUTORAL:** THE INFLUENCE OF IMPLEMENTATION BARRIERS ON THE DEVELOPMENT OF ONSHORE WIND FARMS

No âmbito do Programa Doutoral em Engenharia e Gestão Industrial (PRODEIG) da Faculdade de Engenharia da Universidade do Porto (FEUP), com acolhimento por parte do INESC TEC e parceria com o Núcleo Aplicado à Gestão e Inovação da Universidade Federal do Rio Grande do Norte (NAGI/UFRN), está em desenvolvimento um estudo conduzido por Jamil Ramsi Farkat Diógenes, cujo objetivo consiste em identificar as barreiras para desenvolvimento da Energia Eólica (EE) no Nordeste Brasileiro (NEBra), bem como os esforços efetivados para superá-las.

Por ser fundamental recolher as perspectivas dos diferentes *stakeholders* do setor eólico do NEBra, convidámo-lo(a) a participar neste estudo. Antes de decidir ou não participar pedimos-lhe que leia atentamente as informações seguintes e esclareça qualquer assunto sobre o qual tenha dúvidas.

- Esta entrevista é voluntária, pelo que tem o direito de não responder a qualquer questão e terminar a entrevista em qualquer momento por qualquer razão.
- A entrevista não comporta compensações monetárias, financeiras ou outras de natureza material.
- A informação recolhida é confidencial. A sua identidade não será revelada em quaisquer relatórios ou publicações resultantes deste estudo. Não será usado o seu nome ou qualquer outra referência em concreto à sua pessoa.
- A entrevista terá de ser gravada em formato digital de forma a poder ser referenciada no processo em estudo. A sua permissão para gravar poderá ser revogada em qualquer momento.
- Caso se verifique o abandono desta investigação os dados recolhidos serão eliminados no prazo de um mês após a comunicação ao entrevistado(a).

A tese de doutoramento estará concluída até o fim de 2018. Todas as gravações da entrevista serão armazenadas num espaço de trabalho pessoal, protegido, até o fim de 2019. As gravações serão então destruídas.

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☐ Compreendi os procedimentos descritos acima. As minhas dúvidas foram esclarecidas de modo satisfatório, e concordo em participar neste estudo. Recebi uma cópia deste formulário.

☐ Dou permissão para esta entrevista ser gravada em formato digital.

☐ Dou permissão para que a informação recolhida seja publicada para fins científicos, sem qualquer referência à identidade do entrevistado.

Nome:

Assinatura________________________________________________________ Data____/____/_______

Investigador______________________________________________________ Data____/____/_______

-----------------------------------------------------------------------------------------------------------

INTERVIEW GUIDE

| Data | Local | Gravação | Entrevistado | Formação | Cargo |
|---|---|---|---|---|---|
| | | | | | |
| **Organização** | | | **Categoria Stakeholder e Experiência** | | |
| | | | | | |

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***Round 1:***

(a) Existem condições propícias para a implementação de parques eólicos no Brasil? Se não, indique quais são as barreiras enfrentadas.

(b) Quais dessas barreiras mencionadas impactam mais o processo de implementação de parques eólicos no Brasil.

*** IMPORTANTE:** guiar a entrevista/interação conforme as categorias de barreiras descritas por Painuly [50, 63, 82, 354]: barreiras de mercado, economicas e financeiras, institicional, tecnicas, sociais e outras barreiras. Tentar extrair o máximo de informações conforme sua experiência nacional e estadual, objetivando recolher informações para as quatro unidades de análise.

*** ESTRATÉGIAS:** uma vez citado uma barreira de determinada classificação, indagar se existe ou não mais da mesma natureza. Caso não identificado barreiras de uma determinada classificação, expor esta determinada classificação para que o entrevistado possa recordar uma possível existência destas barreiras.

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***Round 2:***

(a) Conforme as barreiras indicadas, você tem conhecimento de como os desenvolvedores eólicos locais estão superando essas barreiras?

(b) Quais dessas barreiras mencionadas dependem exclusivamente de interveção governamental para serem superadas?

*** IMPORTANTE:** guiar a entrevista/interação para que o entrevistado indique como essas barreiras podem ser superadas desde da fase de planeamento dos parques eólicos, conforme os doze passos para desenvolvmento destes projetos.

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