


Review

From Megawatts to Kilowatts: A Review of Small Wind Turbine Applications, Lessons From The US to Brazil

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Abstract: Increased use of fossil fuels has contributed to global warming due to greenhouse gas emissions, which has led countries to implement policies that favor the gradual replacement of their use with renewable energy sources. Wind expansion in Brazil is a success story, but its adherence to distributed generation is still a big challenge. In this context, the authors of this paper argue that the development of robust and viable distributed power grids will also depend in the future on improving small wind generation as an important alternative to the diversity of decentralized power grids. In this study, the authors present an overview of the small-sized Aeolic (or wind) energy market in Brazil, with the objective to support the debate regarding its expansion. Promoting the small wind market in Brazil is still a big challenge, but lessons can be learned from the United States. In this context, the article uses the United States learning curve, analyzing barriers that were found, as well as public policies implemented to overcome them. The lessons learned in the American market may guide public policies aimed at fostering this technology in Brazil. If technological improvements, certification and introduction of financial incentives were implemented in Brazil, the small wind industry chain could grow substantially, building a trajectory to promote the low carbon economy.

Keywords: small wind review; United States; small wind market; renewable energy; Brazil

1. Introduction

Over the last years, the academic debate has voiced its concerns about maintaining a power consumption profile based on fossil fuels and its consequences for society. Owing to the need for a reduction of carbon dioxide (CO₂) emissions, the structure of the current power supply has been reassessed and the participation of renewable energy (RE) sources in the world power supply has to surpass its actual share of the world electricity generation [1]. According to the Intergovernmental Panel on Climate Change (IPCC) [2] in 1.5 K pathways with no or limited overshoot, renewable are projected to supply 70%–85% of electricity in 2050.

In this context, there is a favorable environment towards the expanding the use of RE sources, driven by the global awareness regarding environmental damage caused by conventional energy

sources, and in particular CO₂ emissions; an additional reason is the awareness of the energetic poverty still persistent in several regions of the globe. This way, the use of solar and wind sources is justified [2–5]. Wind energy occupies an important position among the country's renewable resources, and the expansion of large wind power plants is continuously stimulated through governmental measures. United States (US) electricity generation is mostly fossil fuel, with natural gas accounting for 31.7% of the total generation, coal for 30.1% and RE, such as wind energy and hydropower accounting for 6.3% and 7.5%, respectively (using a base year of 2017). In that country, the wind power achieved 88,973 megawatts (MW) in 2017, considered a great example of success in this sector [6]. In addition, among the forecasts for the domestic market, a capacity additions increase from 2017 through 2020 is expected, averaging more than 9000 MW/year during this period [6].

Wind energy has been consolidated into a large-scale model of exploration. However, this environment provides a Small Wind Turbine (SWT) boost. For small usage [7], one must consider specificities, costs, technical performance, the built environment, barriers and location opportunities (whether urban or rural).

Small-scale wind energy is a small but rapidly growing segment of the RE industry in the US. Like other renewable sources, in its initial stage, the cost of small wind electricity is generally less competitive when compared to current market prices of traditional energy sources. Thus, in an effort to support RE development, many US states have adopted a variety of policies to encourage small wind power. This is in line with the oft-cited idea of states serving as “laboratories of democracy” to experiment with a variety of policy tools [7].

In Brazil over the last 12 years, the wind energy sector received US\$ 14 billion in investments, which is the same amount being used for the construction of the Belo Monte hydropower plant in the state of Pará (11,233 MW). Silva et al. [8] highlighted that the wind power sector will probably achieve its consolidation in Brazil, since the country has the largest wind power market in Latin America, with its prices being among the lowest worldwide in an auction system.

Historically, Brazil has adopted a strategy of including renewable sources in its energy supply, which in the past was based on ethanol and hydropower, and with the current addition of wind and biodiesel. Brazil's power supply is mostly renewable, with hydropower accounting for 68.1% of the total, biomass for 8.2% and wind energy for 5.4%, adding up to a total percentage of 81.7% of RE (using a base year of 2016). However, measures to consolidate and expand decentralized electricity generation sources, such as solar power and small wind energy, are necessary.

In spite of having a different energy profile from developed countries, it is important for Brazil to keep stimulating the use of renewable sources in energy production, taking into account its variety of options such as hydropower plants and large wind power plants, as well as other potential options that could benefit the consolidation of a national low-carbon industry, associating innovation with the creation of jobs.

According to the Energy Planning Company (EPE) [9], 14 gigawatts GW were expected to be installed in large wind generation by 2019. Nevertheless, small wind energy in Brazil did not follow this growth, and the strategies adopted by leading countries need to be studied to guide Brazil's public policies aimed at stimulating its domestic market.

According to the US Department of Energy (DOE) classification [10], SWTs have power ranging from 20 W to 100 kW, noting that smaller turbines produce more costly electricity than the medium- and large-scale wind turbines, especially in poor wind sites. The SWTs can be used as a reliable source of energy when they are sized properly and are used in their optimum conditions. Nevertheless, it should be pointed out that in urban areas it is difficult to achieve optimal conditions. Physical, climatic and infrastructure factors, such as speed, regime, wind direction, soil roughness, height and topographic variations influence the eolic efficiency. Conditions in urban environment are less favorable when compared to the application in open spaces (rural environment).

Given the physical disadvantages in urban spaces, these are attractive for SWT when considering the concept of distributed generation, in addition to the figure of the “prosumer” in the system.

The existence of the distribution network to which the SWT is connected gives it a greater appeal as it reduces performance issues that are typical of intermittent systems.

The wind resource is directly dependent on the weather and the physical characteristics of the place (soil roughness, height, topographic variations and surrounding obstacles), thus presenting seasonality [11].

In addition, unlike what happens in the use of large wind turbines, small-scale wind turbines in rural areas are placed close to the ground. With this configuration, the surrounding area of the wind turbines can become a determining factor for good performance, conditioning an evaluation that aims at identifying permanent or temporary obstacles that can influence the behavior of the wind.

This study aims to assess the current situation of the small wind market in Brazil and its future prospects using as a reference the experience of the United States market (US market), identifying the main characteristics of the sector, its evolution, challenges and opportunities.

The analysis is necessary since in Brazil, wind achievements mainly occur through large enterprises, in the order of megawatt, accounting for 99.98% of the market. This reality provides a gap in the literature, since it is almost exclusively guided by studies that focused on large achievements. In this context, research linked to small achievements is scarce, as well as databases. It is important to note that there is also a predominance of large wind farms in the US, but unlike Brazil, the market has a potential for expansion, with the support of several public spheres.

In this context, it is necessary that this review establishes the environment in which the small wind energy market follows its learning curve. It is acknowledged that in Brazil the development of this type of technology is restricted to research centers and academic settings, as opposed to the US, where it goes beyond academic settings and constitutes a market in search of consumers. It is necessary to map this market's behavior in terms of potential, installed capacity and market demands, as well as benefits and challenges.

The methodological procedures used to achieve the objectives of this study include a review of the literature, which establishes the starting methodological path, followed by an examination of the US case study experience through qualitative and quantitative approaches, seeking to reveal in numbers and information the set of knowledge relevant to this research. This study used an analysis of the literature and basic documents relevant to the subject in focus; among these documents, laws and decrees that comprise the basic legislation to encourage small-scale wind generation technology are highlighted.

Hence, the analysis is concluded through the global panorama of small wind energy, highlighting the US experience, as well as the Brazilian one. Therefore, it includes public policies and regulatory actions conducted in these countries, with the objective to expand the use of this technology.

To map the perception of the different market agents (SWT), the methodological procedure called "survey" was used in association with specialists linked to the theme in the US; specialists were sought from: (1) research centers and universities; (ii) government agencies (national and regional); (iii) commercial and technological companies; and (iv) non-governmental companies.

The use of this technique was made with the objective of obtaining information and collecting data that otherwise would not be possible through bibliographic and documentary research only. The interviews allowed us to capture subjective elements and reveal information determined by the interviewee's own experience and points of view. The interview was outlined in a process of social interaction, where the interviewer focuses on the acquisition of information from the interviewee's experiences and knowledge that complement and/or compose the data collected on a specific scientific topic.

The article is divided into four sections. It starts with the introduction, in Section 1. Section 2 presents a context of small wind energy worldwide, considering its applications, its contribution to the expansion of the low-carbon economy and distributed generation. Section 3 highlights the potential of the market, its supply chain, barriers and strategies, in addition to incentive mechanisms used in the US to promote the technology. Additionally, Section 3 presents the results of a survey conducted in the

US using a focus group composed of experts, academics, and government members. The objective of the survey is to evaluate the current and future perceptions of market agents about the technology, its barriers and the impacts of market expansion. Lastly, Section 4 presents recommendations and final considerations.

2. Context

Since the 1990s, technological development and the expansion of wind technology use have been markedly prominent among the renewable technology of electric generation. The wind energy industry was established commercially through large incentives arising from the adoption of normative and institutional instruments through the support of the National States or regional economic blocks. Such incentives provided the construction of a solid industry that evolved both in the conception and in the process of building and operating its projects. However, this market is sharply structured into large projects, based on the concept of “wind farms” interconnected to the network, a process that relegated small projects to a low profile and limited incentive plans.

Until the 1980s, the focus was on small-scale technologies, and the capacity of most commercial models was below 100 kilowatts (kW). Most turbines have been installed in rural or isolated areas since the initial stages of its development at the beginning of the 20th century, but they are also deployed in developing countries. Electric power supply and water pumping are still the main applications of the technology, both in urban households and rural areas worldwide. Possible applications for SWTs are: electric power generation for households; electric power generation for industries and commerce; electric power generation for farms and isolated villages; use in boats; use in hybrid systems for electric power generation; water pumping; use in desalination and purification systems; remote monitoring; educational systems; researches and telecommunication systems.

In spite of the current consolidation of the large wind market in Brazil, small wind power is still in its initial stages, with little experience, differently from China and the US, which had 573.57 MW and 150 MW installed capacities in 2018, respectively. It should be pointed that between the years 2013–2018 the rate of growth was over 50%, as shown in Table 1.

Table 1. Evolution of installed capacity (MW) and cumulative installed capacity of SWT in various countries (2013–2018). Source: adapted from [6]

Country	Installed Capacity (MW)							Cumulative Years before 2018
	Cumulative Years before 2012	2013	2014	2015	2016	2017	2018	
Brazil	0.00	0.03	0.02	0.11	0.04	0.11	0.09	0.40
China	280.01	72.25	69.68	48.60	45.00	27.27	30.76	573.57
Germany	24.55	0.02	0.24	0.44	2.25	2.25	1.00	30.75
South Korea	2.99	0.01	0.06	0.09	0.79	0.08	0.06	4.08
United Kingdom	77.98	14.71	28.53	11.64	7.73	0.39	0.42	141.40
United States	130.73	5.60	3.70	4.30	2.43	1.74	1.50	150.00
Other countries	626.80	8.65	17.59	16.04	63.30	80.85	13.28	826.51
Global	1143.06	101.27	119.82	81.22	121.54	112.69	47.11	1726.71
Global(cumulative)	1143.06	1244.33	1364.15	1445.37	1566.91	1679.60	1726.71	1726.71

SWT manufacturers are mainly located in a few countries, with the US, China, Canada, the United Kingdom (UK) and Germany accounting for 50% of their total production capacity [12].

International literature displays a consensus about the definitions of microgeneration and minigeneration. According to the American Wind Energy Association (AWEA) [13], SWTs are defined as having a generating capacity of up to 100 kW (60 ft rotor diameter). In Brazil, according to Resolution 438/2012 of the Brazilian Electricity Regulatory Agency (ANEEL), small wind systems are categorized as power stations (which could be composed of one or many wind turbines) with a total rated capacity below 100 kW. In general, wind turbines integrated into buildings, as well as any other technology of distributed power generation, have the same goal of decreasing monthly costs of electric power, providing part of the electricity demand consumed at the location.

Developing countries are a great opportunity for the expansion of the small wind market, especially in regions where the wind potential is notoriously favorable to power generation, allowing for its expansion to be based on low-carbon technologies. Nowadays, commercial models of large wind turbines use the horizontal axis orientation, making SWTs more versatile since they are commercialized with either a horizontal or vertical axis, with the horizontal design being significantly more common according to the World Wind Energy Association (WWEA) [12]. Despite the considerable amount of models above 10 kW, most commercial models available are below 5 kW. Only 25 manufacturers worldwide have the capability to fabricate turbines between 50 kW and 100 kW [12].

Wind turbines have many sizes and applications, varying from a small turbine deployed to feed a dedicated battery to a set of wind turbines for a department store or factory, and this diversity is considered one of their strengths. For their installation, consumers consider cost, reliability and performance. These variables are a function of wind speed and profile, its intensity and direction and topography, which define the amount of energy provided by the wind turbine. Furthermore, one must consider whether or not there is an electrical distribution infrastructure in the surrounding area. Figure 1 illustrates in a simplified manner the typical applications of SWTs and their dimensions, indicating that the annual energy generated is a function of the installed capacity, which increases as the tower height and rotor diameter increase. The surrounding environment also influence system performance [14].

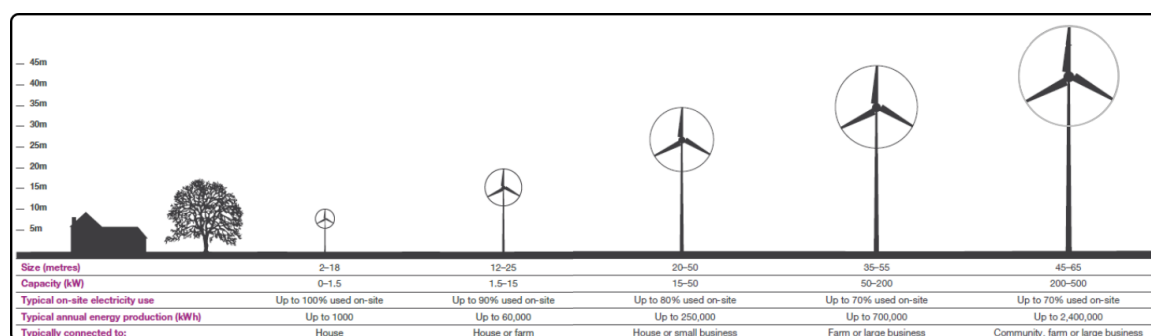


Figure 1. Scale of turbines and typical applications. Source: adapted from [15].

Benefits and Challenges

Small wind power is very close to the daily lives of people since the technology does not require large areas or transmission lines. Moreover, they are appropriate for smart grids in the context of distributed power generation. When compared to other technologies of the same power level, wind turbine maintenance is simple. While the output improves when SWTs are combined with other sources to compose a hybrid system, the cost per kW is still higher than that for large-scale plants [16].

The technological development of SWTs has been significant, which is proven by the many types, sizes and control techniques of the products, but few are available for building integration. Once again, the two main wind technologies are Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). HAWTs are better known, have good performance and are cost effective, favoring their integration. VAWTs, on the other hand, are less efficient in converting the kinetic energy of the wind into electric power. However, they are more resistant, their integration is much better accepted by architects and users, they are safer due to less vibration, and lastly, they take more advantage of the turbulent wind of building rooftops [17].

It is necessary to consider issues related to the structure of the building during the installation of a turbine. The rotation of the blades and the dynamic pressure of the wind that reaches the turbine may cause vibrations that will be transmitted to the structure of the building, compromising its integrity. Moreover, their noise must also be taken into account. While the recommendation for large turbines is

to not exceed 50 decibels (dB) at night from a 500 m distance, for small turbines installed in urban areas the noise limits should not exceed 43 dB at night and 47 dB during the day [18].

In fact, there is a scarcity of experimental data regarding installed wind turbines, in particular in urban areas. According to Dilimulati, Stathopoulos and Paraschivoiu [19], urban settings make it harder to compare turbine efficiencies and the viability of different wind turbines available today. Conventional wind turbines directly located in an urban built environment do not perform well. Some wind turbines, especially VAWTs, still show good results but should be further optimized for urban applications.

Another question regards the sensitivity to siting, according to DOE [20], considering the capacity factors for the 44 projects using 10 kW wind turbines in this selected group of projects ranges from 7% to 46%, supporting the idea that siting issues strongly influence capacity factors.

SWTs must meet either the American Wind Energy Association (AWEA) SWT Performance and Safety Standard 9.1-200915 or the International Electrotechnical Commission (IEC) 61400-1, 61400-12 and 61400-11 standards to be eligible to receive the Business Energy Investment Tax Credit (ITC) (IRS 2015). Certifying a turbine model to a standard is the industry approach to proving that the turbine model meets the required performance and quality standards [6].

Certification is also consistent with industry and DOE goals to promote the use of proven technology; raise its competitiveness; and increase consumer, government agency and financial institution confidence and interest in distributed wind. Regarding grid connection, it should be highlighted that the Public Utility Regulatory Policies Act (PURPA) of 1978 requires utilities to connect with and purchase power from small wind energy systems.

Small wind technology is still at its early state and there is a lot of space to improve; promising directions have already been identified. There are still a lot of questions about the performance of wind turbines and their economics, but continuous research in this area will provide some of the much-needed answers.

3. Discussion and Results

3.1. US Small Wind Market

3.1.1. Potential Market

The use of renewable energy sources has been increasingly stimulated in the US and in many European countries. For instance, the inclusion of electric power from SWTs in the electrical grid has been encouraged by governmental bodies in order to meet the goals set for decreasing air pollution, among others technologies. Even though there are no estimates of carbon emissions from SWTs, it is interesting to point out that, according to [21], considering the life cycle of an onshore plant (V90 turbine of 3 MW), it was estimated that the design would become carbon neutral after 6.6 months of energy production. Moreover, we highlight that 80% of each turbine is recyclable. In Europe and in the US, the consumers is no longer passive elements in the electrical grid; they became an active part of it and a “silent revolution” is in course, allowing for: the generation to think beyond “large blocks of energy”; the promotion of decentralized power generation; the semi-autonomy of households regarding power; energy security; the potential decrease of environmental impacts—provided that life cycle analysis is performed and necessary actions are taken towards the establishment of a positive environmental balance, as well as balanced emissions of Greenhouse Gases (GHG); the decrease of greenhouse gases; the promotion of energy exchange; and the expansion of the green economy, amongst others.

Finland is an example of a country that aims at becoming self-sufficient with regard to electricity production by promoting small-scale distributed generation until 2025 [22]. In 2014, other countries were already self-sufficient or almost self-sufficient, such as Norway (105.5%), Austria (65.9%) and Sweden (61.9%), but that was still based on the expansion of large blocks of energy.

In the US, SWTs can contribute to issues related to energy security, technological strategy, and long-term economic growth. Moreover, they have a high potential for expansion in the country,

mainly taking into account distributed generation and low-cost technologies. SWTs may contribute to decreasing countries’ dependence on foreign energy supply and simultaneously promote many benefits for the domestic economy, such as more jobs.

It should be pointed out that official data of jobs in small wind segment are an incomplete statistic in the US. Data from industry association should be seen with reservation. For instance, according to Zhang and Qi [23] direct jobs offered by the small wind industry in China were 4500–5000 in 2008 (not including the parts and components suppliers), and 25% of the employees were engineers or technicians.

With more governmental support and involvement from companies, it will be possible to expand the US market, increasing the participation of SWTs in its power generation. Estimates from the AWEA [13] indicate that by 2020 the small wind power market could account for up to 8% of the electrical power demand of the country. In addition, the AWEA also singles out that investments in the US market may reach US\$ 1 billion annually, employing 10,000 people in manufacturing, sales, installation and support.

It should be pointed out that SWTs can effectively operate in most rural areas of the US, as 60% of the country has the necessary conditions to generate power from the technology [24]. Figure 2 shows the wind map for small wind applications in the US. Estimates are based on different models and sizes of wind turbines, assuming a tower height of 24 meters.

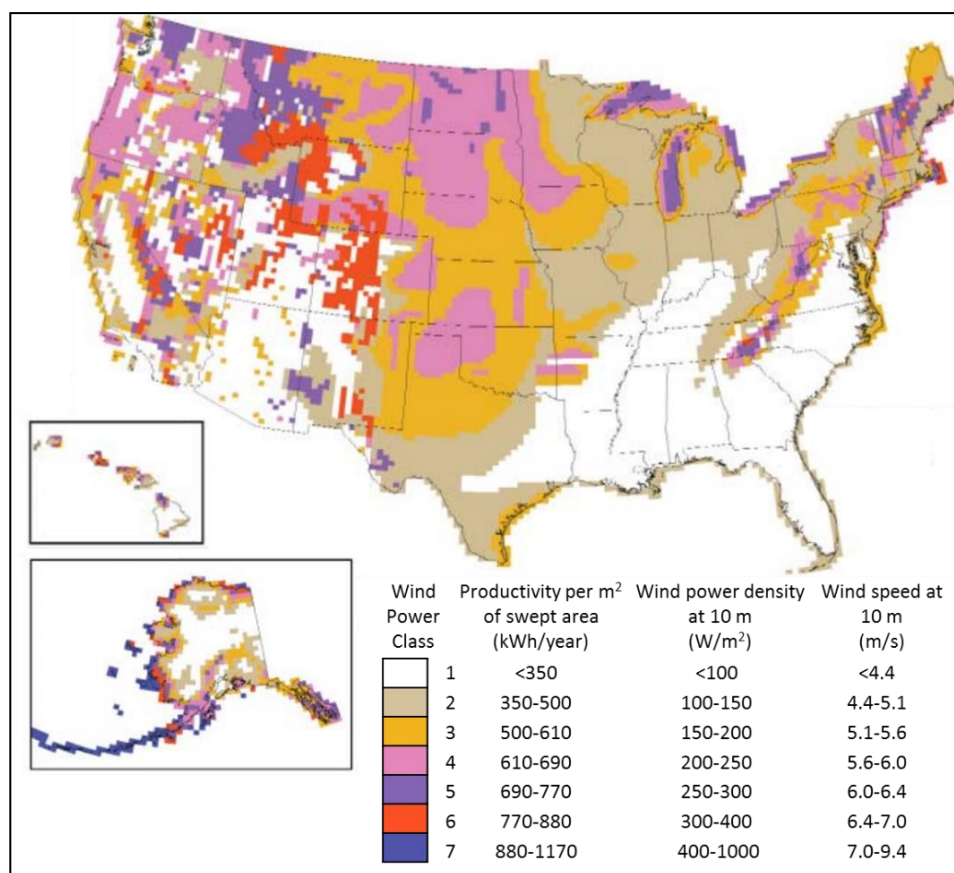


Figure 2. US yearly electricity generation estimated per m² of rotor swept area for a SWT. Source: [24].

The market potential for applications in households and small businesses is substantial, but the market needs to overcome many challenges such as government incentives and technological development. Moreover, it should be highlighted that farms and rural homes represent a large market as well.

According to the National Renewable Energy Laboratory (NREL) [24], distributed wind encompasses three applications of wind power projects: (1) grid-connected systems located behind a meter; (2) grid-connected systems in front of the meter interconnected at distribution voltages; and (3) remote systems not connected to the centralized grid. In practice, these applications range in size from kilowatt-scale off-grid installations to multimegawatt (and multiple-turbine) community wind projects operating either behind or in front of the meter.

Data developed by NREL [24], which are related to the potential economical assessment of the SWT, show a substantial growth of this potential over the short and long term horizons, as favorable policies, taxable structures and technological improvements combine to provide a promising environment. In this scenario, the DOE report [25] shows that, from 2013 to 2018, there was a world record in 101.27 MW installed. During this same period, the US accumulated 19.27 MW. Brazil accumulated only 0.40 MW, as shown in Table 1.

3.1.2. Supply Chain

The supply chain of the small wind market can undergo significant transformations, affecting the market considerably. Two aspects of the supply chain can potentially influence its growth and the growth rate of the market. The first is the fact that manufacturing companies will demand more off-the-shelf components than their own components, allowing for more control of product quality, and this issue becomes more critical due to the exponential increase in production. The second aspect is the marketing of wind turbines. Nowadays, they are directly sold to the final consumer or installer. In the future, sales representatives will be able to offer an installation package through a contract with a certified installer. These alterations in the supply chain are expected to improve product quality and ensure the delivery of a product with a better value to the final consumer [26].

In the US, for the small wind sector, self-reported domestic content levels ranged from 60% to 100% in 2014. DOE [6] verified in a research that magnets were all reported as sourced from outside the US, representing 10% of the overall cost. Manufacturing facilities and supply chain vendors are distributed throughout more than 20 states.

The industry is still trying to enhance its manufacturing processes, aiming at cost reduction, especially the installation costs of SWTs. In this sense, the US government supports the industry through the Competitiveness Improvement Project (CIP) with the purpose to expand and revitalize the leadership of the country in the national and international markets, helping manufacturers decrease the costs of wind turbines. The project focuses on improving manufacturing processes and wind turbine testing, and the costs are shared, which helps certification to be issued and guarantees that performance and safety requirements are met. The project is financed by the DOE, with technical support from the NREL.

Also supporting small wind power, the Sustainable Manufacturing, Advanced Research and Technology (SMART) wind consortium was launched in 2014, financed by the Department of Commerce in a consortium led by the Distributed Wind Energy Association (DWEA). The DWEA staff organized a panel of specialists within the SMART Project to reach a consensus on aspects associated with technology, manufacturing barriers and research topics on the entire supply chain, with the purpose of accelerating technological development and knowledge transfer between research centers and private enterprises, potentially expanding the domestic and international markets.

Average residential retail electric rates range from 8 to 20 ¢/kilowatt hour (kWh) in the continental US, with higher rates in Hawaii, Alaska and Puerto Rico. Considering 73 projects studied by the DOE [6]—for a turbine range between 2.4kW and 100kW—the capacity-weighted average levelized cost of energy (LCOE) is 12 ¢/kWh. As a result, if retail rates are maintained for the final consumer, small and medium wind power would already have technical and economic viability.

In addition to the opportunity of expanding its internal market due to retail electric rates, the international market also represents an opportunity for income generation with wind turbines. In 2014, the export of SWTs from the US (per unit) represented 61% of the world SWT sales. In terms

of capacity, Italy, UK, South Korea and Japan are large markets for the export of wind turbines manufactured in the US.

More recent data show that four US-based small wind manufacturers exported turbines totaling 5.5 MW in capacity with an estimated value of \$42 million in 2017. Figure 3 shows the primary reported countries that received US small wind exports in 2017. The 5.5 MW is down from 10.3 MW, representing a \$62 million in investment in 2016 from six manufacturers, after a peak in 2015 at 21.5 MW of small wind exports from six manufacturers valued at \$122 million [6].

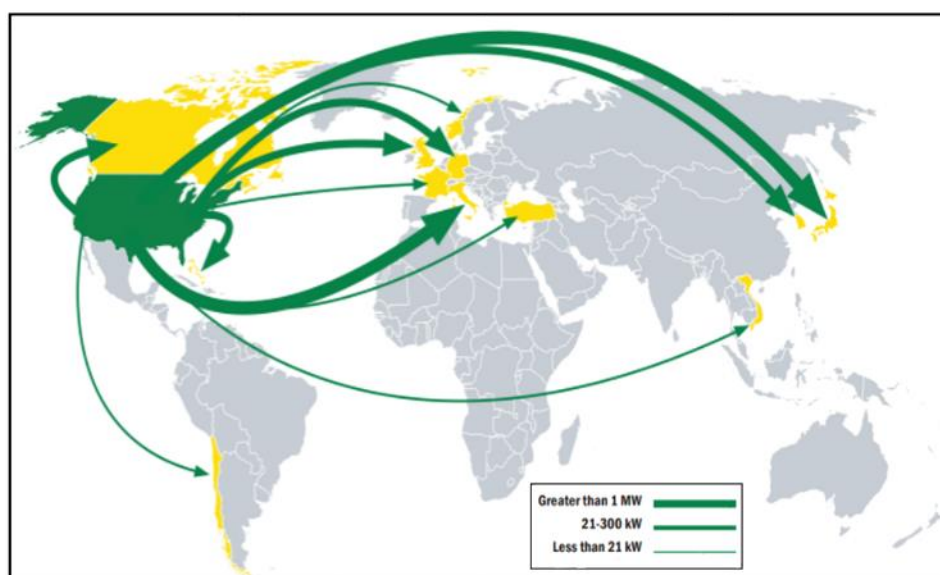


Figure 3. US total SWT export map. Source: [6].

3.1.3. Barriers and Action Strategies

According to a study carried out with stakeholders by the NREL [26], five key areas are identified as barriers for the SWTs' US market: safety, wind resource, turbine technology, building interactions and non-technical obstacles. Table 2 presents a brief description of these main barriers.

Table 2. Summary of built-environment wind turbine (BWT) barriers in the US. Source: adapted from [26].

Areas	Barriers
Safety	The effect of a high-fatigue environment on BWT life is poorly understood. BWTs lack the following safety features: braking redundancy; fail-safe features; ice; and part shedding containment.
Wind Resource	The following aspects of the wind resource in the built environment are poorly understood: turbulence and directional variability; wakes, eddies, and separation zones; three dimensional wind speed profile; and distribution. Existing wind resource maps do not translate to the built environment.
Turbine Technology	The following aspects of turbine technology in the built environment are poorly understood: control strategies to reduce vibration and noise; loads measurements and yaw rates. Design and test standards for BWTs (especially for high-fatigue environments) are non-existent.
Building Interactions	Resonance frequencies (linked building-turbine vibrations) are poorly understood. Code compliance is difficult (most codes do not address BWTs; existing codes add great uncertainty; additional zoning and permitting may apply). Mechanical and electrical integration is costly and difficult.
Non-Technical Obstacles	Hazards exist for personnel installing and servicing BWTs. Outreach and education are required as credible BWT information is limited. Economics (project costs and return on investment) are unpredictable.

Safety is a critical aspect. Wind turbines are installed in close proximity to residential and commercial buildings in urban centers, as well as other properties, so a failure could damage property, injure people and compromise the technology's image.

Evaluating the wind resources is extremely relevant as well, as large differences exist in the wind resource potential of different sites. Information on wind resources is critical for designing the project and estimating the energy production. On the other hand, the impact of the built environment on energy production is not well understood, as limited knowledge exists that can be applied to evaluate wind resources in the built environments. With this lack of information and understanding, important areas to address are [26]:

- Turbulence and directional variability in the built environment;
- Wakes, eddies and separation zones;
- Three-dimensional wind speed profile and distribution.

Turbine technology is also a main issue, as most turbines were designed for the open areas common to rural environments. However, most of the built environment, especially in urban areas, has high turbulence and wind direction variability. This means that the design guidelines, testing methods and control strategies developed for turbines in rural areas must be revised for urban areas. Figure 4 shows the application of SWTs in a built environment.



Figure 4. Wind Turbine at the offices of the International Brotherhood of Electrical Workers (100 kW, 21 m blades diameter and 35 m tower). (Massachusetts, US) Source: [27].

The operating efficiency of a small installation is an important consideration, since SWTs are incapable of reaching the conversion efficiencies of a large-scale wind turbine. Typically, wind speeds in an urban region are lower in speed and contain more turbulence than rural regions. Furthermore, the multitude of obstructions in a typical residential or business region can cause a significant increase in wind turbulence. In a series of wind tunnel experiments, the effects of street obstructions were investigated, revealing an increase in turbulence of 50%–200% when the street obstructions were included [28].

The cost effectiveness of small wind in urban areas is highly variable, with large variations in cost per kW of installed capacity, depending on the turbine size and wind conditions at the installation location.

The lack of knowledge for built environment wind turbines is related mainly to the following areas [26]:

- Control strategies to reduce vibration and noise;
- Loads measurements to validate dynamic models;

- Developing standards and testing for wind turbines.

Building interactions are also relevant. Concerns include not only mounting the turbine on buildings, but also resonance frequencies, code compliance and mechanical and electrical integration. Proximity to people may create additional zoning and permitting issues. If these policies are crafted well by the government, they will reduce installation and servicing hazards, especially in urban areas.

Other non-technical obstacles are also observed, especially hazards related to installing and servicing the turbines, outreach, economics and public policies. Additional concerns are also related to installation, operation and inspections due to the limited space, particularly rooftops of buildings and homes, thus requiring specific safety procedures.

Taking into account the presented barriers, action strategies can be outlined in the near-term. As for the non-technical aspects related to the lack of knowledge of the consumer, a consumer guide and hazard-focused fact sheets are needed. Additionally, for non-technical barriers related to the economic uncertainties associated with the design, field experiments and analyzing the existing data can be suggested.

Creating data assessment standards (protocols) may help with load measurements and enhance knowledge, especially when combined with the technological development of the turbines. Issues related to the building interactions should include mounting, integration and vibration mitigation. Construction codes for different built environments should be revised, and recommendations should be made taking into account the operation of SWTs in these environments. The action strategies are listed in Tables 3 and 4.

Table 3. Barriers and short-term actions. Source: adapted from [26].

Actions	Safety	Wind Resource	Turbine Technology	Building Interactions	Non-Technical Obstacle
Produce a consumer guide and fact sheets					Lack of credible BWT information
Produce risk and hazard focused fact sheets				Mechanical and electrical integration issues	Lack of credible BWT information (installation, planning, permitting)
Create standardized resource data assessment protocols		Poor understanding of: turbulence and directional variability in the built environment; three-dimensional wind speed profile and distribution	Poor understanding of: load measurements; yaw rates		
Survey and analyze existing data				Costly and difficult mechanical and electrical integration; Poor understanding of resonance frequencies	Unpredictable economics (project costs and return on investment)
Investigate and compare wind resource modeling methods		Poor understanding of: wakes, eddies, and separation zones; turbulence and directional variability			

The creation of a document addressing the best practices and recommendations would be an answer to these issues related to safety, wind resources, building interactions and non-technical obstacles. Case studies on turbines in urban environments, discussing the lessons they teach, should be produced and published to help develop best practices and decrease the asymmetry of information on the sector. Additionally, case studies should be useful to review building codes, increasing their applicability and the acceptance of the technology in built environments.

Table 4. Barriers and medium-term actions. Source: adapted from [26].

Actions	Safety	Wind Resource	Turbine Technology	Building Interactions	Non-Technical Obstacle
Create best practice recommendations	BWTs lack braking redundancy, parts shedding and ice-throw containment	Poor understanding of wakes, eddies, and separation zones		Mechanical integration issues (develop and refine mounting strategies)	Hazards to personnel installing and servicing BWTs
Adapt data assessment tools		Poor understanding of: 3-D wind resources; existing wind resource maps do not translate to the built environment			Unpredictable economics (create economic assessment tool)
Instrument existing BWTs		Poor understanding of: 3-D wind resources; turbulence and directional variability	Poor understanding of the loads and yaw rates (measure and correlate to 3-D wind)	Poor understanding of resonance (measure and correlate to 3-D wind)	
Conduct model validation at demonstration sites		Poor understanding of: Wakes, eddies, and separation zones; turbulence and directional variability (measure)	Poor understanding of loads and yaw rates (measure)		
Provide recommendations to governing bodies and standards		Poor understanding of 3-D wind resource	Non-existent BWT design class	Model effects of building codes	
Conduct turbine research and development	BWTs lack braking redundancy, fail-safe turbine features		Vibrations and noise (address control strategies to reduce)		

Recommendations for the government and planning agencies should be useful in issues related to the following barriers: wind resources; turbine technology; and building interactions. Research and development should be accelerated for issues regarding the safety and durability of SWTs, addressing specific concerns of developers. Lastly, new control strategies to reduce vibration and noise, particularly in urban environments, must also be researched.

In general, the use of SWTs depends on the type of building, the site and the demand profile. In contrast to rural applications, understanding the performance of the technology in urban areas still represents a great challenge. In this sense, taking into consideration the entire potential of power production, research and development must be aimed at assessing the performance of turbines in built environments.

3.1.4. Incentive Mechanisms

The future of small wind energy and its role as an alternative for microgeneration depends on lowering technology costs, incentive policies, interest of investors, perception of final consumers, certification and safety. It is worth acknowledging the dependent characteristic of the technology on climate variables in its local of use. Proper use of technology is fundamental; otherwise poor performance can harm its applications. The development of instruments that enable a precise evaluation of the energy production potential of SWTs is an important part of a public policy aimed at enhancing this alternative. The expansion of the sector following the large wind energy model still represents a great challenge, even in developed countries such as the US and the UK. However, understanding the moving forces behind the technology of SWTs is essential as its participation in the world market increases.

SWTs started being used decades ago, and their installation has increased in both rural and urban areas. According to Carbon Trust [29], the small wind market has strongly increased in many countries. The main moving force behind the market penetration are concerns related to climate change and to possibly lowering greenhouse gas emissions, which are constantly debated in the context of replacing fossil fuels for power generation. Studies published by Carbon Trust [29] suggest that by 2050, the widespread installation of microgeneration could reduce household carbon emissions by up to 15%. More optimistic estimates indicate that total emissions of greenhouse gases in the UK could be reduced by up to 5% (using a base year of 2006). Additionally, people are interested in producing their own energy and becoming less dependent on the grid, and SWTs are one of the available technologies.

Even though other issues affect the driving forces behind the US market for both supply and demand, awareness of technology, environmental concerns and electricity prices are the most important in the decision process of the final consumer. On the other hand, consumer incentives, public policies, more investments and market growth stimulate supply, increasing production and the availability of off-the-shelf technology.

According to [30], distributed wind energy is commonly understood as home, agriculture, commercial, institutional or industrial systems physically or virtually connected to the consumer's meter or directly to the distribution grid. Since the definition is related to the distance from the system to the final user and to infrastructure distribution instead of the size of the system, distributed wind energy includes turbines of many sizes. For instance, 1 kW systems could be installed in remote areas, 10 kW systems for homes, and systems of several MW for universities and large factories.

Data published by the DOE [20,30] showed generation costs of distributed wind energy varying with turbine size, the height of the tower and the type of equipment. In the US, the kW cost for SWTs in 2011 ranged from 2,300–10,000 \$/kW, with an average of 6,400 \$/kW. In that same year, the average cost was 8,200 \$/kW for turbines smaller than 2.5 kW, 7,200 \$/kW for turbines between 2.5 and 10 kW and 6,000 \$/kW for turbines between 11 to 100 kW [22]. In 2017, the average cost reached 11,953 \$/kW for SWTs up to 20 kW and 7,389 \$/kW for those between 21 and 100 kW [6,30]. According to the World Wind Energy Association, the US industry is still under development and a larger production is necessary to ensure cost reduction and economies of scale. In order to achieve that, appropriate legal frameworks and support schemes are required. The worldwide expansion of wind energy shows that a very common incentive tool for renewable energies is the feed-in tariff scheme. The use of the a feed-in tariff was one of the main instruments to influence RE sources in the world, especially wind energy, particularly in Spain, Germany and Denmark. On the other hand, this mechanism has created controversy, as critics saw in it an instrument that does not promote efficiency as it distorts relative source prices.

In Table 5, the feed-in tariffs for some countries are shown for SWTs. It is interesting to observe that countries such as the US, the UK and Japan adopt this scheme, and in some cases the incentives vary according to the capacity and location. It is worth considering also with information about electricity the electricity prices for household consumers (taxes included—2018). According to Eurostat [31], in the European Union, for instance, the price was 0.204 EUR/kWh, in Portugal 0.224 EUR/kWh, in Italy 0.206 EUR/kWh, in Cyprus 0.189 EUR/kWh, in the UK 0.183 EUR/kWh and in the US 0.129 \$/kWh (Indiana 0.123 \$/kWh, Vermont 0.182 \$/kWh, Hawaii 0.338 \$/kWh) (US—Energy Information Administration [32]).

Incentive mechanisms for SWTs are not limited to the feed-in tariff. Other measures are also geared towards small wind and create a more favorable business environment for the technology, such as net metering, tax credits and capital subsidies, and research funding. According to the DOE [20], SWTs are eligible for the Business Energy ITC, in which the credit is equal to 30% of the expenditure for turbines of up to 100 kW in capacity, as long as they meet the performance and quality standards set forth by either the American Wind Energy Association Small Wind Turbine and Safety Standard 9.1-2009, or the International Electrotechnical Commission standards 61400-1, 61400-12 and 61400-11.

Table 5. Small wind feed-in tariff (selected countries) Source: adapted from [33].

Country/Region	Size Limit	EUR/kWh	Country/Region	Size Limit	EUR/kWh
Chinese Taiwan	1–10 kW	0.185	Japan	< 20 kW	0.418
Canada				≥ 20 kW	0.167
Ontario	< 10 kW	0.074	Lithuania	< 10 kW	0.095
Nova Scotia	< 50 kW	0.332		10–350 kW	0.092
Cyprus	< 30 kW	0.220	Portugal	< 3.68 kW	0.432
	Off-grid	0.190	Slovenia	< 50 kW	0.095
Greece	< 50 kW	0.250	Switzerland	< 10 kW	0.247
	> 50 kW	0.090	UK	< 100 kW	0.207
	Off-grid	0.100	US		
Italy	1–20 kW	0.285	Indiana	5–100 kW	0.130
	20–200 kW	0.262	Hawaii	< 20 kW	0.123
	0.2–1.0 MW	0.146		20–100 kW	0.105
Israel	< 15 kW	0.250	Vermont	< 15 kW	0.181

According to the United States Department of Agriculture (USDA) [34], through the Rural Energy for America Program Renewable Energy Systems and Energy Efficiency Improvement Loans and Grants (REAP) of the USDA, it is possible to obtain loans of up to 75% of project costs or a maximum loan of US\$ 25 million for RE projects. Grants are issued for up to 25% of project costs or for a US\$ 500,000 maximum for RE projects. A loan and grant combination may cover up to 75% of total costs of the project, and small wind energy is one of the many technologies eligible for USDA funds. The REAP provides financial aid to agricultural producers and rural small businesses to purchase, install or construct RE systems or make energy efficiency improvements in non-residential buildings and installations, use renewable technologies that decrease energy consumption and take part in energy audits and in assisting the development of renewable energies.

The state of Oregon has a program of cash incentives for small wind generators (Energy Trust of Oregon), in addition to state and federal tax credits in which the subsidy can reach up to 80% of turbine costs. One of the incentives pays \$5.00 per kWh produced up to a limit of 9000 kWh produced annually, thus reaching the amount of \$45,000. The incentive is granted for wind turbines of up to 50 kW in capacity.

In addition to the governmental effort to promote the industry, other incentives have been adopted by some US states. Many of them offer rebates or buy-down programs which are normally financed by the sale of retail electricity. The funds generated by these systems are designated by law, with the purpose of subsidizing RE projects and promoting the development of the industry.

Figure 5 shows the diversity and the dynamics of incentive mechanisms used in the US specifically to promote SWTs in residential buildings between the years 2008 and 2010. States such as California, Illinois, Rhode Island and New Jersey offer rebate subsidies for SWTs, with eligibility requisites for the Rebate Program varying from state to state. Other states offer tax credits, tax reduction and net metering. It is worth mentioning that incentive policies are fragmented and constantly changing. The changes occur when local communities and legislators notice the economic and environmental importance of the sector, pressuring the government to expand incentives for SWTs in the country.

Federal and state incentives have a limited period for their application, which is interesting for economic balance and the business environment. The fact that the government supports RE sources and stimulates companies to become more energy efficient, while maintaining the fiscal balance of the administration in the long run, is a good sign for the market.

Each incentive mechanism offers different trade-offs between profits and costs for stakeholders, besides different results. For example, the NREL has partnered in research with manufactures to make small wind more productive and cost effective. This collaboration between Universities and Centers of research promotes the technology and moves the industry forward. According to the Database of State Incentives for Renewables and Efficiency (DSIRE) [35], the partnership between companies and the

NREL was fundamental to the development and manufacturing of new blades for SWTs, decreasing the cost for the final user by more than \$3000.

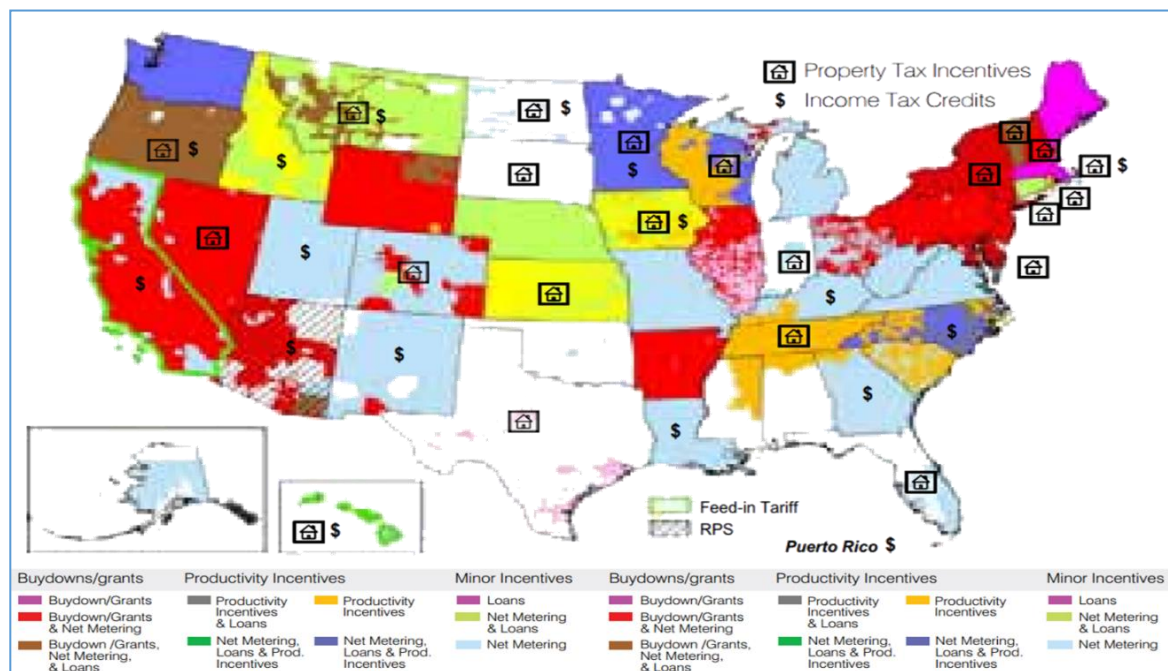


Figure 5. Residential incentives for SWTs in the US in 2010. Source: [24].

Although incentive mechanisms have expanded the size of the large-scale wind energy market, as well as export support, considering the reduction of costs over time, other issues must also be considered, such as photovoltaic solar technology, which has a sharper drop in costs (which also receive the 30% ITC), in addition to competing with the market niche in urban areas. However, this incentive instrument needs to be rethought in the future so as to consolidate this market.

Mihaylov and Radulescu [36] pointed out that merely subsidizing production is not sufficient to mitigate the dependence on fossil fuels. Green energy needs to effectively offset the consumption of gray energy (i.e., energy from mixed sources). Although net metering and feed-in tariffs motivate the injection of clean energy, they provide no incentives for consumers to actually use the injected energy. In addition, these policies reward production without considering the impact of peak supply on the low-voltage grid.

3.2. Perceptions of Market Agents in the US

The selection of a methodological instruments is directly related to the problem to be studied; the choice depends on the various factors related to the research, that is, the nature of the phenomena, the object of the research, the time, the financial resources, the available human resources and other elements that may arise in the field of research. As part of the procedure for collecting data, it is considered that these vary according to the circumstances or the type of investigation. In general terms, Lakatos [37] presented the following research techniques: documentary collection, observation, interview, questionnaire, form, opinions and attitude measures, marketing techniques, tests, sociometry, content analysis and life history.

Becker [38] concluded that the choice of method should not be rigid but rather rigorous, that is, the researcher does not need to follow a strictly rigid method, but any method or set of methods that are used must be rigorously applied.

In order to map the perception of the different market agents (SWT), a methodological procedure named “survey” in the literature was used, which allows direct actor questioning through the use of questionnaires, which after quantitative data analysis allows the formulation of possible interpretations.

In this work a semi-structured questionnaire was chosen, associating open and closed questions, where the actor possessed the possibility to present his perceptions about the proposed theme, being the segment of small wind energy. It should be pointed out that the collection of information through a questionnaire is a fundamental point in the methodological structure, where only literature review and observation are not enough to capture both objective and subjective information.

The choice of this technique lies in the fact that it adjusts to the “study of motives, attitudes, values, tendencies” and to reveal the different visions that, at first glance, are not presented with sufficient clarity. From this conception the consultation with a set of specialists was structured, in a way that could reflect the personal and collective perceptions experienced by this set of actors, thus problematizing the different ways of understanding the drivers of the small wind market (perceptions, motivations and values), and how the learning curve of the development of this technology in the US can be appropriated and potentiated in Brazil. In addition, this information may assist future public policies on the sector aimed at implementing best practices to increase competitiveness, as well as measures to stimulate the small wind market in Brazil based on lessons learned from the US market.

In this context, the definition of the actors consulted is considered a relevant task, since it implies the ability to contribute to the objectives of the research, and additionally requires special attention and rigor, mainly because the actors are expected to contribute a critical, reflexive and propositive capacity to the objectives of the research.

It is important to emphasize that the group of specialists who are dedicated the topic of small-sized aeolic (or wind) energy market in a variety of settings, whether in government, academia or in the market, is restricted, reflecting the dominance and interest of large-sized wind technology.

The definition of the population to be interviewed was conducted by tracking specialists linked to the topic in the US; therefore we searched: (i) research centers and universities; (ii) government agencies (national and regional); (iii) technology and commercial companies; and (iv) non-governmental companies, thus reaching a total of 84 actors to whom the questionnaires were sent. It should be emphasized that the research was guided by the principle of parity, seeking to avoid bias in the definition of the actors who participated in the consultation, these being distributed by: academics, agent of the productive sector and of the financial market, state agents and developers of technology.

After information was collected using a web questionnaire, the operational stages of the study were continued, such as: preliminary screening of information, organizing and tabulating information, verifying typing, elaborating a preliminary descriptive report, elaborating the database, carrying out descriptive statistics and an exploratory analysis of the data, and the analysis of the information and its consolidation.

The analysis of the data with statistical techniques in the context of the energy economy (line of research) encompasses many stages, for even in the case of a well-planned study it is not possible to predict all conditions that will be found, the problems that may arise, basic assumptions that will not be satisfied, etc. On the other hand, using field questionnaires together with a theoretical foundation enables a qualitative leap of the information and consequently a better understanding of the reality of the small wind market.

Survey Analysis

In the survey of the US small wind market were obtained a total of 15 answer from specialist in small wind considering many institutions/companies (For example: Pacific Northwest National Laboratory, Advanced Energy Systems LLC, Self-Reliance, G-Tower, Air Power Systems – PLLC, Distributed Wind Energy Association – DWEA, Fortiswindenergy, National Renewable Energy Laboratory - NREL, KFSwartz Consulting, Bergey Windpower Co., Mass. Clean Energy Center, Sustainable Energy Developments – SED, University of California—Berkeley). Considering the number of interviewees,

it is worth to present the answers per segment in the value chain, and to note that we aimed at having many segments represented. However, the answer rate was higher for universities and research centers (40%), which is natural since the interviewees work with the studied subject on a daily basis and are interested in contributing to the research as part of a *modus operandi* to gain more knowledge.

By assessing the perception of agents of the current scenario of SWTs in the US, it can be learned that 50% of them think that the sector is still constrained due to the strong competitiveness of photovoltaic panels. However, they do recognize their significant potential, especially in the context of global warming and the rise of RE. Below are shown the complete reports of the respondents discussing growth prospects for SWTs in the US over the next ten years.

The small wind market is finding its way towards a new normal. After years of significant expansion between 2008 and 2012, the market is still in decline compared to 2013. Manufacturers are looking at export markets and new financing schemes, as well as new national climate regulation to change the momentum.

The market is currently very constrained. Zoning restrictions are common and very difficult and expensive. Photovoltaic (PV) is much easier and now very competitive. Installed system costs need to come down and many manufacturers are working toward that end. If the public decides that climate change is important, incentives improve and costs come down, there is a very large potential market.

As for the main challenges for the consolidation and expansion of the market, considering the present scenario and the next 10 years, both for the internal demand and for a potential foreign demand, they mentioned incentive policies, issues related to reliability, certification and costs that are still higher than solar energy. The complete answers of other respondents on the key barriers for the segment are shown below:

LCOE too high compared to solar, shortage of financing (e.g., leasing), permitting time and cost, decreasing state support and potential decrease or elimination of federal support. These will remain the major challenges for the foreseeable future.

The challenge is multifold. Unsteady incentives from the federal and state side have led to fits and starts in the past and might do so in the future. Competition from solar will likely remain strong. Soft costs, including permitting, and other non-hardware related costs, can increase a project's cost substantially.

Small wind technology in the current scenario and over the next ten years was positively assessed by 70% of respondents, especially the recent advances on certification and enhancements of controllers and inverters. However, adjustments are still needed, such as cost reduction and improving the reliability of SWTs.

This gap demands attention from governmental institutions so that the entire supply chain becomes stronger, involving innovation and approximation between companies and universities/research centers.

For rival sectors of the industry, the main competitiveness variable is the successful introduction of innovation by one or more companies that compete in the market, allowing them to work with lower costs and more competitive products. As a result, they capture a larger share of the market and increase their profits in comparison with their rivals. In this sense, the country aims to transform the current scientific knowledge into a real technology, capable of transforming the means of economic production and increasing the level of productivity of companies, as well as stimulating new markets.

Below are presented the answers of respondents about the current scenario of the technology and its future prospects for the next ten years:

The recent certification requirements for turbines sized up to 100 kW have helped to increase the quality standards of SWTs. Sellers of SWTs are successful at exporting their turbines across the globe (to over a dozen countries in 2014), representing the high level of quality that the items have reached.

Technology can and will be improved to improve LCOE.

The main competitor in the small wind market was among the many evaluated topics. For 100% of respondents, the answer is photovoltaic solar energy. Moreover, long-term competition will still be the low-cost technologies related to fossil fuels.

All interviewees had a positive opinion about the impacts of the expansion of the small wind market, even though they worried about the reliability of the turbines. Two answers are shown below:

Distributed wind also supports the nation's manufacturing economy as US-based SWT manufacturers rely largely on a US supply chain for their wind turbine components. These manufacturers supply the majority of the SWTs deployed domestically and are leading exporters to an expanding global market.

It makes the use of RE visible, only small space required to install, easy to recycle.

Lastly, potential lessons from the US scenario that could be applied to the Brazilian market should be listed. In this sense, it can be pointed out that 60% of answers mentioned the certification of the equipment, and 40% the need for long-term financial incentives. Other issues were also discussed, such as simplified connection regulations and the need to invest in research and development. It is important to analyze some answers of the agents:

Hybrid solar/wind/diesel systems are well suited to off-grid applications like remote villages and cell phone sites. Certification is important to safeguard consumers. Consumers need a federal law, like PURPA Section 210 (1978) in the US, that guarantees them the right to connect on-site renewable generation to the grid and get paid for excess energy delivered to the grid. Subsidies are needed to develop the market.

Research and development is very important. Before selling your first product, make sure that it works and meets the power curve committed. That is why testing and prototyping are very important. It might cost some additional time and money. However, if you make sure that your products work upfront, that will save you more money in the long-term. Besides that, it will bring reliability and good reputation.

3.3. Lessons from the US

Current distributed generation projects in Brazil, particularly those related to small wind energy, are still pilot researches, in spite the country's substantial potential for the exploration of wind power. Moreover, the lack of a strong incentive program for distributed generation using alternative sources, ensuring cost reduction through economies of scale, prevents market expansion as well.

Many incentive mechanisms are adopted by federal and state governments in the US, allowing the industry of RE sources to expand, especially for new RE sources. In Brazil, the focus is given to the expansion of large-scale wind energy, which relies on demand-inducing mechanisms, through the Incentive Program for Alternative Electricity Sources (Proinfa). It is stimulated by energy auctions and through mechanisms to encourage the location of productive activity, through public financing provided by the National bank for Economic and Social Development (BNDES); incentive mechanisms are not very common, in spite of their vast potential for contributing to the diversification of power generation and to increase energy security. Table 6 presents the main incentive policies for RE sources in the US and in Brazil.

SWTs could contribute substantially to issues related to energy security, technological strategy and long-term economic growth in the US. They have a high growth potential in the US market in the context of distributed generation and low-cost technologies. Moreover, SWTs may also contribute to lessen the dependence on foreign energy and bring other benefits such as the creation of jobs in the supply chain.

Table 6. Incentive policies to promote renewable energies. Source: adapted from [33,39].

Incentive Policies to Promote Renewable Energies	Country	
	US	Brazil
Feed-in tariff	(*)	
Renewable portfolio standards/quota	(*)	
Capital subsidies, grants and rebates	X	
Investments or other tax credits	X	X
Sales tax, energy tax, excise tax or value-added tax (VAT) reduction	(*)	
Tradable re certificates	(*)	
Energy production payments or tax credits	X	
Net metering	(*)	X
Public investment, loans or financing	(*)	X
Public competitive bidding	(*)	X

Note: (*) applicable in some states on the federal level.

With the governmental support of subsidies and communication between companies, universities and research centers, it was possible to decrease innovation costs and obtain economies of scale, expanding the US market. The role of SWTs in power generation may still grow, and a recent research carried out by the DWEA [40] indicates that is possible to set the goal of 30 GW of distributed wind power generated by 2030. The goal would begin with 1 GW in 2015, with an average growth of 30% per year and a projected annual income of US\$ 12.7 billion, employing 150,000 people. Although these data are from agent interests and should be regarded with caution, the data are interesting, mainly in their magnitude. NREL [41] presented more reasonable results and pointed out the possibility of growth, indicating new technological routes and business opportunities.

In spite of the goal being difficult to attain, the US is making efforts to promote small wind energy. Identifying the barriers and opportunities of the sector was essential to better understand the actions that need to be implemented through public policies. Moreover, they made it possible to assess which strategies would be more effective to consolidate the sector, both to enhance the technology and to promote a favorable business environment. In addition, these actions take into account the need to promote best practices in the market for security, wind resources, building interactions and non-technical obstacles.

The US industry is still expanding and being consolidated, thus its production needs to increase in order to ensure economies of scale and cost reduction. It is interesting to observe that countries such as the US, the UK and others use direct incentives through the feed-in tariff, and in some cases incentives vary according to the capacity and location.

Financing is fundamental since offering credit to a specific technology does not suffice when there are many barriers in other areas. If a technology is still in its initial stages of development, with high costs and low market participation, it needs a strong legal framework to regulate it and lower risks for investors.

In the US, federal tax credits were essential for the sector to expand, such as the reduction by up to 30% of the income tax for residential installations for a certain period of time. Moreover, public financing is fundamental to lower initial investment costs. After that, certification also became a concern, as well as the development of standards and tests for turbines in urban areas.

To increase technology adoption, more effective marketing and more successful and long lasting deployments are needed, so that people see wind turbines on their neighbors' properties. To enable increased deployment, access to lower financing rates is needed.

In Brazil, the strategic actions needed have not been identified yet, as more information about the sector is necessary for its expansion and planning. Research carried out by Electrical Power Research Center (CEPEL) [42] on the small wind market pointed out the main barriers to the consolidation and expansion of the market in Brazil: the lack of financial support and tax incentives, the uncertainty regarding the generated power, high initial investments and the need for public policies that promote

small-scale distributed generation connected to the electrical system and smart grids. According to the study, 50% of 172 interviewees agreed that the lack of financial and tax support, as well as the uncertainty regarding the generated power, are barriers for the segment, thus public policies are necessary to enhance the sector. On the other hand, the interest of the Brazilian society in RE sources keeps growing, and the country has plenty of wind resources to be explored, including in urban centers, even though the technology of built environment wind turbines needs to be improved. Moreover, Brazilian manufacturers need to be ready for demand growth for SWTs.

As for the economic aspects in Brazil, as in the US, the initial investment still presents a barrier to expanding the use of the technology, as well as the return on investment.

It should be pointed out that successful industrial policy experiences show that policies that support particularly promising economic sectors, when well formulated and oriented, can have advantages for their most direct beneficiaries (entrepreneurs, suppliers, employees and clients) and, at the same time, generate externalities for the rest of society. In this vein, below are listed the lessons from the US for the promotion of the Brazilian market, considering the literature reviewed:

- Technology-specific development mechanisms;
- Financing and interest rates more favorable to technology;
- Strategic partnerships between universities and research centers with the industry aiming at improving technology and reducing costs;
- Financing program for the development and improvement of turbines for urban and peri-urban areas;
- Turbine certification program;
- Mapping of wind potential at low and medium heights, including urban areas;
- Detailed mapping of market potential, considering financial return methodologies and projections, similar to that developed by NREL;
- Development of public access economic evaluation tools;
- Development of a public database of projects, enabling the reduction of asymmetry of information and greater predictability of projects;
- Dissemination and demonstration campaign in schools and cultural centers;
- Labor training program.

The survey also allows to infer, through the voice given to the actors, other lessons experienced in the US that may be relevant (barriers or opportunities) to the development and consolidation of the SWT:

- Photovoltaic technology, either due to its price or simplicity of set-up and operation, assumes the position of greatest competitor with SWT. There is a need for improvements in order to reduce the SWT's costs and improve its LCOE;
- The regulations under the Climate Convention, such as the "Paris Agreement", present an opportunity for the inclusion of the SWT in the Nationally Determined Contributions (NDC); in the case of Brazil, renewable sources must be expanded, in addition to hydropower, in the total energy matrix for a 28% to 33% contribution by 2030. In this context, actions that include the SWT are important;
- SWT manufacturers estimate that costs may decrease and are making efforts towards it. In the Brazilian case, the Brazilian industry is still at an earlier stage of development, making such efforts superlative;
- The challenges for the American industry are: adapting its incentive policy; improving certification standards; new financial planning; and fostering export and domestic demand, in addition to the legal framework that simplifies the connection to the electricity grid. In the Brazilian case, these challenges take on a greater dimension;

- Innovation is a central variable for industry improvement, strengthening the production chain. In this sense, the close correlation between companies and universities/research centers is fundamental. The Brazilian reality presents an even greater distance, requiring a performance reflection among its actors in order to accelerate national technological development, particularly regarding SWT;
- Brazilian manufacturers believe that the generation distributed in the US has the potential to promote social and economic development by strengthening its supply chain. The Brazilian reality shows that almost the entire production chain is external, generating limited added value to the domestic economy. SWT, being in its initial stages, opens space to structure itself through public policy incentives, in order to collaborate with endogenous development.

Figure 6 summarizes the objects of analysis addressed in the article and portrays the development potential of SWTs in the Brazilian market—a market consolidated by the concept of wind farms through the use of large turbines—from US market lessons. It shows that the average individual power of the large turbines is in the order of 1.5 MW, while the small turbines are set at an average of 1 kW. The order of magnitude of installed powers also changes strongly. For large turbines, the World, US, and Brazilian averages are shown in the order of GW, and for the small market, values are in MW.

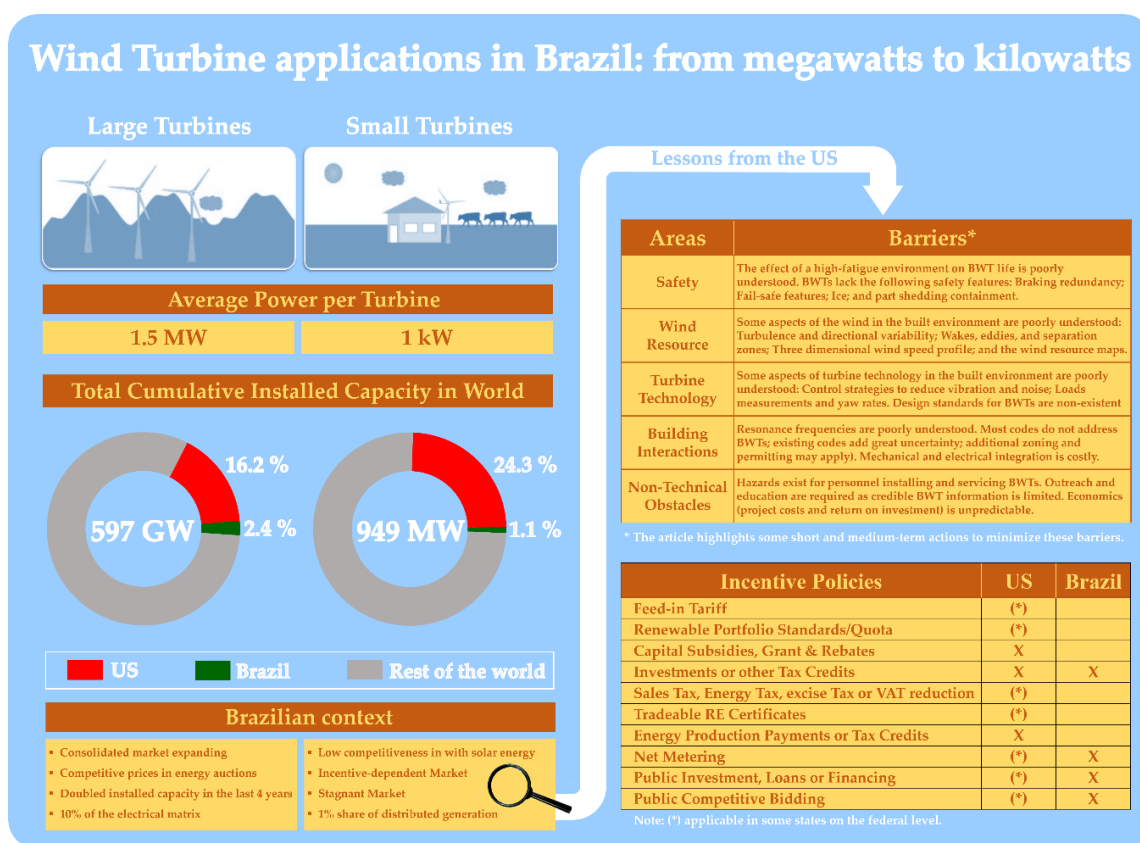


Figure 6. Potential for development of Brazilian SWTs from lessons of the US market. Elaborated by the authors based on [26,34,39,42].

In this context, bringing small-scale wind power to the debate goes beyond a market defense, that is, it contributes directly to the satisfaction of the public interest as the promotion of sustainable development and the promotion of technologies with low environmental impact. Technology is seen as an alternative to decentralization, not competing with other centralized technological options, but complementing where the large size does not have the technical capacity of operation, in particular in the urban centers, bringing gains both for developed and developing countries.

4. Conclusions

This review shows that in Brazil the wind market stands out in the context of RE sources, and the large wind market has grown continuously owing to governmental actions that stimulated the sector. While large wind power gains strength in the Brazilian market, small wind power is still in its initial stages, with few experiences, in contrast to countries such as China and the US.

The market for small wind in the US is, today, dependent of incentives. In addition, the government has been supporting this market by building a good business environment seeking to articulate and promote the interactions between the manufactures and research institutes. This has lead investors to invest with lower risk and the company reducing the cost of equipment.

Tummala [43] pointed out that the future of the continuous growth of small-scale wind turbines depends upon the cost at which it is being generated. Two major factors are the initial cost per W power and the unit cost per kWh it produces.

The small wind industry still depends on the decrease of technological costs to expand its penetration and become a microgeneration alternative. Incentive policies, interest from investors, improving consumer perception, certification and security, in addition to instruments and models that allow us to better assess the potential for power generation, are also necessary. The expansion of the sector following the example of large wind energy still represents a great challenge, even in developed countries such as the US.

The small wind market should receive more focus and investments to keep up with the prices from distinct RE technologies available on the market, therefore contributing to the dissemination of distributed power generation. Public policies and specific financial incentives determine how fast the market of RE sources develops. The results of incentive mechanisms and public policies aimed at small wind energy in the US are undeniable, and the sector may still grow over the next 15 years.

Moreover, incentive mechanisms are not limited to feed-in tariffs. Many measures are adopted to promote the small wind market, creating a favorable business environment, such as net metering, tax credits and capital subsidies. States such as California, Illinois, Rhode Island and New Jersey offer subsidies for SWTs, while other states offer tax credits, tax reduction and net metering. It is worth observing that incentive policies are fragmented and constantly changing since local communities and legislators become increasingly aware of the economic and environmental importance of the sector, pressuring the government to expand its incentives for the small wind sector in the US.

In Brazil, in order to reach large-scale commercialization from an infant technology, including searching for foreign markets to export the technology, the industry must first prepare itself for this productive leap. Consequently, public policies need to work together to promote renewable energies in the country, taking into account the long-term goals of inclusive development already defined. These actions should be taken together with stakeholders with the goal of decreasing the technological gap and obtaining economies of scale.

If technological enhancements, certification and the introduction of financial incentives such as the feed-in tariff were implemented in Brazil, its small wind industry could grow substantially, in an interesting path that would create jobs and add value to its low-carbon economy.

Technology training and outreach are necessary as well, enabling the technology to be accepted beyond certain niches. Governmental bodies may promote the technology by including a goal for consumption of power generated by SWTs in its strategic planning, showing the importance of the sector for society and contributing to its economies of scale.

Promoting the small wind sector in Brazil is still a great challenge, but lessons can be learned from the US, where research centers and universities work together with developers, creating an environment of dialogue and constant interaction between science and the market. In this sense, for example, it is possible to establish that the goal of 1 GW of installed capacity in Brazil is attainable on the long-term, and it would contribute directly to the diversification of the country's power supply, strengthening Brazil's leading role in the RE scenario worldwide.

In this context, it is also important to highlight other possibilities of using small wind farms, that are relevant to the water–food–energy nexus in regions of high vulnerability, such as the Brazilian rural semi-arid areas, where there is a contradiction that has become more intense with the development and use of large-scale wind and solar energy resources in the region.

If, on the one hand, the familiarity with scarcity in this region, the result of recurrent prolonged drought, historically dominates the life and identity of its population—where about 27 million people live (12% of Brazil’s population) [44]—on the other hand, the high solar and wind potential registered in the semi-arid region presents this region as a space of energy abundance; in other words, scarcity and abundance determine the new semi-arid rural area, where the challenge must incorporate accessible technologies to energy exploitation.

It is a fact that the Brazilian historical process conformed a reality of abandonment of different technologies with low constructive complexity and high capacity of dissemination among users. Thus, it is necessary to promote studies that evaluate, in the light of the available technical knowledge, the technical and economic feasibility of the (re)insertion of small wind farms associated with water and energy production systems in rural areas with a low social development index, as an alternative for generating work, income and quality of life. This insertion must start from a technological update, without thereby imposing additional costs on the attractive technological simplicity.

The article advances knowledge by bringing elements to the debate regarding the expansion of renewable energy sources, particularly small wind energy power. It argues for the need for structuring a Brazilian market that contemplates opportunities for research and development with the objective to evaluate, plan and promote actions that enhance gains towards the promotion of sustainability, which can be obtained by the insertion of generation distributed through the SWT.

Among the difficulties and limitations for achieving the objectives of this study is the dominance of the large wind industry. Having average turbines of 1.5 MW, it imposes a complexity in the market—both for the impressive technological development, and for financial volumes handled around the world—which overshadows the small turbine production chain. This reality establishes an environment of limited production and publication of technical and economic information on this particular topic, which limits the production of new research and exchange of experience, and prevents the presence and relevance of its authors. There is also a lack of knowledge from the public authorities about the potential technology contribution towards the diversification of the electric matrix, in addition to its improvements to a low carbon economy.

It is also important to expand the scope of this research, so that it may address environmental developments, as well as economic repercussions, in an integrated manner.

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