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Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state ☆

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ABSTRACT

Brazil's wind energy program is a successful public-private sector response to an electricity supply crisis in 2001 that created an attractive target for investors in renewable power. But evidence is accumulating that environmental impacts, which lead to territorial conflicts, livelihood erosion, and political responses, contradict sustainability claims of wind power development. We synthesize conflicts emerging in coastal Ceará state, a pioneer in Brazil's rapid development of wind power. Environmental impacts caused by wind farms, which locate on dune fields and other coastal systems, create conflicts by denying traditional communities access to resources that sustain livelihoods and cultural identities. Resource-access conflicts produce political responses that seek mitigation measures, but may escalate into a wider political challenge to continued development of wind power. We highlight the importance of land-tenure policies to assure the territorial integrity of traditional communities in areas targeted for wind power implementation. Analysis of conflicts supports suggested solutions for governments, firms, and traditional communities that may be applied in other developing countries and may help investors and planners avoid future conflicts.

Contents

☆ABEEólica is the Associação Brasileira de Energia Eólica (Brazilian Wind Energy Association). BNDES is the Banco Nacional de Desenvolvimento Econômico e Social (National Economic and Social Development Bank).

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1. Introduction

Social and political responses to onshore wind energy development are highly variable globally, with strong local or community support reported in the North American Great Plains [1,2]. However, numerous cases of opposition to utility-scale wind power in North America and Europe provide evidence for persistence of the "social gap", defined as the difference between national public opinion favorable to wind power and local opposition to wind power, which has often resulted in canceled projects [3,4]. "Imposition" of wind power without compensation or mitigation may cause conflicts between people and wind power [5,6]. "Imposition" results when investors and planners prioritize technical matters of efficiency and wind quality above social considerations, such as the human attachment to place, identity with landscape, and disruption to resources-based livelihoods. However, little is known about opposition to wind power in developing countries, with the exception of southern Mexico [7,8].

In Brazil, rapid expansion of wind power has encouraged optimism in the peer-reviewed literature [9,10]. Here we review and synthesize mounting evidence indicating that social conflicts could make Brazil's wind development unsustainable because environmental impacts threaten livelihoods and encourage political responses against wind power. We describe types of social conflict, political strategies, and outcomes observed in coastal Ceará state, Brazil's second-leading state for wind power potential. One of Brazil's pioneering states for wind power, Ceará's installed wind capacity increased from 518.9 MW in 2010 to 1.4 GW from 49 wind farms in 2015 (Table 1), mainly located in coastal areas (Fig. 1). According to Brown, Ceará "is a bellwether in the debate over how grid-scale renewable energy can grow sustainably in the developing world" [11]. Although some English-language peer-reviewed articles have indicated aspects of this impending sustainability crisis [11–13], our synthesis identifies social-environmental themes and processes that may exist in developing countries, commonly referred to as the "Global South". These themes and processes, if properly considered by investors and planners, could avoid future conflicts in Brazil and elsewhere in the Global South, particularly in sites characterized by high social and economic inequality, uneven environmental regulation, and poor access by affected social groups to the judicial state. Identification of drivers of conflict between communities and wind developers may help governments and investors avoid sites that generate conflict or work collaboratively to develop mitigation plans that reduce conflict. Table 2 synthesizes our argument by identifying actions that states, firms, and communities may take to address sustainability challenges regarding environmental systems, resource access, and economic outcomes. These suggested solutions may apply in other developing countries where renewable power is located on or near sites claimed by people who lack political power. Attention to these challenges and solutions may create an improved image for wind power and reduce high-profile injustices caused by renewable energy deployment.

2. Background

2.1. Opposition to wind energy development in the Global North

Scholarly analysis of opposition to wind power has included concerns for aesthetic impacts of turbines [14], but researchers abandoned the simplistic "not-in-my-backyard" (NIMBY) description of opposition [15,16] in favor of the claim that public perceptions are "complex [and] multidimensional" [17]. For example, debates regarding wind farms are characterized as "complex, multifaceted and passionate, tapping into deeply held beliefs and value systems" [18].

Institutional factors, especially public participation in decision-making processes, help form social perceptions of wind power development [15,19–21]. Local ownership, through co-operatives or other institutions, are thought to lead to greater social acceptance of wind power [22,23]. Economic reasons may support social perceptions; people in economically depressed areas have high acceptance of wind farms [21,24,25]. In Ontario, Canada, the technocratic siting process termed "decide-announce-defend" [26] helped produce conflicts within communities hosting wind power [27–29].

Pasqualetti synthesized many of these concerns, noting that "imposition" of wind power generated opposition among people marginalized from resources because of wind power [5,6]. In most cases, people were not compensated for their loss of resources. Moreover, "social embeddedness", which refers to human attachment to place and landscape, should be considered at early stages of wind power planning: "developers should strive for earlier and more complete understanding of the human landscape at the location of each proposed project", including criteria such as "belief systems, land tenure, perceived personal costs and benefits, and local history" [6].

However, this significant empirical and conceptual work on opposition to renewable power is globally uneven, with little research conducted in the Global South. This is a significant omission when compared to global wind power potential and the state of knowledge on wind power conflicts and possible resolutions. For example, Lombard and Ferreira's optimistic study of proposed wind farms in South Africa [30] and emerging research on controversial wind farms in southern Mexico [7,8] are among the only peer-reviewed studies of social aspects of wind power in the Global South. Moreover, the significant potential for onshore wind farms in the Global South [31] may be difficult to develop in socially and politically sustainable ways if investors and planners ignore major differences in regulatory capacity, independent judiciary, income distribution, land tenure, and political empowerment compared to North America and Europe. If ignored, these processes may develop into major obstacles preventing global development of renewable power sources.

2.2. Wind energy development in Brazil and Ceará state

The rapid expansion of wind power in Brazil, from 28.6 MW in 2005 to 5.9 GW of installed capacity in 2014 [32], responded to an electricity crisis in 2001 caused by the failure of hydropower to meet increasing electricity demand. The federal government

Table 1
Operational wind farms in Ceará state, Brazil. Fig. 1 shows location of wind farms.

Wind Farm	Capacity (MW)	Owner	Municipality
Praia Formosa	105.0	Eólica Formosa Ger. e Com. de Energia S.A.	Camocim
Canoa Quebrada	57.0	Bons Ventos Geradora de Energia S.A.	Aracati
Eólica Icaraizinho	54.6	Eólica Icaraizinho Ger. e Com. de Energia S.A.	Amontada
Bons Ventos	50.0	Bons Ventos Geradora de Energia S.A.	Aracati
Volta do Rio	42.0	Central Eólica Volta do Rio S.A	Acaraú
Dunas de Paracuru	42.0	Ventos Brasil Ger. e Com. de Energia Elétrica S.A.	Paracuru
Icaraí II	37.8	Central Geradora Eólica Icaraí II S.A	Amontada
Parque Eólico Enacel	31.5	Bons Ventos Geradora de Energia S.A.	Aracati
Junco I	30.6	Usina de Energia Eólica Junco I S.A.	Jijoca de Jericoacoara
Junco II	30.6	Usina de Energia Eólica Junco II S.A.	Jijoca de Jericoacoara
Mundaú	30.0	Central Eólica Mundaú S.A	Trairi
Guajirú	30.0	Central Eólica Guajirú S.A	Trairi
Fleixeiras I	30.0	Central Eólica Fleixeiras I S.A	Trairi
Buriti	30.0	Nova Eólica Buriti S.A.	Acaraú
Cajucoco	30.0	Nova Eólica Cajucoco S.A	Itarema
Ilha Grande	29.7	Central Elétrica Ilha Grande Ltda	Amontada
Faísa V	29.4	Eólica Faísa V Ger. e Com. de Energia Ltda	Trairi
Faísa I	29.4	Eólica Faísa I Ger. e Com. de Energia Ltda	Trairi
Eólica Praias de Parajuru	28.8	Central Eólica Praia de Parajuru S.A	Beberibe
Praia do Morgado	28.8	Central Eólica Praia do Morgado S.A	Acaraú
Icaraí I	27.3	Central Geradora Eólica Icaraí I S.A	Amontada
Faísa II	27.3	Eólica Faísa II Ger. e Com. de Energia Ltda	Trairi
Embuaca	27.3	Embuaca Ger. e Com. de Energia S.A	Trairi
Coqueiros	27.0	Nova Eólica Coqueiro S.A.	Acaraú
São Cristovão	26.0	Central Eólica São Cristóvão S.A	Trairi
Parque Eólico de Beberibe	25.6	Eólica Beberibe S.A.	Beberibe
Quixaba	25.5	Central Eólica Quixaba S.A	Aracati
Trairí	25.4	Central Eólica Trairí S.A	Trairi
Foz do Rio Choró	25.2	SIIF Cinco Ger. e Com. de Energia S.A.	Beberibe
Eólica Paracuru	25.2	Eólica Paracuru Ger. e Com. de Energia S.A.	Paracuru
Faísa IV	25.2	Eólica Faísa IV Ger. e Com. de Energia Ltda	Trairi
Faísa III	25.2	Eólica Faísa III Ger. e Com. de Energia Ltda	Trairi
Boca do Córrego	24.3	Central Elétrica Palmas Ltda	Amontada
São Jorge	24.0	Central Eólica São Jorge S.A	Trairi
Malhadinha I	23.1	Geradora Eólica Bons Ventos da Serra I S.A.	Ibiapina
Taíba Águia	23.1	Central Geradora Eólica Taíba Águia S.A.	S. G. do Amarante
Ribeirão	21.6	Central Eólica Ribeirão Ltda	Amontada
Itarema V	21.0	Eólica Itarema V S.A	Itarema
Colônia	18.9	Central Geradora Eólica Colônia S.A.	S. G. do Amarante
Itarema II	18.0	Eólica Itarema II S.A	Itarema
Icaraí	16.8	Eólica Icaraí Ger. e Com. de Energia S.A	Amontada
Taíba Albatroz	16.5	Bons Ventos Geradora de Energia S.A.	S. G. do Amarante
Taíba Andorinha	14.7	Central Geradora Eólica Taíba Andorinha S.A	S. G. do Amarante
Santo Antônio de Pádua	14.0	Central Eólica Santo Antônio de Pádua S.A.	Trairi
Eólica Canoa Quebrada	10.5	Rosa dos Ventos Ger. e Com. de Energia S.A.	Aracati
Eólica de Prainha	10.0	Wobben Wind Power Industria e Comércio Ltda	Aquiraz
Eólica de Taíba	5.0	Wobben Wind Power Industria e Comércio Ltda	S. G. do Amarante
Lagoa do Mato	3.2	Rosa dos Ventos Ger. e Com. de Energia S.A.	Aracati
Mucuripe	2.4	Wobben Wind Power Industria e Comércio Ltda	Fortaleza

declared emergency electricity rationing, which reduced economic output by 1.5–2% and caused approximately US$10 billion in losses to the Brazilian economy [33].

Wind climatology and state incentives make Brazilian wind farm development attractive to investors [10]. Starting in 2001, government officials developed aggressive policies for installing wind power by the use of state-led auctions, reduced import duties, streamlined licensing, and subsidies from Brazil's Banco Nacional de Desenvolvimento Econômico e Social (BNDES; National Economic and Social Development Bank) [9,32,34,35]. Approximately 95% of wind projects receive BNDES financing. Ceará state became a national leader, although neighboring Rio Grande do Norte (2.1 GW installed capacity) is Brazil's leading state [36]. Wind power in northeastern Brazil is desirable because of high wind quality and because periods of high wind potential and high capacity factors coincide with periods of low rainfall [9,10].

Reports on Brazilian wind power are highly optimistic, lacking mention of social, political, or environmental problems [37]. For example, Juárez and colleagues [9] described “integration of renewable sources such as wind into the Brazilian electric grid” as a “win-win situation”. Filgueiras and Silva [35] see renewable sources such as wind power as contributing to the “self-sustainability of the Brazilian electrical system” because of how wind power complements hydropower in the dry season. Benefits of wind power include reduced transmission costs because turbines are well distributed geographically and employment generation occurs through manufacturing components. Supporters also believe that “wind farms harmoniously share land with the original farm and ranch activities” and “land lease payments have a very significant value in the rural economic environment” [35]. Others argue that logistical considerations are positive because wind farms are on the coast and relatively close to ports, offering strong returns on capital invested [10].

Similarly, Araújo and Freitas [32] argue that social and environmental concerns are limited to the fact that operation and maintenance of turbines do not generate many jobs and that visual impacts “are one of the most critical problems” in Brazilian windpower development. These authors note two possible

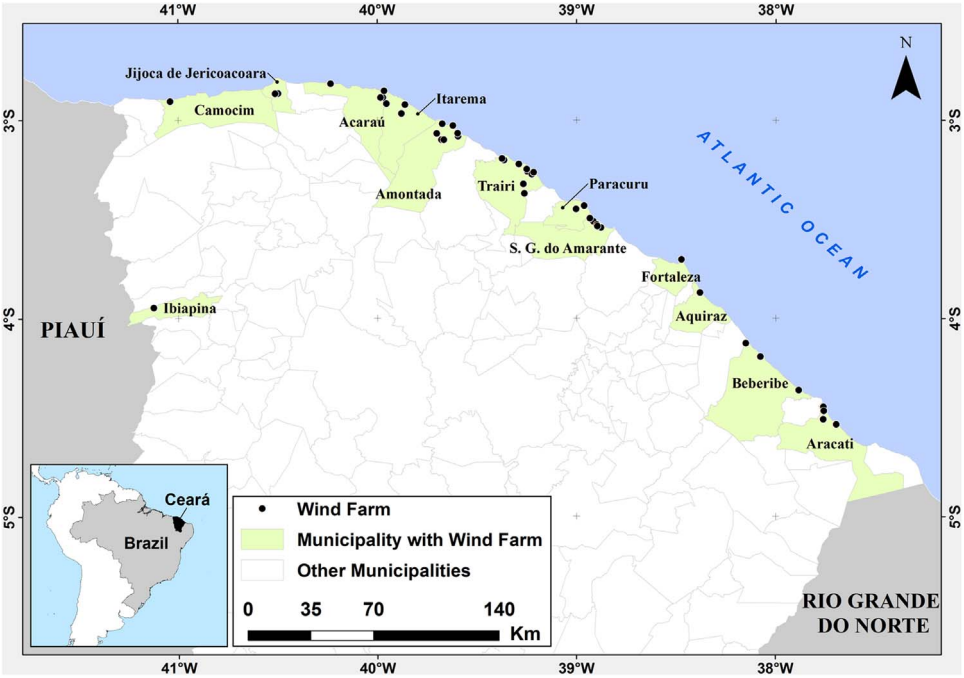

Fig. 1. Wind farms in Ceará state, Brazil.

Table 2
Sustainability challenges in Brazilian coastal wind farm development and suggested solutions for state, firms, and communities.

Sustainability challenge	Suggested solutions		
	State actions	Firm actions	Community actions
Reduce impact on beach, dune, mangrove and riparian systems	– Require rigorous analysis of environmental impacts – Declare moratorium against wind farms on beach, dune and mangrove systems	– Avoid implementing wind farms on beach, dune and mangrove systems – Skepticism of environmental consultancies	– Provide local knowledge of system fluxes and functions – Monitor impacts on affected systems
Ensure access to land and resources by traditional communities	– Strengthen land- and sea-tenure security for traditional communities – Require impact reports to analyze resource access by traditional communities – Declare off-limits buffer zones around traditional communities	– Adapt wind farms to existing resource uses – Avoid fraudulent land transfers – Exert greater scrutiny of local political and economic elites	– Create maps showing spatial aspects of resource uses
Improve economic outcomes for traditional communities	– Require economic instruments that benefit communities – Improve oversight and regulation of firm-community interactions	– Avoid co-optation and division of community groups – Avoid inflated promises of employment and economic benefits	– Create association or council to manage financial resources

aesthetic impacts: on the one hand, wind turbines may interfere with coastal scenery, but on the other hand, wind turbines may attract visitors to coastal areas [32]. Finally, the head of Brazil's Associação Brasileira de Energia Eólica (ABEEólica; Brazilian Wind Energy Association) argued that “the generation of employment and income in poor regions shows the relevant role of positive externalities of wind power” [38].

3. Materials and methods

3.1. Field work

We conducted field work in two sites representative of coastal wind development in Ceará state. Our team observed similar processes compared to reports of other authors elsewhere in the state [11,13,39,40]. In Xavier community, a traditional settlement of 20 families (66 residents), livelihoods rely on fishing with non-motorized boats, collecting shellfish and shrimps, and practicing small-scale agriculture, similar to other coastal areas of Brazil where common property is the norm and definitive land title is rare (Fig. 2). In 2009 construction began on 50 turbines capable of generating 104.4 MW, Brazil's largest wind farm until February 2015. 200 m away from the nearest turbine, houses are situated on a stretch of beach near dune fields, river and estuary system, the Atlantic Ocean, and small areas of arable land known locally as *vazante*. No tourism infrastructure exists. The nearest government services are approximately 1.5 km away in Amarelas, a district of the Camocim municipality with 60,158 inhabitants. Our research in Xavier included participant observation, group workshops, transect walks, construction of a problem-potential matrix, collective discussion regarding land-use planning, and analysis of textual materials in 2013, 2014, and 2015.

Acaraú, with a population of 57,551, has 411 turbines in 19 wind farms with installed capacity of 478 MW, primarily on coastal dune fields and tidal flats (Fig. 3). Coastal land tenure is informal. Residents lack definitive title to land and commonly held resources, such as mangroves and tidal flats. Tourism is moderately

Fig. 2. Wind farm in Xavier, Camocim municipality, Ceará, Brazil. One wind turbine is 200 m from the nearest residence.
Source: Jocicléa de Sousa Mendes.

Fig. 3. Wind farm in Acaraú, Ceará, Brazil.
Source: Caroline Loureiro.

developed, limited mainly to Brazilian tourists seeking an alternative beach destination. We conducted informal interviews with people residing in communities and leaders of local associations during three field campaigns (June 2013, May 2014, and March 2015). In Xavier and Acaraú, similar to most of coastal Ceará, traditional communities are "good faith occupants" (*posseiros de boa fé*) without legal guarantees to land [41].

We supplement these observations with analysis of textual materials, such as legal documents from judicial proceedings arising from wind development and documents contained in environmental impact reporting. We also rely on qualitative assessments of environmental impacts caused by wind farms based on field observations and interpretation of remotely sensed imagery; these environmental metrics eventually could be quantified in terms of flux and area, but they are beyond the scope of this review.

3.2. Analytical framework

We rely on well established analytical concepts to interpret our qualitative data. Environmental governance, defined as the processes by which state actors, social groups, and firms make decisions that determine or influence access to environmental resources [42,43], frames our overall approach to socio-environmental aspects of renewable power. Second, we rely on the observation that "invisible" people live on highly desired resources in Brazil. Elites in Brazil are known to "eliminate or reduce (to the minimum possible area) the territories of indigenous peoples and traditional communities, [and] consider them to be elements from the past that survived, an archaic obstacle to progress" who today occupy land sought for large infrastructure projects [44]. Third, we rely on a set of terms and concepts commonly used to analyze social and environmental politics in Brazil. For example, "blocking coalitions" are networks of people and organizations that aim to stop policy decisions relating to land uses or resource access [45]. Blocking coalitions against hydroelectric dam projects have appeared frequently in Brazil [46]. The *Ministério Público* (Public Prosecutor) is highly influential in supporting blocking coalitions regarding environmental issues [47], although the uneven application of justice in Brazil's legal system is notorious [48]. Finally, public activism, such as demonstrations and protest marches that attract public attention and increase means to negotiate with state authorities, is a proven strategy of Brazil's land-based social movements [49].

4. Results

4.1. Modification of sand dunes, estuaries, and beaches

Wind farms in Ceará have been located on highly unstable coastal areas, such as active sand dunes, estuaries, and beaches [50,51]. In Xavier, wind farm construction and construction of access roads to turbines caused burial of inter-dunal lakes [12]. Heavy machinery removed vegetation on stable dunes for the construction of roads and installation of turbine components (Fig. 4). Destruction of fixed and mobile dunes occurred to flatten land for the erection of turbines on dune fields. These interventions interrupted fluxes between river and lake systems. One specific example is destruction of a large inter-dune freshwater lake during the construction phase by earth-removal equipment entering and leveling the dune field. The disappearance of this lake removed a site of leisure and fish supply for the nearby community.

In Acaraú, wind farms have been built on coastal, fluvial, and estuarine plains. The coastal plain is a recent geomorphological formation, influenced directly by marine, wind, fluvial, and precipitation processes. Fluvial plains are relatively flat, resulting from

Fig. 4. Wind farm in Xavier constructed in dune field.
Source: Jocicléa de Sousa Mendes.

Fig. 5. Wind turbine in Acaraú requiring protection from coastal erosion. *Source:* Caroline Loureiro.

fluvial sedimentation and subject to flooding, while estuarine plains are sometimes vegetated with mangrove species and share interdependencies with tidal flats known as *apicuns* [52]. Wind turbines altered environments primarily during the construction phase. Land was altered by tractors, backhoes, and bulldozers to allow for trucks to haul construction material. Dune and beach environments are desired as sites for tourism, but they were altered by wind turbines, especially the materials used to protect the turbines from coastal erosion (Fig. 5).

Wind farm developers have been reluctant to build wind farms on the more stable coastal plateau that is better suited to construction equipment. This is partly the result of political pressure, as residents protested wind farm construction on the coastal plain [53]. Coastal plateau sites have high wind potential, but they are not normally considered by firms because of narrow consideration of the economic costs of land, which are lower in coastal plains because land is often untitled and communally used by traditional communities who have little access to political power and decision making.

These environmental impacts are present elsewhere on Ceará's coastline. In the Cumbe community of eastern Ceará, for example, residents complained about modification of the natural landscape from the levelling of dunes and burial of lakes to build wind farms. Social conflicts focused on complaints about heavy truck traffic and limits on human mobility across dune fields [11,54,55].

4.2. Territorial conflicts and livelihood impacts

Environmental transformations resulting from wind farm construction have had several negative impacts on nearby traditional communities, who are largely "invisible" in the planning and siting processes. In Xavier, the wind farm created roadblocks that denied physical access by Xavier residents to nearby Amarelas, prolonging the absence of public services such as transport to school, sanitation, collection of garbage, and access to health care. The wind farm also privatized common resources in the dune fields. Xavier residents suffer from a food deficit because they are unable to access fish in former lakes. These lakes were used for artisanal fishing when residents were unable to fish in the Atlantic Ocean because of fish scarcity or because fishing for certain species, such as lobster or Red snapper, was prohibited. Moreover, proposed expansion of the wind farm threatened to usurp *vazante* agricultural lands. Finally, residents reported discomfort from the noise that turbines generated and constant fear of an accident involving the turbines. Residents made reference to a turbine that exploded and caught fire in 2009 [56].

Conflicts have been reported with people who rely on extraction of shellfish near Camocim, where erection of a wind farm impeded access to communally held areas used to collect the mollusk *Anomalocardia brasiliana* [57]. Conflicts also resulted from kitesufing by foreign tourists, hotels, and a shrimp farm. These conflicts have reduced territories available for fishing and mollusk extraction among families, which reduced food security. Families are forced to travel an additional 1 km daily between residences and extraction areas.

In Aracaú, residents of communities near wind farms report difficulty in obtaining mangrove resources because of new land ownership, construction of access roads, and removal of vegetation associated with wind farm development. Alteration of tidal flats, an important component of the mangrove system for nutrients and food chains [52], also represents a threat to traditional livelihoods. Wind farms denied access to mangrove areas for subsistence activities, such as fishing, shrimping, and mollusk extraction by privatizing commonly held resources; moreover, mangrove dynamics were altered by the construction of wind farms. This process is apparent in Espraiado, site of a traditional community that relies on 498 ha of estuarine, coastal, tidal flats, and mobile dunes. Residents of communities near wind farms report difficulty in obtaining mangrove resources because of new land ownership, the construction of access roads, and removal of vegetation associated with wind farm development. Evangelista et al. [58] report that the establishment of a wind farm in Praia das Fontes (eastern coastal Ceará) and ensuing landscape modifications, including a concrete wall separating houses from resources, changed daily routines.

Finally, false promises of economic benefits exacerbate negative livelihood impacts. Firms and political elites justify wind energy projects with claims of electricity production and improved quality of life. Wind farm developers have used promises of compensatory measures and permanent employment to obtain the support of traditional communities [11,40,59]. Residents report disappointment with promised benefits, pointing to the unfulfilled "local jobs, local benefits" claims that wind developers reproduced as they promoted their investments [60].

4.3. Political responses

Residents of traditional communities have not passively observed changes to environments and livelihoods. In Xavier, which lacked electricity until one year after the wind farm was erected, legal disputes were negotiated in stages through the local representative of the Ministério Público and the community association. First, the wind farm operator conceded authorization to install electricity lines for the Xavier community in 2010 [56]. The wind farm impeded community electrification, but the construction of the wind farm also provided new arguments for this public investment. The irony of a small community, in the shadow of a large wind farm, lacking electricity was likely too much for local elites to withstand politically.

Second, community access to the road linking the wind farm and the nearest house was made official by a legal agreement in 2013. The road provided access for workers to access turbines for maintenance, and is today the only road that provides access to Xavier. However, access between 2010 and 2013 was restricted by a security gate with armed guards working for the wind farm operator, impeding daily tasks such as selling fish, going to school, and accessing health care [61].

Third, the wind farm provided financial support for construction of brick houses in Xavier, replacing one-room huts built with mud, wood, and thatch (known locally as *taipa*, or wattle-and-daub construction; Fig. 6), and a closed structure housing a freezer for storing fish and serving as headquarters of the community

Fig. 6. Wattle-and-daub house in Xavier that was replaced by a brick house funded by mitigation policies. The electricity connection was established after construction of the wind farm.
Source: Jocicléa de Sousa Mendes.

association. These legal agreements, negotiated among the Ministério Público, the community association (Associação dos Moradores de Xavier), and the wind farm, describe the terms for mitigating the impact of the wind farm and remove the operator from any responsibility beyond supplying funds [13].

In 2009, the residents of the Xavier community were unanimous in opposition to the wind farm [56]. This community-wide view lasted until the middle of 2014, after the investment of the housing fund used to mitigate the negative impacts of the wind farm. We estimate that half of the community members changed their view of the wind farm from negative to positive. This change created internal conflict even though all families have strong family and social inter-relations. Some families now want to sell their houses to outsiders, while others strongly resist selling, fearing the disintegration of the tight-knit community [13,61].

In Acaraú, the Curral Velho community resisted the attempt to build wind turbines on common property consisting of mangrove, tidal flats, beach, and dunes [62]. The wind farm would have isolated the community from resources and undermined livelihoods. This community had previously resisted attempts to convert their lands into shrimp farms, using public activism and blocking coalitions in alliance with non-governmental organizations and the Ministério Público. Participatory mapping of resources, led by researchers from Ceará's federal university, helped promote community awareness of resources and territory, while other groups helped organize public activism that attracted negative media attention to the shrimp farm. After denying the shrimp farm, community members used their political skills to oppose an attempt to claim land fraudulently for erecting wind turbines on lands used for traditional resource extraction. As a result, wind developers shifted their investments to nearby communities that were less well organized.

5. Discussion

5.1. Land-tenure insecurity

Land-tenure insecurity, which may not be visible to wind developers, is a first-order problem explaining the emergence of conflicts in coastal Ceará. Traditional fishing villages, without land title, occupy coastal beaches, dune fields, mangroves, and tidal flats, where they obtain resources supporting their livelihoods. Local elites, supported by (and sometimes including) elected officials, claim land fraudulently then use false titles to establish relations with investors to establish wind farms. Land-title insecurity, therefore, provides the ideal institutional setting for local elites to claim land and negotiate with wind farm operators and their political allies, thus creating opportunities for personal and corporate enrichment at the expense of people separated from resources. Longstanding isolation of coastal areas from the state's economic core and lack of resources devoted to providing land title are among the many underlying reasons for land-tenure insecurity.

Land-tenure insecurity in Brazil has long historical roots and often involves some combination of violence and fraudulent land transfers. Although the federal government has implemented technical procedures for rectifying this wide-reaching problem [63], these measures have not reached coastal dunes, tidal flats, and mangroves, leaving these areas open to the practice of claiming land through fraudulent means by political and economic elites. However, it is naive to think that only strengthening judicial aspects relating to siting procedures is sufficient to address social and environmental impacts. This is because of the large distance, metaphorically and institutionally, between wind investors and the people who live close to wind farms and experience impacts first-hand. Investors normally use intermediaries to create this institutional distance between their firms and the wind farms. Municipal and state governments support this practice by making information on wind farm ownership difficult to obtain. For example, in June 2015 Ceará's environmental agency disbanded its geographic information group, which had maintained shapefiles of wind farms. Nevertheless, a clearer, more rigorous and transparent land-tenure policy would be an important first step in empowering residents of traditional communities to negotiate with local elites and outside investors.

5.2. Weak economic institutions

Land-tenure insecurity discourages the development of economic institutions, such as contracts, regulations, and statutes, that could better distribute benefits of wind power. Wind developers have not enacted economic institutions that would generate material benefit to communities whose livelihoods are negatively affected by wind farms. In contrast with North American and European wind farms, economic institutions in Ceará do not benefit host communities. Land rent and royalties are reported in news media, but these benefits flow to formal landowners, who may have fraudulently obtained land. No institutions have been established to generate royalties or other economic benefit to host communities, unlike contracts that provide wind power royalties to landowners in North America [64]. Instead, institutions in Brazil allow capital accumulation to local political and economic elites who obtained untitled costal lands suited for wind power.

Federal government authorities developed economic institutions, especially in response to the 2001 electricity crisis, but these have privileged environmental licensing, auction prices, grid connections, import duties, and finance [9,10,32,34,35]. One specific institution, the licensing procedure, has recently been shown to be corrupt. Araújo [60] reported that one environmental consulting firm prepared environmental reports for dozens of wind farms in Ceará. In 2014, individuals associated with this firm were arrested, tried, and sentenced for fraud in the preparation of environmental licenses. Moreover, wind investors use a complex chain of intermediaries apparently designed to hide the land transactions and political negotiations leading to wind farm construction. Unlike North American wind farms, which have a clear corporate logo proudly displayed on their infrastructure and sponsored projects, Ceará's wind farms make it difficult to determine ownership and

management; moreover, Ceará's environmental agency creates obstacles to the most basic inquiries regarding licensing documents and the territorial footprint of wind farms.

Strong economic institutions could help reduce conflict in instances where wind investors reduced or prohibited access to resources for livelihoods and leisure among traditional communities. For example, mitigation measures, a type of economic institution negotiated among community leaders, wind farm operators, and local authorities, could reduce negative impacts [11]. Xavier residents received mitigation measures in the form of financial resources for new housing construction, which increased the acceptance of wind power.

5.3. Processes of imposition

Construction of wind farms in Ceará has caused substantial environmental impacts and major changes in traditional livelihoods of coastal residents, providing an example of "imposition" [5,6] also observed in southern Mexico [7,8]. Emergence of a blocking coalition, similar to the political opposition to hydroelectric dam projects in Brazil [46], is imminent and may have negative consequences for the growing wind power industry.

The Ceará cases reviewed here reveal specific ways in which wind power represents "imposition" on people and resources. Pasqualetti defined "imposition" and "social embededness" and highlighted the importance of understanding cases in which wind power has marginalized people from resources and how human attachment to place and landscape should be considered at early stages of planning [5,6]. The cases we analyze add to these claims by focusing on the underlying reason–land-tenure insecurity–for imposition, the resulting livelihood issues critical to place attachment, and the ensuing political dynamics involving wind farm operators, the state, and non-governmental organizations in public activism and blocking coalitions. Land dispossession through fraud may occur for shrimp farming or for wind power. For traditional communities, the external threat does not matter; more important is that the external threat undermines livelihoods and identity or place attachment. Aesthetic issues are a modest concern, in contrast to a study of a wind farm controversy at a near-shore Dutch site, where the key issues were scenic and ecological values and a siting process that did not involve public consultation. These factors led to eventual failure of the project [14].

The process of imposition we describe offers comparison with other possible cases of opposition to wind power in developing countries. In Ceará, elites have collaborated with environmental consultants, who produce the reports necessary for licensing, to keep communities "invisible" [44] and used their privileged access to economic institutions to obtain royalties and leases, while negating economic institutions that would benefit affected communities. These interventions are dysfunctional because they created an excluded group in the context of highly uneven access to the judiciary [48]. It is predictable, therefore, that public activism and blocking coalitions against wind farms have appeared. These political responses have also appeared in North America, Europe, and other locations [3–6], although Brazil's insecure land tenure and limited political avenues for conflict resolution create certain specific characteristics of conflicts that may be repeated in other developing countries.

We add to Pasqualetti's notion of imposition and social embeddedness by evaluating the discourse of "benign" renewable power developing countries. Most analyses of Brazilian wind energy emphasize that wind farms coexist with diverse economic activities such as cattle and agriculture, and that landowners continue residing on their land and may increase rural productivity through the investment of wind royalties and rents. This process may occur in areas where land tenure is secure and legal stability of property is established. Optimistic "win-win" scenarios may be desired by supporters of utility-scale renewable power, but they are not yet apparent in coastal Ceará.

Finally, the Ceará case indicates an important new aspect of the "social gap" phenomenon. In their revision of the "social gap", Bell and co-authors [4] argued for the need for more detailed understandings of politics and power in particular cases of wind energy deployment. Conflicts emerging in coastal Ceará indicate that developing countries present a new repertoire of processes, such as land-tenure insecurity, weak economic institutions, and dysfunctional judiciary, which are not normally found in the sites that have received the most attention from social scientists interested in social acceptance or rejection of utility scale renewable power. The presence of territorial conflicts relating to traditional communities, on the one hand, and the networks of opaque intermediaries supporting wind farms, on the other hand, present a new phenomenon that may be present in developing countries with high wind potential and eager investors.

5.4. Solutions for addressing sustainability challenges

Our analysis of conflicts highlights three sustainability challenges and solutions appropriate to governments, firms, and communities (Table 2). To reduce negative impacts on beach, dune, mangrove, and riparian systems, governments should require more rigorous analyses and declare certain systems off limits to renewable energy development. Wind firms should avoid these sites in favor of less contentious locations and accept that state environmental regulators may not be neutral actors. Environmental consultancies may be similarly compromised. Community residents may provide knowledge of system fluxes that states and firms should respect and use; communities are also well positioned to monitor impacts through citizen science protocols.

Governments should strengthen rights to land and resource access by traditional communities. Declaring certain areas off-limits or establishing buffer zones would offer legal protections to communities. Environmental impact reporting should include resources that wind farms may interrupt. Firms should adapt wind farms to existing resource uses, avoid fraudulent land transfers, and exert greater scrutiny of local elites, whose aims may differ considerably from renewable energy firms. Communities may strengthen their claims to land and resources by creating cartographic products depicting territory, residences, and resource zones [61], breaking out of the "invisibility" problem [44].

Finally, improved economic outcomes may result if governments require economic instruments that benefit communities and if they provide greater oversight of economic instruments. Firms are well aware of economic instruments that may provide community benefits and should avoid co-optation of community groups and the creation of internal divisions. Royalties and rents have helped create high social acceptance of wind power in some North American sites [2,64]. Inflated and misleading claims of employment generation are counter-productive. Communities should establish associations or councils to manage economic resources resulting from wind power. Overall, this synthesis may help to define criteria for identifying "win-win" scenarios in Ceará and other sites of renewable power in developing countries.

6. Conclusions

Private firms and public officials have supported the establishment of large wind farms in coastal Ceará and other areas in northeastern Brazil in response to the need to diversify electricity generation beyond hydropower. The importance of wind power for Brazil's electricity grid is potentially high, but the continued

establishment of wind farms in ways that threaten environmental resources and traditional livelihoods will generate social and legal conflicts that may escalate into political challenges to wind farm development. The erection of wind farms in coastal areas, especially in traditional communities, will cause and exacerbate socio-environmental conflicts that negatively affect livelihoods and lead to political actions that will bring negative publicity to wind power.

Suggested solutions to environmental, resource, and economic challenges to renewable power sustainability require action by governments, firms, and communities. The cases reviewed here show the need for detailed planning in the siting of wind farms, with special concern for communities lacking political power, before siting decisions are made. Wind power should be adjusted to physical and human environments to avoid territorial conflicts with traditional resource users, which create a highly negative view of the wind power. An essential first step is a stronger land-tenure policy that would make residents of traditional communities less “invisible” and allow them to be legitimate negotiating partners in planning and siting processes. Firms should exert greater scrutiny of local elites, avoid erroneous employment benefits, and make better use of economic instruments. Communities have a role to play in monitoring impacts, documenting their territory and resources, and managing financial resources they may obtain through economic instruments.

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