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Original Article

Assessing environmental licensing guidelines for wind energy in Brazil: implications for biodiversity conservation

Avaliando as diretrizes de licenciamento ambiental para energia eólica no Brasil: implicações para a conservação da biodiversidade

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Abstract

In the global pursuit of energy security and climate change mitigation, wind energy is a key low-carbon energy source. Brazil ranks sixth in global wind energy generation, with high demand concentrated in the Northeast region. However, the sector's environmental licensing has faced criticism for offering limited contributions to environmental protection and ecosystem integrity, particularly concerning vulnerable or bioindicator taxa such as birds, amphibians, and reptiles. We evaluated the quality of environmental licensing guidelines for wind energy in nine northeastern Brazilian states using an analytical checklist based on 66 guiding questions, focusing on recommendations for collecting data on these groups. Our findings revealed that six states have specific guidelines for wind energy licensing and showed the highest quality indicators. In contrast, states that rely on general or non-specific regulations demonstrated the lowest performance. Given these results, we recommend the urgent revision of licensing guidelines across all nine states. These guidelines should be clear, comprehensive, and require primary data specifically on birds, amphibians, and reptiles during environmental assessments. By addressing these aspects, licensing processes will better contribute to biodiversity conservation and support wind energy in becoming an ecologically sustainable energy source, reinforcing its vital role in the energy transition and climate solutions.

Keywords: clean energy, environmental impacts, environmental legislation, terrestrial vertebrates.

Resumo

Na busca global por segurança energética e mitigação das mudanças climáticas, a energia eólica é uma fonte essencial de energia de baixo carbono. O Brasil ocupa o sexto lugar na geração global de energia eólica, com alta demanda concentrada na região Nordeste. No entanto, o licenciamento ambiental do setor tem enfrentado críticas por oferecer contribuições limitadas à proteção ambiental e à integridade dos ecossistemas, particularmente em relação a táxons vulneráveis ou bioindicadores, como aves, anfíbios e répteis. Avaliamos a qualidade das diretrizes de licenciamento ambiental para energia eólica em nove estados do Nordeste brasileiro usando uma lista de verificação analítica baseada em 66 perguntas norteadoras, focando em recomendações para a coleta de dados sobre esses grupos. Nossos achados revelaram que seis estados possuem diretrizes específicas para o licenciamento de energia eólica e apresentaram os indicadores de maior qualidade. Em contraste, estados que dependem de regulamentações gerais ou não específicas demonstraram o menor desempenho. Diante desses resultados, recomendamos a revisão urgente das diretrizes de licenciamento em todos os nove estados. Essas diretrizes devem ser claras, abrangentes e exigir a coleta de dados primários especificamente sobre aves, anfíbios e répteis durante as avaliações ambientais. Ao abordar esses aspectos, os processos de licenciamento contribuirão melhor para a conservação da biodiversidade e apoiarão a energia eólica para que se torne uma fonte de energia ecologicamente sustentável, reforçando seu papel vital na transição energética e nas soluções climáticas.

Palavras-chave: energia limpa, impactos ambientais, legislação ambiental, vertebrados terrestres.

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1. Introduction

Wind energy is a renewable source that has experienced rapid growth in several countries (GWEC, 2025). In the context of climate change, it has become one of the leading global alternatives for reducing greenhouse gas emissions (IPCC, 2023). It is important to note, however, that not all scholars view renewables as a 'complete transition' away from fossil fuels, but rather as an 'addition' to the global energy matrix (York and Bell, 2019). Nevertheless, wind power remains a crucial low-carbon source for mitigating climate change and diversifying the national electricity grid, particularly in Brazil. Brazil ranks sixth globally in wind energy generation, with 1,109 wind farms and an installed capacity of 34 GW (ABEEólica, 2024). Due to strong, unidirectional, and stable winds, the eastern coast and the interior of the Northeast region are the most attractive areas for expansion (ANEEL, 2008; Azevedo et al., 2020). Although 90% of the country's wind capacity is concentrated in this region (ABEEólica, 2024), expansion is advancing particularly in the Caatinga seasonal dry forests, which are characterized by high ecological fragility (Silva et al., 2017).

The implementation of wind farms brings several benefits, including diversification of the energy matrix, job creation, and an approximate 20% increase in the Human Development Index (HDI) and Gross Domestic Product (GDP) of the municipalities involved (ABEEólica, 2024). Nevertheless, this energy source also poses direct threats to wildlife, especially birds, amphibians, and reptiles, and its negative effects on natural systems remain underestimated, particularly in countries with high wind generation such as Brazil (Bernard et al., 2014; Oliveira et al., 2023). In this context, environmental licensing becomes a key instrument for preventing, mitigating, controlling, and compensating for potential environmental damage.

In Brazil, environmental licensing was established as a regulatory tool for controlling activities with environmental impacts through Law No. 6.938 of August 31, 1981, which instituted the National Environmental Policy (Brasil, 1981). With the return to democracy, the 1988 Federal Constitution laid the foundation for the decentralization of licensing by assigning responsibility to the federal government, states, the Federal District, and municipalities for managing activities that may impact the environment (Brasil, 1988). As a result of this decentralization, several resolutions from the Conselho Nacional do Meio Ambiente (CONAMA) were issued to regulate the process. For example, Resolution 001/86 established the initial guidelines for environmental impact assessments and defined licensing as the primary tool for controlling potentially polluting activities (Brasil, 1986). Resolution 237/1997 detailed the licensing procedures, expanded the requirements for enterprises, broadened the definition of projects subject to licensing, and introduced classification criteria based on potential environmental impact (Brasil, 1997). Later, Resolution 279/2001 introduced significant changes, setting stricter criteria for impact analysis and expanding public participation in the process (Brasil, 2001).

Subsequently, Complementary Law No. 140/2011 consolidated decentralization by outlining the responsibilities of each level of government – federal, state, and municipal – in the environmental licensing process (Brasil, 2011a). According to this law, the federal government is responsible for licensing projects with large-scale environmental impacts, such as major hydroelectric plants, activities that cross state borders, and those involving federal protected areas. The states are responsible for licensing activities with local or regional impacts, such as wind farms and mining, by developing their own regulations adapted to regional contexts. Municipalities, in turn, are tasked with licensing activities that have local environmental impacts, such as the construction of small-scale urban infrastructure. With the expansion of wind energy in Brazil, Resolution 462/2014 specifically regulated the licensing process for wind energy generation projects, although state regulations may require procedures tailored to local environmental conditions (Brasil, 2014).

Although Resolution 462/2014 regulates wind farm licensing at the federal level, the states are responsible for determining the level of environmental impact for each project. This is because most wind farms span one or more municipalities within the same state, where procedures and technical requirements can vary significantly. When state environmental agencies classify a wind energy project as having low environmental impact – based on its size, location, and pollution potential – only a simplified environmental report is required (Brasil, 2014). Although this legal framework is intended to be an effective regulatory instrument, delegating impact assessment to the states has resulted in heterogeneous criteria and frequent simplification of licensing procedures (Alho, 2008). As a result, in some cases, the current licensing model for wind farms is overly permissive and of questionable effectiveness, often failing to accurately assess the true environmental impact of this energy source on wildlife and ecosystems (Bernard et al., 2014). Indeed, some of the first studies to document these serious socio-environmental damages, such as the destruction of dune fields and impacts on traditional communities along the Northeast coast, highlighted the lack of rigor in the environmental licensing of wind farms in the region (Meireles, 2011; Meireles et al., 2013).

Indeed, like any other large-scale development, the implementation of wind farms alters natural environments and leads to biodiversity loss (Santos et al., 2010). Unfortunately, data on environmental impacts, mitigation approaches, and management proposals are not openly accessible (Bernard et al., 2014). However, independent studies on the impacts of wind energy on wildlife have primarily focused on birds and bats (Bernard et al., 2014; Thaxter et al., 2017), often neglecting the effects on non-flying terrestrial animals such as amphibians and reptiles (e.g., Brito et al., 2012; Lovich and Ennen, 2013; Oliveira et al., 2023, 2025). Therefore, reconciling wind energy generation with biodiversity conservation requires a critical evaluation of the current wind farm licensing model, with an urgent need to revise and strengthen its guidelines (Bragagnolo et al., 2017; Gorayeb et al., 2018; Barros and Bernard, 2019; Sánchez and Duarte, 2022). This necessity is underscored by persistent flaws documented in the literature, ranging from critical deficiencies in planning and decision-making processes (Gorayeb et al., 2018) to concrete evidence of socio-environmental damage to landforms and traditional communities on the coast (Meireles et al., 2013). Our study, thus, builds upon these critical evaluations to systematically analyze the terms of reference used in the environmental licensing of wind farms in the nine states of Northeastern Brazil. We then compared the quality and rigor of the environmental studies, focusing on the recommendations for data collection on birds, amphibians, and reptiles. We conclude by recommending updated guidelines for Brazil and other countries experiencing rapid wind energy expansion.

2. Material and Methods

Our analysis was conducted between April and August 2023, through the request for terms of reference or other documents containing the guidelines used to support the studies required in the environmental licensing process of wind farms from the state environmental agencies of the nine states in Northeastern Brazil (Figure 1). All states responded to our request through Brazil's Access to Information Law No. 12.527 (Brasil, 2011b), except for the states of Bahia and Piauí, from which information was collected directly from institutional websites. We evaluated the quality of the terms of reference or equivalent documents using an analytical checklist based on 66 guiding questions (Table S1, Supplementary Material). These questions were developed from a prior evaluation of the available terms of reference and from standard methodologies used in the surveying and monitoring of wildlife in areas influenced by developments and activities with potential environmental impacts (e.g. Agostinho et al., 2008; Barros and Bernard, 2019), as well as according to Instruction No. 13, dated July 19, 2013, of the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Brasil, 2013).

This approach allowed us to identify the requirements for primary data collection, sampling periods and frequencies, specific information requested for each taxonomic group, as well as methods for data sampling and analysis. To assess the quality of the guidelines in terms of objectivity and comprehensiveness, we organized the guiding questions according to the flowchart presented in Figure 2. Guidelines were considered objective when the recommendations or requirements for data collection during the environmental assessment were specific regarding the required methodologies, sampling effort (e.g., frequency and duration), and the quantitative parameters to be measured. In other words, objectivity meant the guidelines lacked interpretive ambiguity by clearly defining what data to collect and how to collect it. Guidelines were considered comprehensive when the recommendations for data collection addressed a broader range of taxa, including birds, amphibians, and reptiles.

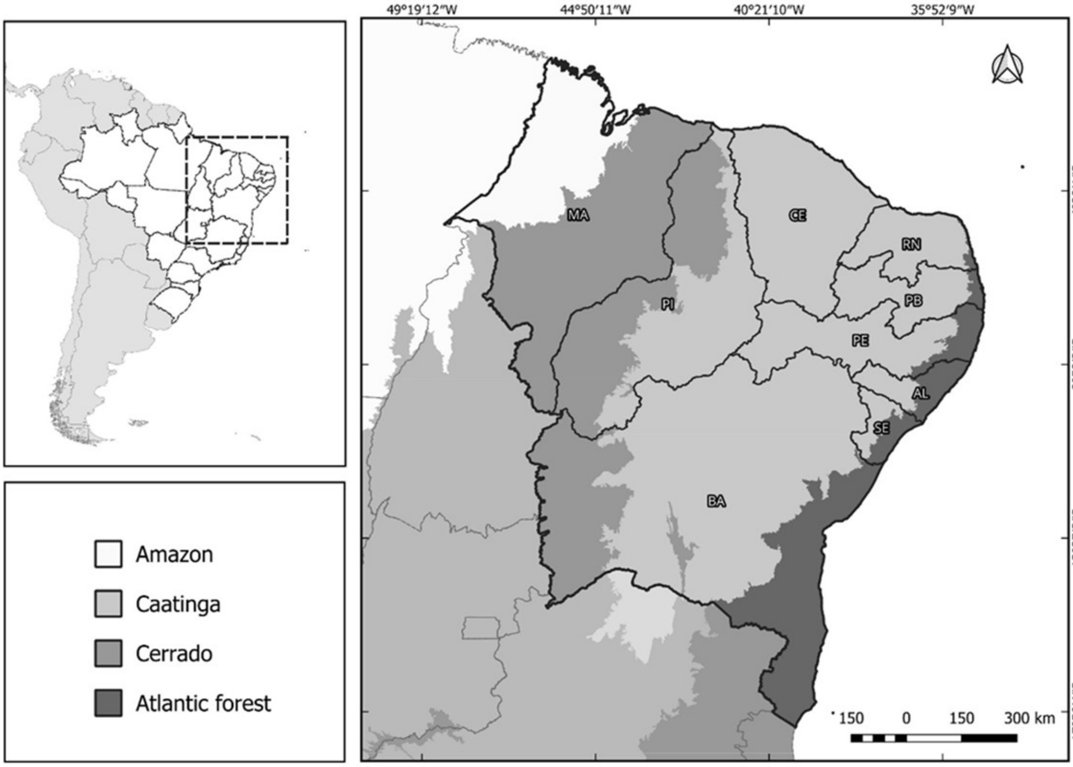

Figure 1. Geographic distribution of the nine states in Northeastern Brazil, with their respective abbreviations: Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Rio Grande do Norte (RN), and Sergipe (SE). Note that the Caatinga biome (light gray) covers large areas across the states of the region.

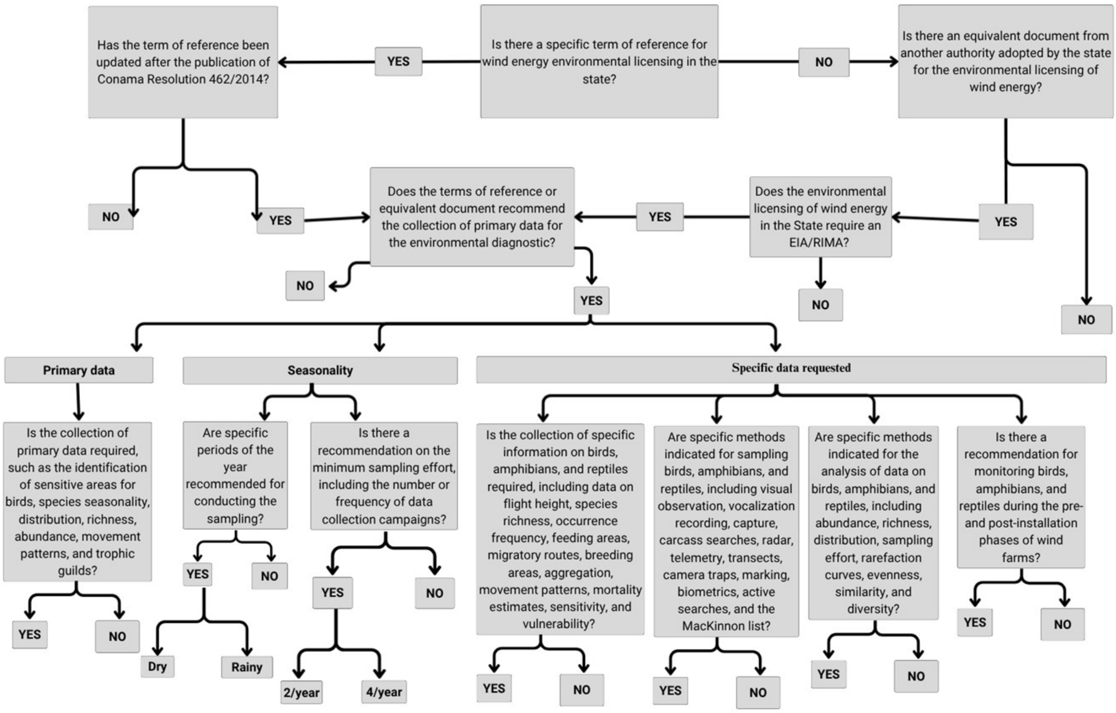

Figure 2. Flowchart of the analytical checklist used to analyze environmental study requirements in the terms of reference for wind energy licensing across nine Northeastern Brazilian states, detailing the organization of the 66 analytical items by criteria (Objectivity and Comprehensiveness).

To create a ranking of the guidelines from the nine Northeastern states, we assigned one point for each affirmative ("yes") response to the guiding questions. However, questions that addressed key aspects of environmental studies were weighted differently. We defined 'key aspects' as those requirements that significantly increase the rigor, comprehensiveness, and ecological relevance of the impact assessment. For instance, states with a specific term of reference for wind energy licensing that required more complex studies (e.g., EIA/RIMA) received two points, while those requiring only simpler studies (e.g., RAS) were assigned one point. Terms of reference that included sampling across different seasons also received two points, as ecological indices (e.g., species richness and abundance) can vary substantially between different periods of the year (e.g., dry and wet seasons).

For terms of reference that addressed more than one faunal group – birds, amphibians, and reptiles; required the use of multiple sampling techniques; specified data analysis methods; and included more detailed information for each group – one point was awarded for each item present in the guiding questions (Table S1, Supplementary Material). Finally, we summed the points from all affirmative responses and calculated a percentage score relative to the total number of questions. The percentage of positive responses for each state was calculated based on a total of 65 questions, since the existence of either a "Specific Term of Reference" (question 1) or an "Alternative Document" (question 2) is mutually exclusive.

Additional information, such as the legislation used to guide the licensing process in each state, the polluting potential, and the criteria for classifying wind farms, was also extracted from the analyzed documents.

3. Results

Our results revealed that among the nine states in the Northeast region of Brazil, only six have specific terms of reference for wind energy licensing: Alagoas, Bahia, Ceará, Maranhão, Paraíba, and Rio Grande do Norte (Table 1). In contrast, the remaining states regulate wind energy licensing based on state-level generic resolutions – Piauí follows CONSEMA Resolution 46/2022 (Piauí, 2022) – or national ones – Sergipe applies CONAMA Resolution 01/1986 (Brasil, 1986), and Pernambuco follows CONAMA Resolution 279/2001 (Brasil, 2001). Moreover, although six states have specific terms of reference, only Ceará, Maranhão, Paraíba, and Rio Grande do Norte updated their guidelines following the publication of CONAMA Resolution 462/2014. The others continue to rely federal resolutions prior to 2014: Alagoas and Sergipe follow Resolution 01/1986 (Brasil, 1986); Bahia and Pernambuco apply Resolution 279/2001 (Brasil, 2001); and Piauí follows the state-level CONSEMA Resolution 46/2022 (Piauí, 2022).

Regarding environmental studies, all states foresee the use of the Simplified Environmental Report (RAS) when the Environmental Impact Assessment and Report (EIA/RIMA) is not required. Initially, Pernambuco was the only state where

Table 1. Summary of requirements outlined in the terms of reference or other official documents for wind energy licensing in the nine states of Northeastern Brazil for wind energy licensing in the nine states of Northeastern Brazil.

Guiding questions	AL	BA	CE	MA	PB	PE	PI	RN	SE
Which states have a specific term of reference?	✓	✓	✓	✓	✓			✓	
If there are no specific terms of reference, is there an equivalent document adopted by the state?						✓	✓		✓
Were the terms of reference updated after Conama Resolution 462/2014?				✓	✓			✓	
Does the environmental licensing of wind energy require an EIA/RIMA?	✓	✓	✓	✓	✓		✓	✓	✓
Primary data requested									
Delimitation of sensitive areas for birds	✓								
Species seasonality	✓	✓	✓	✓				✓	
Distribution	✓							✓	
Richness	✓			✓					
Abundance	✓			✓					
Movement patterns	✓								
Trophic guilds								✓	
Sampling periods									
Dry season	✓	✓	✓	✓	✓		✓		
Rainy season	✓	✓	✓	✓	✓		✓		
Sampling frequency									
2 samples per year		✓	✓	✓	✓				
4 samples per year	✓								
Sampling animal groups									
Birds	✓	✓	✓	✓				✓	
Amphibians				✓				✓	
Reptiles				✓				✓	
Specific data requested									
Flight altitude	✓	✓						✓	
Species richness	✓	✓		✓					
Frequency of occurrence	✓			✓					
Foraging areas	✓	✓							
Migration routes	✓	✓	✓						
Breeding areas	✓	✓	✓					✓	
Aggregation/concentration		✓							
Movement patterns	✓	✓						✓	
Mortality estimates	✓		✓						
Sensitivity				✓					
Vulnerability				✓					
Sampling animal groups									
Birds	✓		✓					✓	
Amphibians									
Reptiles									
Sampling methods									
Visual observation	✓		✓					✓	
Vocalization recording									
Capture									
Carcass searches	✓								
Radar	✓								
Telemetry			✓						
Transects			✓						
Camera traps			✓					✓	
Track beds			✓						
Tagging				✓					
Biometrics				✓					
Active search								✓	
MacKinnon list								✓	
Sampling animal groups									
Birds	✓		✓	✓				✓	
Amphibians			✓	✓					
Reptiles			✓	✓					
Data analysis methods									
Abundance	✓			✓				✓	
Richness	✓			✓				✓	
Distribution	✓							✓	
Sampling effort			✓	✓					
Rarefaction curve				✓					
Evenness				✓					
Similarity				✓					
Diversity				✓					
Monitoring requirements									
Birds	✓								
Amphibians									
Reptiles									

Abbreviations: Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Rio Grande do Norte (RN), and Sergipe (SE).

Table 2. Scores obtained in the qualitative assessment of terms of reference or other guidelines.

	Alagoas	Bahia	Ceará	Maranhão	Paraíba	Pernambuco	Piauí	Rio Grande do Norte	Sergipe
Guiding questions	12	10	10	12	8	1	4	9	4
Primary data	6	1	1	3	0	0	0	3	0
Sampling periods	2	2	2	2	2	0	2	0	0
Sampling frequency	1	1	1	1	1	0	0	0	0
Faunal information	9	8	4	7	0	0	0	6	0
Sampling methods	4	0	6	2	0	0	0	5	0
Analysis methods	4	0	4	10	0	0	0	4	0
Monitoring	1	0	0	0	0	0	0	0	0
Total	39	22	28	37	11	1	6	27	4
%	60	33.8	43.1	56.9	16.9	1.5	9.2	41.5	6.1

RAS was the sole instrument for wind energy licensing (Table 1). In the other states, the requirement for EIA/RIMA depends on how the licensing authority classifies the wind energy projects (Table 1). However, the classification criteria for requiring EIA/RIMA and interpretations of the polluting potential vary considerably among states (e.g., ≥10 MW in Maranhão and Sergipe; ≥20 wind turbines in Piauí). Other criteria also trigger the requirement for EIA/RIMA, such as: (1) wind farms located in dunes, wetlands, Atlantic Forest remnants, buffer zones of protected areas, important areas for migratory birds, or habitats of threatened species (Ceará and Rio Grande do Norte); (2) removal of traditional populations, suppression of more than 60% of vegetation, or intervention in protected areas or caves (Alagoas and Maranhão); and (3) projects likely to cause significant environmental degradation (Ceará and Bahia).

With regard to recommendations for primary data collection during environmental studies, seven states received positive scores for this criterion (Table 1). Only Alagoas demonstrated concern for identifying sensitive areas for birds and analyzing movement patterns, while Alagoas, Bahia, Ceará, Maranhão, Paraíba, and Piauí clearly recommended data collection during both the dry and wet seasons (Table 1). The frequency specified for sampling in Bahia, Ceará, Maranhão, and Paraíba is twice per year, while Alagoas requires four annual samples (Table 1).

Only the guidelines from Alagoas, Bahia, Ceará, Maranhão, and Rio Grande do Norte require specific data collection for birds, including species richness and frequency of occurrence (Table 1). However, only Maranhão and Rio Grande do Norte also require specific data collection for amphibians and reptiles. Specific sampling methods – such as visual surveys and camera traps – are included in the guidelines of Alagoas, Ceará, and Rio Grande do Norte, though only for birds (Table 1). In addition, data analysis methods – such as sampling effort, species abundance, and richness – are mentioned only in the guidelines of Alagoas, Ceará, and Rio Grande do Norte (Table 1). While data analysis methods for birds appear in the guidelines of Alagoas, Ceará, Maranhão, and Rio Grande do Norte, only Ceará and Maranhão extend these requirements to amphibians and reptiles. Finally, only the guidelines from Alagoas require monitoring of migratory or threatened bird species during the installation and operation phases of wind farms (Table 1).

Finally, the states with the highest scores in their wind energy licensing guidelines were Alagoas (60%), Maranhão (56.9%), Ceará (43.1%), Rio Grande do Norte (41.5%), and Bahia (33.8%). On the other hand, the remaining states had significantly lower scores: Paraíba (16.9%), Piauí (9.2%), Sergipe (6.1%), and Pernambuco (1.5%) (Table 2).

4. Discussion

This study qualitatively assessed the environmental licensing guidelines for wind energy projects across the nine states of Brazil's Northeast region. Our findings indicate that only six states have specific, relatively objective, and comprehensive guidelines tailored to address the impact of wind energy on birds, amphibians and reptiles. However, faunal groups are not equally addressed; when specific requirements are present, they predominantly focus on avifauna. This underscores the importance of high-quality terms of reference to ensure effective conservation of the studied groups.

Terms of reference are documents that delineate the criteria for conducting environmental studies required from developers during the environmental licensing process (Brasil, 1981). These documents are crafted to accommodate the specificities and demands of each project, considering its type, scale, and potential impacts. Therefore, it is imperative for states to establish specific guidelines for licensing wind energy projects. The level of detail in the terms of reference should correspond to the complexity of the required study: more comprehensive and technically detailed for Environmental Impact Assessments (EIA/RIMA), and less complex for Simplified Environmental Reports (RAS) (Brasil, 2014). While states should base their guidelines on Resolution 462/2014, they should not be confined to its recommendations, as the resolution offers limited guidance on faunal data collection. For instance, RAS mandates surveys of bird species, migratory routes, nesting areas, resting sites, and the presence of endemic or threatened species. In contrast, EIA requires studies on breeding, resting, and migratory routes of birds, along with seasonal behavior mapping of birds and bats. However, given the known negative impacts on fauna, these requirements are considered insufficient and have been criticized for their limited environmental contributions (Bernard et al., 2014; Valença and Bernard, 2015; Gorayeb and Brannstrom, 2016; Dantas et al., 2019; Sánchez and Duarte, 2022).

Evidence suggests that wind farm installations can affect animal groups through various pathways, with impacts varying across different geographic areas (Northrup and Wittemyer, 2013; Dias et al., 2019; Tolvanen et al., 2023). Environmental impacts associated with wind farms include habitat reduction and fragmentation, increased fire risk, soil impermeabilization, barriers to gene flow, local climate alterations, and wildlife collisions (Dai et al., 2015; Lovich and Ennen, 2017). These issues are particularly concerning in ecologically sensitive ecosystems due to their prolonged recovery times (Dai et al., 2015). The Caatinga biome, the largest and most biodiverse seasonally dry forest in the Americas (Silva et al., 2017), exemplifies such an ecosystem. Spanning 912,000 km^2 in Brazil's Northeast, the Caatinga encompasses 70% of the country's priority areas for wind energy generation (ANEEL, 2008) but has less than 2% under full protection (Fonseca et al., 2018). Furthermore, high wind potential areas often overlap with regions officially designated as biodiversity conservation priorities within this biome (Brasil, 2018). The consistent strong winds make the hilltops in the Caatinga prime locations for wind farm installations (Neri et al., 2019). However, these areas contain remnants of native vegetation that serve as refuges for wildlife, especially endangered species, leading to conflicts between wind energy development and biodiversity conservation (Dias et al., 2019; Neri et al., 2019). These factors highlight the need for heightened attention to the negative impacts of wind energy projects in the region and the necessity for guidelines that mandate comprehensive environmental assessments of the affected biodiversity.

Indeed, the methodology employed in environmental studies directly influences the quality of the resulting environmental assessments (Sánchez, 2020). This premise holds true not only for wind energy, but also for other renewable sources, such as hydroelectric power (Agostinho et al., 2008), and solar energy (Silva Sobrinho et al., 2022). Consequently, the Environmental Impact Assessment (EIA) and its corresponding Environmental Impact Report (RIMA) are crucial tools for informed decision-making regarding projects with significant environmental impact potential (Sánchez, 2020).

However, our analysis reveals that the criteria for requiring EIA/RIMA vary considerably among the states studied. This is because the classification of a project's polluting potential differs regionally, undermining the overall effectiveness of the environmental licensing process (Gorayeb and Brannstrom, 2016; Bragagnolo et al., 2017; Gorayeb et al., 2018; Dantas et al., 2019; Maia et al., 2023). This fragmentation is further exacerbated by the use of vague and subjective criteria, such as requiring a full EIA/RIMA only for 'projects likely to cause significant environmental degradation' (a criterion cited in the Ceará and Bahia guidelines). The reliance on such ambiguous terminology, lacking a clear, measurable definition for 'significant impact,' introduces substantial interpretative discretion and directly compromises the need for objective guidelines, which is a central finding of this study. The most glaring example of this regulatory failure is the finding that Pernambuco was the only state initially relying solely on the Simplified Environmental Report (RAS) for wind energy projects, thereby severely compromising the evaluation of potentially significant impacts. This issue extends beyond the initial guidelines, affecting the quality of studies submitted in practice. For instance, Araújo et al. (2020), analyzing Simplified Environmental Reports (RAS) in Coastal Ceará, revealed how companies can appropriate and manipulate licensing materials, suggesting that even in states with relatively better frameworks, the simplified procedures can be exploited, leading to flawed assessments and generating socio-environmental conflicts in host communities. This fragmented approach is a direct consequence of a historical political and regulatory framework that often fails to incorporate the true societal and ecological value of biodiversity into development strategies (Alho, 2008), ultimately favoring economic short-term goals.

This finding regarding the general deficiency and subjectivity of state guidelines is strongly corroborated by focused thematic analyses. For instance, a comparative study evaluating the quality of state-level wind energy licensing in Brazil specifically concerning the impacts on bats found similar regulatory weaknesses (Barros and Bernard, 2019). The authors highlighted that most state guidelines are "vague" and fail to require critical data for proper bat impact assessment, particularly within simplified licensing procedures. The convergence between the overall normative deficiency identified in our general ranking (especially in states scoring below 20%) and the lack of specific fauna requirements observed in the bat study reinforces the argument that the lack of technical detail and clarity is a systemic regulatory issue compromising the effectiveness of environmental licensing in the Northeast region (see also discussion in Bernard et al., 2014; Valença and Bernard, 2015).

Consequently, this variability allows companies to exploit the system by licensing multiple wind farms with low polluting potential using simplified environmental studies (RAS) within the same area (Valença and Bernard, 2015; Silva Sobrinho et al., 2022). Such simplification introduces uncertainties regarding potential wildlife impacts, ensuring that the cumulative and synergistic effects on affected ecosystems remain underestimated (Voigt et al., 2012; Bernard et al., 2014; Sánchez, 2020).

This regulatory fragility is not isolated; it is exacerbated by the current political agenda in Brazil that favors the simplification and potential dismantlement of environmental safeguards. This posture is materialized in legislative proposals such as the Complementary Law Project 2.159/2021, widely known as the 'PL da Devastação'. This proposed law represents a direct threat by expanding licensing exemptions and proposing self-licensing for medium-impact activities, which would inevitably worsen the existing inconsistencies documented in our study (Vitorino et al., 2025). The failures identified in the state Terms of Reference – such as the subestimation of impacts in sensitive ecosystems like the Caatinga – are thus symptoms of a broader political scenario where the simplification of environmental regulation is promoted to accelerate economic activity at the expense of socio-environmental protection (Doğan, 2025; Gomes and Braga, 2025). In this context, our findings gain urgency, as they confront the assumption that simplification should override the need for technical rigor, positioning the defense for robust guidelines as a critical issue of socio-environmental justice.

Specific impacts of wind farms on each studied group have been investigated by various authors, including studies on birds (Zwart et al., 2016; Thaxter et al., 2017; Whalen et al., 2019), amphibians (Caorsi et al., 2019; Park and Do, 2022; Trowbridge and Litzgus, 2022; Oliveira et al., 2023, 2025), and reptiles (Brito et al., 2012; Lovich and Ennen, 2013, 2017; Keehn et al., 2019). Therefore, collecting specific data for each group is essential for informed decision-making during the licensing process. The absence of biological, ecological, and behavioral data collection is particularly concerning, as it hampers a comprehensive understanding of the negative environmental impacts of wind energy on wildlife (Lovich and Ennen, 2013; Oliveira et al., 2023).

Our results indicate that the guidelines from Alagoas, Bahia, Ceará, Maranhão, and Rio Grande do Norte are relatively satisfactory, maintaining a reasonable level of requirements. Conversely, due to the lack of detailed information required for environmental diagnostics, the guidelines from Pernambuco, Piauí, and Sergipe fall short. However, a critical anomaly emerges when considering the correlation between regulatory robustness and installed capacity. While states like Bahia, Rio Grande do Norte, and Ceará – which possess the most comprehensive guidelines according to our analysis – are also among the national leaders in installed wind power capacity, Piauí represents a notable exception. Piauí is one of Brazil's largest energy producers but possesses a fragile regulatory framework, scoring low on the criteria for required environmental diagnostics. This rapid development, decoupled from strong licensing criteria, can have profound socio-environmental implications. Araújo and Gorayeb (2023), in their study on the state, found that the lack of effective public participation and robust legal requirements in the licensing process generates severe conflicts and concerns regarding the procedural and distributive justice of wind energy implementation in local communities.

For avian species, understanding flight altitude, foraging behavior, and species richness is vital to estimate collision risks with wind turbines. Additionally, wind farm areas may serve various functions for birds, including feeding, resting, and migratory pathways. The presence of threatened or migratory bird species is a criterion for requiring EIA/RIMA or even grounds for project denial (Brasil, 2014). Comprehensive diagnostics can also enhance our understanding of the life histories of studied animal groups. For instance, in the past two decades, new amphisbaenian species have been described from specimens collected during fauna monitoring and rescue phases of licensed projects (e.g., Ribeiro et al., 2024; Mott et al., 2008; Almeida et al., 2018). However, the impacts of wind farm infrastructure on reptiles, especially fossorial species, remain poorly understood, necessitating urgent studies (Ribeiro et al., 2024).

Seasonality's effect on biodiversity is crucial for understanding how cyclical and predictable environmental variations influence species diversity and organism adaptation, essential for formulating effective conservation strategies amid climate change impacts on ecosystems (Tonkin et al., 2017; White and Hastings, 2020; Gao et al., 2024). For amphibians, which exhibit strongly seasonal behaviors, licensing guidelines should mandate data collection during the reproductive period, typically in the rainy season (Oliveira et al., 2023, 2025). Migratory birds often alter their occurrence areas during migration (Cooper et al., 2017; Tedeschi et al., 2020), and this variability must be accounted for in sampling efforts.

Similarly, species richness and movement patterns are variable and should be analyzed during the licensing process. Appropriate methods must be defined for each type of data to be collected, considering species and habitat diversity, including active searches, marking, and vocalization recordings for estimating species abundance and richness. Sampling methods such as camera traps, telemetry, and carcass searches are essential for assessing wind farms' impacts on fauna before and after installation. These data can reveal population fluctuations, reflecting changes in species richness and composition associated with habitat alterations and losses (Northrup and Wittemyer, 2013; Falavigna et al., 2020; Tolvanen et al., 2023). These complementary methods can be decisive for detecting threatened species before wind farm installation, influencing the type of environmental study required during licensing. Therefore, data collection for each studied group is pivotal for understanding how fauna responds to wind farm presence. For example, while evidence suggests that amphibian abundance and richness may not be directly influenced by wind farm installation (Oliveira et al., 2023), wind farm noise has been associated with chronic stress, immune system suppression (Park and Do, 2022), and alterations in calling behavior (Caorsi et al., 2019; Oliveira et al., 2025).

Beyond data collection, it is also important for guidelines to specify methods for data analysis. Although there is no standardization, our results reveal that states with their own terms of reference specify methods for data collection and analysis. Analyzing data results is crucial for evaluating potential changes in species population structures. For instance, interpreting results can help identify population declines and species migrations (Tolvanen et al., 2023). Additionally, it is essential that licensing guidelines require fauna monitoring both before and after the installation of wind farms (Falavigna et al., 2020). In this regard, only the state of Alagoas included such a recommendation, and even then, it was limited exclusively to avifauna. However, systematic monitoring can provide valuable insights into how species and ecosystems respond to wind farm development, enabling the implementation of more effective conservation strategies (Dias et al., 2019; Oliveira et al., 2023).

5. Conclusions

This study critically evaluated the quality of environmental licensing guidelines for wind farms across nine states in Northeastern Brazil, directly addressing the urgent need to reconcile rapid renewable energy expansion with biodiversity conservation. The most important finding of this work is the pronounced and concerning variability in state-level guidelines, specifically the widespread absence of clear, specific requirements for assessing impacts on birds, amphibians and reptiles. This regulatory oversight leaves highly vulnerable taxa exposed to substantial risk from wind farm development and confirms that, despite federal regulation, the decentralized Brazilian licensing system is currently failing its mandate to protect biodiversity at the state level.

The most crucial practical implication emerging from our analysis is that this regulatory gap is not due to technical impossibility, but rather to political and administrative choices. Our finding that Maranhão and Rio Grande do Norte have successfully integrated amphibian and reptile requirements (not excluding birds) into their terms of reference shows that establishing detailed, specific guidelines is not only possible but necessary within the current federal framework. This result offers a direct pathway for policy – a clear example for the remaining seven states to immediately strengthen their environmental protocols, urging them to move beyond generalized (EIA/RIMA) or simplified assessments (RAS) to require the animal group-specific primary ecological data necessary for informed licensing decisions.

Therefore, the long-term integrity of wind energy as a truly "clean" and ecologically responsible solution to climate change hinges on the rigor of its environmental governance. Our comparative analysis of licensing documents offers an essential tool for policymakers, not only in Brazil but in any country rapidly expanding its renewable energy matrix. By providing a metric for evaluating and strengthening environmental terms of reference, this research underscores that aligning energy security with biodiversity conservation is an achievable policy goal, essential for securing the enduring ecological sustainability of the global energy transition.

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Data Availability Statement

The entire data set that supports the results of this study was published in the article itself.

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Supplementary Material

Supplementary material accompanies this paper.

Table S1. Analytical Checklist detailing the 66 analytical items (guiding questions) used for the scoring of environmental licensing guidelines for wind energy in Northeastern Brazilian states, organized by criteria (e.g., Objectivity and Comprehensiveness).

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