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Policy Forums

Wind energy expansion in Brazil and implications for the conservation of threatened amphibians, birds and reptiles

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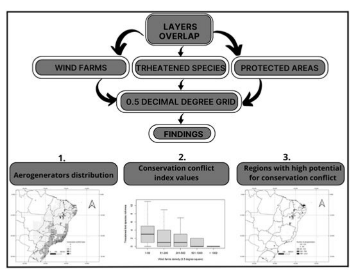
HIGHLIGHTS

- Wind energy has grown rapidly in Brazil.
- Target areas for wind energy also overlap with biodiversity conservation priorities.
- We identified sensitive areas for wind farm installation across Brazil.
- Wind turbines, protected areas, and endangered species show spatial overlap.
- Findings reinforce the urgent need for stronger environmental licensing frameworks.

GRAPHICAL ABSTRACT



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ABSTRACT

Although considered a clean energy source, wind energy can negatively impact wildlife. This situation is more worrying in countries with high wind potential and ecologically sensitive areas, like Brazil. Here, our goal was to identify sensitive areas for globally threatened amphibians, birds, and reptiles in Brazil. We overlapped shapefiles of protected areas, endangered species, and wind farms to delimit areas of potential conflicts for conservation, projecting those datasets into 0.5-degree grid cells. Our results revealed no apparent tendency for areas with higher densities of wind turbines to overlap with greater richness of endangered species, although a moderate negative correlation was observed for bird species richness. Although there is no positive correlation with endangered species richness, there is still notable spatial overlap between wind energy generation, protected areas, and endangered species. While we do not intend to question the logic behind the expansion of renewable energies and their notable environmental benefits, we emphasize that the negative impacts on biodiversity must be considered in wind energy development. For wind energy to achieve this goal, it is crucial to promote more effective environmental licensing. Given the rapid expansion of wind energy in Brazil and worldwide, addressing these concerns is crucial to minimizing impacts on threatened amphibians, birds, and reptiles, which are declining globally.

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Introduction

In the face of the climate emergency, wind energy has been identified as one of the global alternatives in the transition to a low-carbon economy (Gasparatos et al., 2017). The need for diversification of the energy matrix, coupled with technological advances and tax incentives, has allowed for a rapid expansion of wind energy in various parts of the world (Global Wind Energy Council, 2025). In this direction, with 34 GW of installed capacity, Brazil ranks sixth in the world ranking of wind energy generation (Associação Brasileira de Energia Eólica, 2025). In the country, the most relevant areas for wind generation are located along the Atlantic coast and in the Borborema Plateau (Agência Nacional de Energia Elétrica, 2008; Azevedo et al., 2020). Given the rapid growth of wind energy in Brazil, the environmental impacts on wildlife and affected ecosystems still need to be reduced and mitigated (Bernard et al., 2014; Valença and Bernard, 2015).

Despite being considered a clean energy source, like any other large-scale venture, the implementation of wind farms alters natural landscapes and promotes biodiversity losses (Santos et al., 2010). Although habitat reduction and alteration are identified as the main negative impacts of wind energy expansion in terrestrial ecosystems (Santos et al., 2010; Lovich and Ennen, 2017), understanding indirect impacts such as noise and light pollution demands more attention. Previous studies have predominantly investigated impacts on birds and bats (Thaxter et al., 2017), leaving gaps in the knowledge of wind farm impacts on non-flying terrestrial animals, such as amphibians and reptiles (Lovich and Ennen, 2013; Oliveira et al., 2023). However, understanding these impacts is crucial, as 13% of bird species, 21% of reptile species, and 41% of amphibian species are included in the International Union for Conservation of Nature Red List of globally threatened species (IUCN, 2025).

Indeed, careful spatial planning has been identified as the most effective means to prevent or reduce the damages caused by wind energy (Balotari-Chiebao et al., 2023). This situation is especially delicate in Brazil, as extensive areas mapped as priorities for biodiversity conservation are also targets for wind energy generation (Ministério do Meio Ambiente, 2018). Despite the conflicting relationship between wind energy generation and priority conservation areas being evidenced in the Caatinga (Neri et al., 2019), gaps remain for other Brazilian biomes, like Atlantic Forest and Pampas. Furthermore, the implications of this expansion on threatened species are poorly understood. Here, we identified sensitive areas for wind farm installation in Brazil, where protected areas and threatened species of birds, amphibians, and reptiles overlap, identifying areas of potential conservation conflicts.

Material and methods

Protected areas

We included in our analyses the 336 federal PAs officially mapped by the Ministry of the Environment, which are widely distributed across all biomes of the country. Federal PAs are part of the National System of Protected Areas – SNUC Law 9.985/2000 (Brazil, 2000), and are divided into two conservation categories: integral protection (Ecological Station; Biological Reserve; National Park; Natural Monument; Wildlife Refuge) and sustainable use (Environmental Protection Area; Area of Relevant Ecological Interest; National Forest; Extractive Reserve; Fauna Reserve; Sustainable Development Reserve).

Occurrence of globally threatened species in Brazil

We established the occurrence area of globally threatened amphibians, birds, and reptiles in Brazil using vector files from the spatial database of the International Union for Conservation of Nature (IUCN, 2022) available at https://www.iucnredlist.org/resources/spatial-data-download. Only vector files of the most threatened species, categorized as Endangered (EN) and Critically Endangered (CR), as well as species occurring in terrestrial habitats such as forests, savannas, shrublands, grasslands, and wetlands were selected. For birds, we also included threatened migratory species that use the country in their annual migration, as they are particularly susceptible to collision with wind turbines (Northrup and Wittemyer, 2013; Thaxter et al., 2017).

Wind energy generation in Brazil

In Brazil, the distribution and density of wind farms, as well as the number of wind turbines per project, vary considerably. Since the synergistic and cumulative effects on impacted species depend on the number of turbines in each wind farm, we considered not only their presence but also their density. To better understand potential conservation conflicts, we used geographic coordinate data for every individual installed and planned wind turbine, based on the same database used by Neri et al. (2019). As this database includes turbines planned as of 2019, most (if not all) should now be operational, given their prior listing in the Brazil's Geographic Information System of the Electric Sector (Agência Nacional de Energia Elétrica, 2018).

Data analysis

To evaluate potential overlaps between protected areas, endangered species (birds, amphibians, and reptiles), and wind farms – while accounting for uncertainties in species distribution data – we projected all three datasets onto a 0.5-degree grid using QGIS version 3.34 (QGIS, 2024). Each grid cell recorded the number of wind turbines and the presence or absence of both protected areas and each endangered species within its boundaries (any overlap within a cell was considered a presence). Each grid cell was saved in shapefile format, and the corresponding attribute table (.dbf format) was accessed for further analysis in R (R Core Team, 2024).

To assess potential conservation conflicts arising from the presence of wind farms in the distribution ranges of endangered species and near protected areas, we applied three analytical approaches using R: (i) generated boxplots of total endangered species richness per cell containing wind turbines; (ii) calculated Spearman's rank correlations between species group richness and wind turbine density within cells; and (iii) developed an index to identify cells with the highest potential for conservation conflict.

The potential conservation conflict index was calculated by summing values assigned to each cell as follows: 1 point if the number of wind turbines in the cell was equal to or greater than the median, or 2 points if it was equal to or greater than the third quartile; 1 point if the number of endangered species from each taxonomic group was equal to or greater than half of that group's total species count; and 1 point if a protected area was present within the cell. The resulting index ranged from 0 to 6. This table was saved in. dbf format and re-imported into QGIS for mapping using the calculated index values.

Results

Based on the wind turbine data, our findings identified a grid comprising 1773 cells of 0.5-degree each, of which 1650 are empty (i.e., contain installed or planned wind turbines), highlighting the Brazilian northeast (Fig. 1). The remaining 123 cells contain between 2 and 1514 turbines per cell, exhibiting a right-skewed distribution (1 st quartile: 33.5; median: 73; 3rd quartile: 209).

In addition, we found no apparent tendency for areas with higher densities of wind turbines to overlap with greater richness of endangered species (Fig. 2). Spearman's rank correlation between turbine density and the richness of endangered amphibian and reptile species was not statistically significant ($\rho = -0.12$, $p = 0.19$; $\rho = -0.03$, $p = 0.69$, respectively), whereas a moderate negative correlation was observed for bird species ($\rho = -0.37$, $p < 0.001$).

Furthermore, the conservation conflict index ranged from 0 to 4, with a high number of cells scoring 1 and five cells exhibiting the highest level of detected conflict (Fig. 3).

Our findings also revealed that areas with the highest potential for conservation conflicts coincide with those having the highest density of wind turbines. This indicates that, although there is no positive correlation with endangered species richness, there is still moderate spatial overlap between wind energy generation, protected areas, and endangered species (Fig. 4). Among the five cells with the highest conflict values, three are located in the state of Bahia, one in Paraná, and one in Rio Grande do Sul.

Discussion

Here, we identified sensitive areas for wind farm installation in Brazil, where protected areas and threatened species of birds, amphibians, and reptiles overlap. These findings underscore the importance of careful spatial planning for wind energy development in Brazil, a country recognized for its megadiversity. The observed spatial overlap between wind energy generation, protected areas, and endangered species reinforces the urgent need for more effective environmental licensing frameworks.

Our results revealed a moderate spatial overlap between wind turbines, protected areas, and endangered species. This overlap indicates a concentration of conservation conflicts in areas with the highest turbine densities. Although the distribution of installed and planned turbines spans Brazil's eastern region, Northeast shows the greatest potential for wind energy development (Azevedo et al., 2020). This region is dominated by the Caatinga – a seasonally dry forest – which contains approximately 80% of the 6313 installed turbines and another 14,696 planned turbines (Neri et al., 2019). Furthermore, in the near future, 50% of the Caatinga's priority conservation areas will host wind turbines, meaning that about 13% of the biome – roughly 11.6 million hectares – will be shared by biodiversity conservation efforts and wind energy interests (Neri et al., 2019).

Our conservation conflict index revealed no significant relationship between turbine density and the richness of endangered species, though we did detect a moderate negative correlation for birds. Impacts of wind farms on birds are well documented, particularly due to collision-related mortality, which is especially concerning for migratory species using coastal flyways (Newton, 2007; Northrup and Wittemyer, 2013). Power transmission lines further increase mortality risks through electrocution,

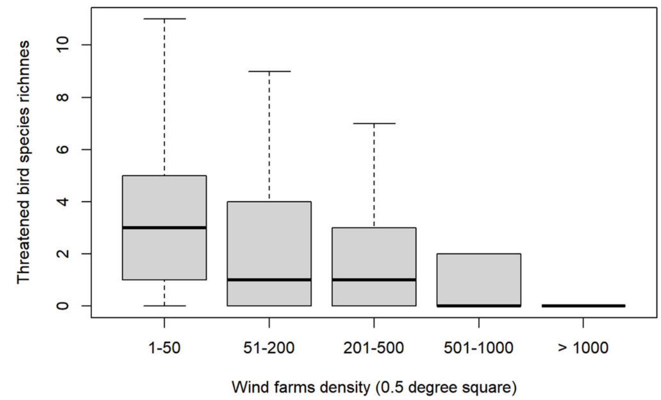

Fig. 2. Frequency distribution of the conservation conflict index values observed in each 0.5-degree grid cell.

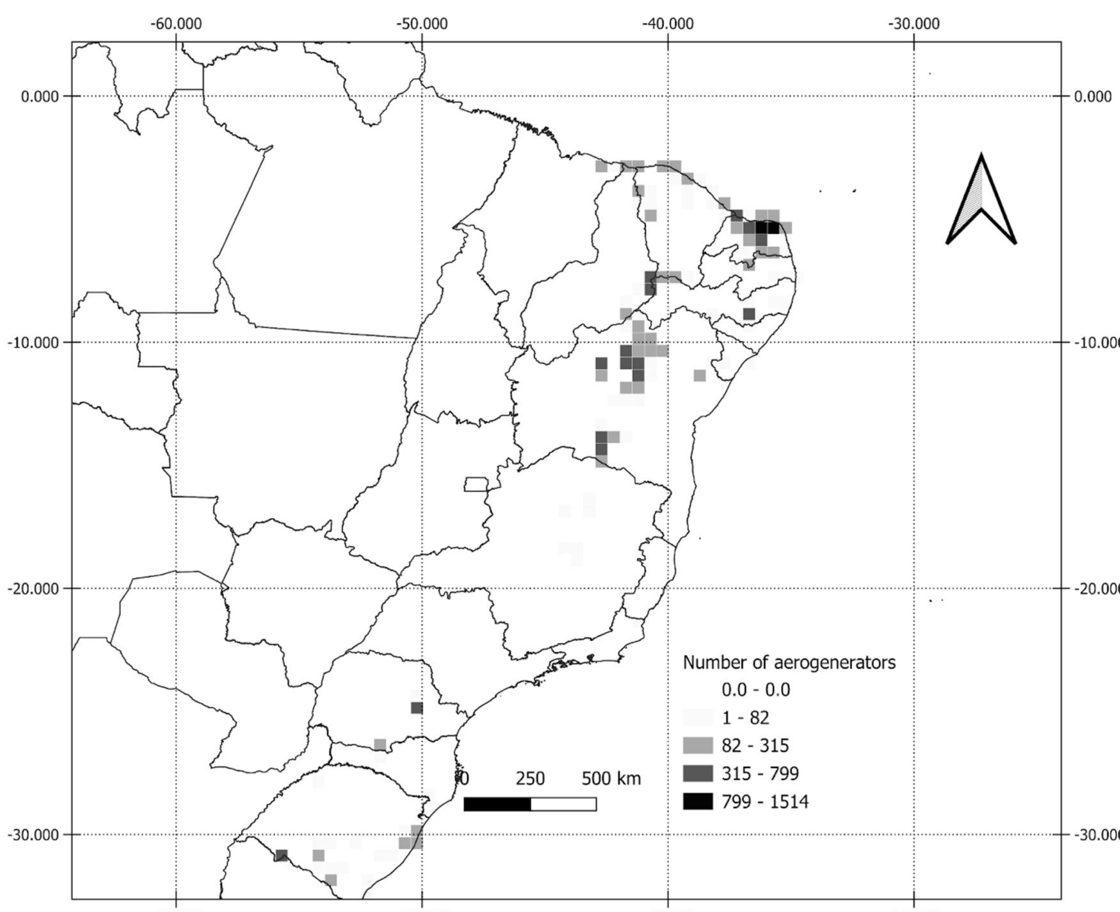

Fig. 1. Distribution of wind turbines density installed and planned in Brazil in 2019.

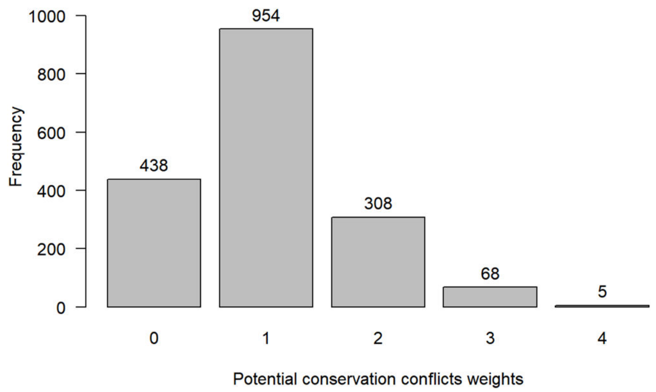

Fig. 3. Frequency graph of the sum of values related to the conservation conflict index observed in each cell with 0.5-degree.

especially for large gliding species (Bevanger, 1998). For example, dozens of electrocution incidents involving Lear's macaw (*Anodorhynchus leari*), a large endemic parrot of the Brazilian Caatinga, have been reported, suggesting electrocution as a significant threat to its conservation (Biasotto et al., 2023). Even though direct mortality rates may appear low, these impacts can still dramatically increase extinction risks for long-lived species with small population sizes (Carrete et al., 2009; Biasotto et al., 2023).

By contrast, the effects of wind farms on amphibians and reptiles remain poorly understood, particularly in the Neotropics – a region known for high biodiversity and rapid wind energy expansion (Oliveira et al., 2023). While habitat loss is the most frequently cited impact (Lovich and Ennen, 2017), studies also report declines in species richness (Santos et al., 2010), and both behavioral (Oliveira et al., 2025a) and physiological disturbances in amphibians (Park and Do, 2022). Reptile mortality due to roadkill along access routes to wind farms has also been reported, altering local population structures and abundances (Lovich and Ennen, 2013; Keehn et al., 2019). Despite this, only two northeastern states – Maranhão and Rio Grande do Norte – currently require detailed data collection for these groups during wind farm licensing (Oliveira et al., 2025b). However, the lack of biological, ecological, and behavioral information severely hampers our ability to understand and mitigate the impacts of wind energy development on these taxa (Lovich and Ennen, 2013; Oliveira et al., 2025a).

Wind farms have expanded rapidly across Brazil, often with limited oversight from federal and state agencies. Given the flexibility of environmental licensing guidelines, they have been criticized for their inability to accurately assess the true impacts of wind energy on wildlife and ecosystems (Bernard et al., 2014; Valença and Bernard, 2015). This underscores the need to revise and strengthen licensing regulations — a call that has gained traction both in Brazil (Valença and Bernard, 2015; Oliveira et al., 2025b) and internationally (Camina, 2012; Voigt et al., 2012). Amphibians, birds, and reptiles are already facing compounding pressures from invasive species, climate change (Gasparatos et al., 2017), and emerging diseases (Santos et al., 2024). Consequently, licensing frameworks must adopt a more robust and integrated approach to ensure the protection of these vulnerable groups.

Moreover, infrastructure associated with wind farms – such as roads and transmission lines – can have significant ecological consequences. Therefore, beyond considering turbine presence, it is essential to account for their density and proximity to sensitive habitats. A relevant example is the Boqueirão da Onça National Park, a strictly protected

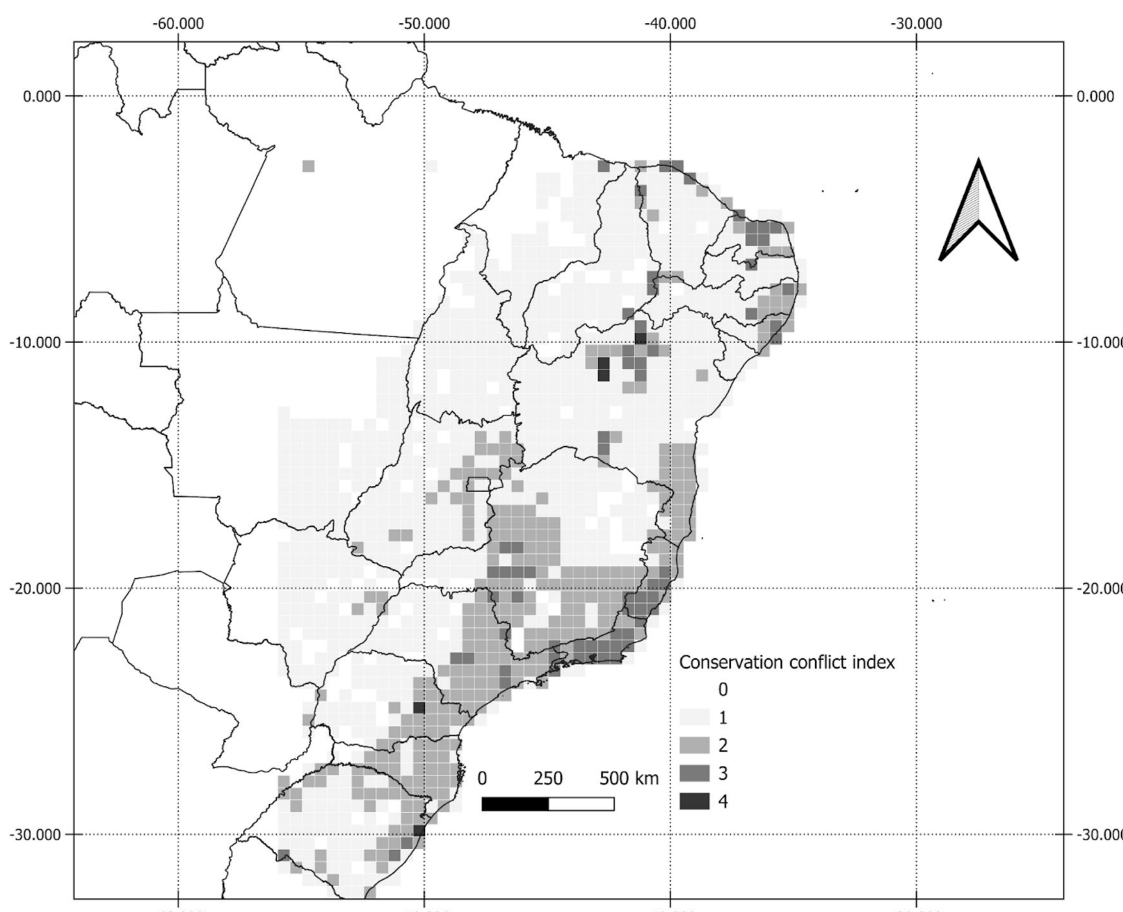

Fig. 4. Regions with the highest potential for conflict, considering wind turbines density, endangered species, and protected areas in Brazil.

area surrounded by multiple wind farms, which has been directly impacted by habitat fragmentation and infrastructure, threatening one of the last remaining jaguar populations in the Caatinga (Dias et al., 2019). To address such challenges, larger buffer zones should be established around sensitive areas, and these zones must be formally incorporated into the delineation of direct and indirect areas of influence in licensing processes. Additionally, licensing guidelines should mandate comprehensive monitoring programs before and after installation, tracking how wildlife responds to environmental changes (Falavigna et al., 2020; Oliveira et al., 2025b). These efforts are crucial for identifying and mitigating unforeseen post-construction impacts, ultimately enhancing the protection of local fauna (Brazil, 2014). Addressing these issues is essential for minimizing impacts on threatened amphibians, birds, and reptiles, which are experiencing alarming global declines (IUCN, 2025). Integrating these considerations ensures that wind energy is not only cleaner in terms of emissions but also genuinely sustainable for biodiversity conservation (Gasparatos et al., 2017; Araújo et al., 2020).

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Declaration of Generative AI and AI-assisted technologies in the writing process

Statement: During the preparation of this work the authors used ChatGPT in order to GRAMMATICAL REVIEW. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no financial or non-financial conflicts of interest.

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