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Essays and Perspectives

Harmonizing nature and power: Mainstreaming biodiversity into electric grid expansion

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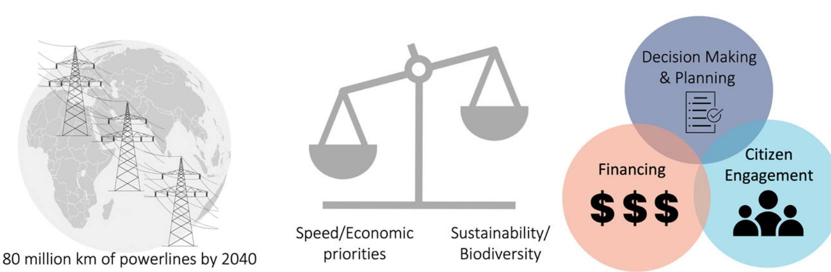
HIGHLIGHTS

- Balancing energy growth with biodiversity is key for sustainable development.
- Regulations are weakening biodiversity protections amid grid expansion.
- Biodiversity policies lack focus on grid impacts despite global commitments.
- Policy action is needed in planning, financing, and public engagement.

GRAPHICAL ABSTRACT



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ABSTRACT

The global transition toward renewable energy is demanding a massive expansion of electric grids worldwide. By 2040, more than 80 million km of powerlines will need installation or upgrading globally. Such grid expansion can heavily impact biodiversity if not planned properly. Integrating benefits for human well-being, climate change mitigation and biodiversity impacts is key to ensuring equitable and sustainable development. Current regulations prioritize rapid development over sustainability. Based on our review of biodiversity targets in NBSAPs prior to the Kunming-Montreal Global Biodiversity Framework, only 2% of parties explicitly addressed grid impact mitigation, suggesting that grid expansion has received limited attention in biodiversity planning. In order to foster mainstreaming of biodiversity into sustainable grid expansion, this paper suggests the following three lines of policy interventions focusing on different levels of action: decision making and planning, financing, and engagement of citizens with decision makers. This concerted approach aims to help harmonize energy infrastructure expansion with biodiversity conservation, fostering a more sustainable pathway for renewable-based energy systems.

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Introduction

The impacts of climate change have hastened the transition from fossil fuels to renewable energy sources such as solar photovoltaic or wind energy. This shift represents a pivotal step in mitigating the effects of climate change and aligning with the goals set forth in the Paris Climate Agreement. Such transition has been further propelled by reactions to geopolitical threats, such as the REPowerEU plan, aiming to reshape the energy transition agenda of the European Union (EU) in response to the Russian invasion of Ukraine. The imperative of a global transition toward renewable energy will drive a profound transformation in our energy systems, which requires a massive expansion of electric grids, including transmission and distribution infrastructure. The International Energy Agency (IEA, 2023) estimates that by 2040, more than 80 million kilometres of powerlines will need to be installed or upgraded worldwide, the equivalent to the entire existing global grid. Such expansion is already occurring at a fast pace, with initiatives as the EU 'Action Plan for Grids' (Commission, 2023), or the 'Building a Better Grid Initiative' from the former Biden Administration in the USA (US. Department of Energy, 2024). China is probably the foremost investor in grid infrastructure, with significant investments in ultra-high voltage power transmission projects, both domestically and internationally (IEA, 2023; Nedopil, 2024).

Despite the laudable benefits in accelerating energy transition, the extensive grid expansion is expected to present significant threats to biodiversity (McElwee et al., 2025). These impacts primarily include wildlife mortality due to collision and electrocution (mostly birds and bats, but also other species, such as primates), as well as habitat loss and fragmentation, which can lead to changes in ecosystem functioning and services (Biasotto and Kindel, 2018; D'Amico et al., 2018; Gauld et al., 2022; Hyde et al., 2018; Martín et al., 2022; Serratosa et al., 2024). For example, in western Rajasthan, India, hundreds of kilometres of powerlines from solar and wind farms threaten the Indian Bustard (*Ardeotis nigriceps*), primarily due to collisions, now a leading cause of their mortality (Uddin et al., 2021). Powerline expansion can further trigger adverse effects beyond direct mortality. The construction of new corridors and access roads for grid installation may lead to significant habitat loss, particularly in forest ecosystems (see *Case Study - Transmission grid and native forest cover in Brazil*), while also promoting the spread of non-native species and enabling illegal activities like logging and mining (Gibson et al., 2017). Even protected areas do not prevent the construction of renewable energy installations. For instance, *ca.* 3000 renewable energy facilities, either operational or in development, have encroached upon critical conservation areas, causing significant degradation to 886 Protected Areas, 749 Key Biodiversity Areas, and 40 distinct wilderness regions (Rehbein et al., 2020). All those installations inevitably entail grid connections cutting through those conservation areas, further exacerbating the environmental impact.

Case study - transmission grid and native forest cover in Brazil

In Brazil, the grid network grew by around 1200 km annually between 1985 and 2005 (WebMap EPE, 2025). Since 2005, this rate has surged to over 6500 km per year, with an additional 48,000 km planned. This rapid expansion has coincided with a marked decline in native forest cover in the surroundings of grid corridors, especially in the Amazon (Fig. 1). Brazil's heavy reliance on hydropower, which supplies 65% of the national energy capacity, necessitates long transmission lines to connect northern dam sites with the southern energy consumption centres (Hyde et al., 2018). The Madeira system is a prime example, standing as one of the longest transmission lines in the world with a 2385 km corridor, supported by nearly 5000 pylons and carrying 19,000 cables (see URL: iemadeira.com.br). This system, along with others, is set for further expansion across the country, particularly through the Amazon region (Fig. 1). As a result, both existing and new lines are expected to accelerate deforestation in the region. In fact, the spread of powerlines in this region has facilitated land occupation, as the construction of roads for their installation accelerates settlement and

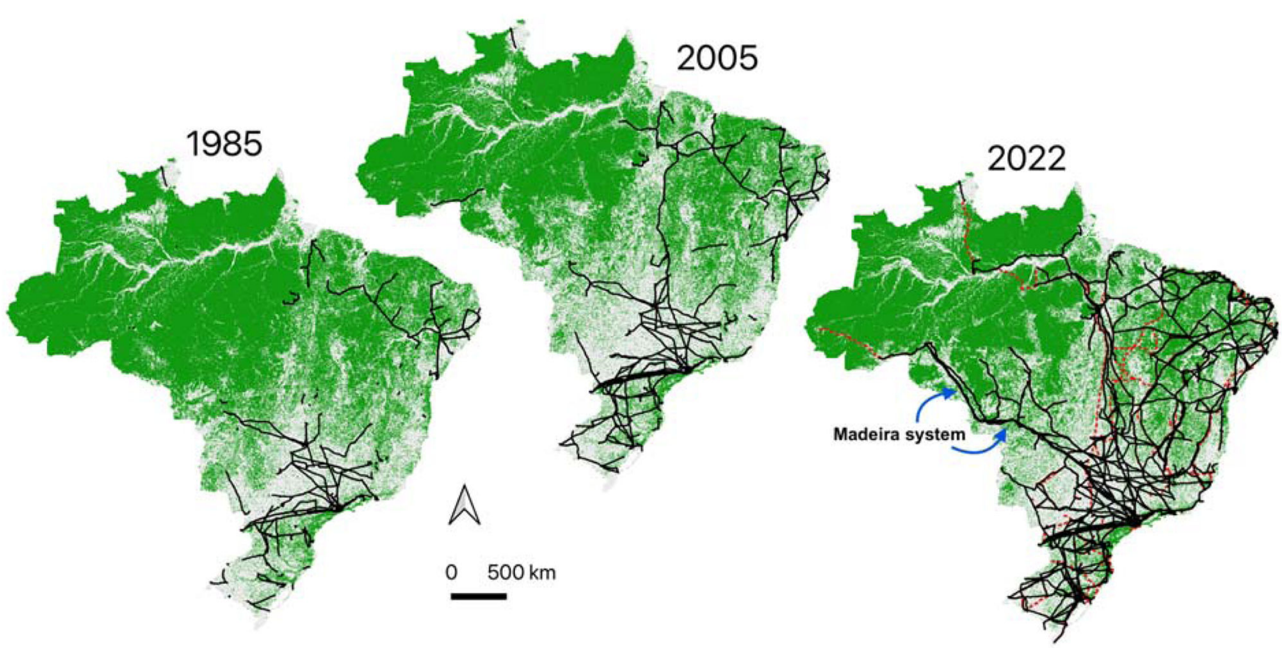

Fig. 1. Evolution of the distribution of transmission grid and native forest cover in Brazil. The expansion of transmission infrastructure across the Amazon represents a critical biodiversity threat with cascading ecological consequences. The temporal analysis reveals that there is an association (whether direct or indirect) between forest loss in and the proximity to grid corridors, with deforestation rates increasing markedly after 2005 when grid expansion intensified from 1200 to 6500 km annually. This pattern could give rise to the necessity to investigate how energy infrastructure expansion is associated with environmental degradation, enabling access to previously remote areas. Forest cover (green areas) and existing grid information (black lines) was retrieved from MapBiomas (Souza et al., 2020). The 'Madeira system', the longest transmission line corridor in the world (2385 km) is highlighted. Planned grid information (red lines) was obtained from 'Sistema de Informações Geográficas do Setor Energético Brasileiro' (WebMap EPE, 2025).

intensification, amplifying deforestation rates (Hyde et al., 2018).

Under pressure

There is a demand for tailored policies to facilitate the accelerated expansion of the grid. (Commission, 2023; IEA, 2023). However, this may exacerbate the pressure on governments and regulators to expedite procedures to approve new power line routes, weakening the regulation process. This raises concerns about the effective mainstreaming of biodiversity values into decision-making processes. In particular for EU, the recent climate and energy policies, namely the Directive 2022/0160/EU and European Council Regulation 2022/2577, have raised concerns about compromising biodiversity protective legislation (Durá-Alemañ et al., 2023; Serrano et al., 2020). Those policies, part of the REPowerEU plan to boost renewable energy infrastructure, aim to streamline permit-granting processes and expedite renewable energy deployment. However, they also propose shorter deadlines, simplified environmental impact assessments, and reduced environmental controls, potentially undermining biodiversity conservation efforts. The establishment of a framework that presumes renewable energy projects as overriding public interest without thorough environmental assessments could pose risks to ecosystems and public health. Furthermore, these regulations are directly binding across EU Member States, bypassing the need for individual transpositions into national legislation. This EU scenario is likely to be replicated elsewhere, and such signs reinforce the need for mainstreaming biodiversity into power grid expansion (e.g., OECD, 2024).

Biodiversity policies overlook grid impacts

We questioned the extent to which global frameworks for biodiversity conservation reflect concerns about power grid expansion, as a proxy of the likelihood to mainstream biodiversity in power grid expansion policies. Many countries have pledged their commitment to sustainability through multilateral environmental agreements such as the United Nations Framework to Combat Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). Ideally, the translation of those commitments into sets of goals and targets, e.g. the Sustainable Development Goals or the Kunming-Montreal Global Biodiversity Framework, should weave sustainable development, biodiversity conservation and human wellbeing, while multi-sectoral engagement would support implementation more effectively, and with higher accountability (Perino et al., 2022; Reyers and Selig, 2020). But, to what extent have parties of the Convention on Biological Diversity (CBD) incorporated concerns related to power grid expansion in their National Biodiversity Strategic Action Plans (NBSAPs)?

To address this question, we first identified the Parties of the CBD that mention the energy sector in their national targets (see Supplementary material S1). Our assessment is based on the list of national targets defined prior to the adoption of the Kunming-Montreal GBF (COP15), as this represented the most comprehensive global dataset available at the time, given that most countries had not yet defined post-COP15 sets of targets. We then reviewed the pre-COP15 National Biodiversity Strategic Action Plans (NBSAPs) for those countries, with the exception of Kuwait since the document was only available in Arabic. When several languages were available for a given country, we always chose the language of the longer version (see information in Table S1.1). We extracted the information of the NBSAP by searching the same keywords that were used to identify the national targets and looked whether the strategy mentions specifically (1) energy related issues; (2) the distribution of energy and/or the power grid; (3) its impact; (4) the avoidance of the impact; (5) the mitigation of the impact. We proceeded to extract the data in a nested way, that is if the answer to one of the questions was "Yes" we proceeded to the next, if "No" we considered that all other questions would also have a negative answer and moved on to the next country and its biodiversity strategy. We further searched in each of the 30 national strategies if a ministry or stakeholder related to the energy sector was listed as a contributor to the document.

According to our review (see Fig. 2, and Tables S1.1 and S1.2 in Supplementary Material S1), only 31 CBD Parties (out of 193) had designed a national biodiversity target that specifically mentions energy or related topics (Table S1.1). About half of those ($n = 14$) explicitly refer to the energy grid or the distribution of energy in their national biodiversity strategies (Table S1.2). Also, 14 reviewed documents had a ministry or stakeholder related to energy involved in their production, although this does not lead to stronger considerations for energy-related issues, since half of those countries did not mention the energy grid and its impact in their strategies. Of the countries identified, Austria, Greece, Italy, and Portugal are the handful of cases that explicitly address the avoidance and/or mitigation of the impacts of the energy grid on biodiversity. Most of the other strategies refer to biodiversity mainstreaming into the energy sector, as well as the development of alternative and renewable energy.

In essence, the global significance of power grid impacts on biodiversity remains underemphasized in biodiversity-related policy documents, failing to match the growing momentum behind expanding grid infrastructures.

Lines ahead

The balance of the benefits of grid expansion for human well-being and climate mitigation with its potential biodiversity impacts is essential. Policies and decisions should aim to minimize the environmental footprint of this infrastructure. We advocate for national and international policies to consider biodiversity at every stage of grid development, proposing three key interventions to mainstream biodiversity into sustainable grid expansion efforts.

Improve regulations and commitment

Regulatory frameworks should mandate the incorporation of biodiversity information into the initial phases of grid development projects (OECD, 2024). This must be a fundamental component of upstream planning, design, and construction processes. Emphasizing the importance of assessing biodiversity impacts right from the start ensures that considerations for environmental values are integral to decision-making. The consideration of biodiversity in early stages of planning reduces the potential conflicts in latter stages of the project that could be important for project delays, common in the energy sector (IEA, 2023). This process begins with choosing areas that avoid potential impacts, selecting corridors distant from areas important for biodiversity, within the scope of Strategic Environmental Assessments, which must integrate the costs of biodiversity loss. This will help to identify and address potential risks to biodiversity early on, enabling informed decision-making that balances the need for electricity infrastructure with the protection of ecosystems. Fostering collaboration between energy planners, and researchers in biodiversity conservation and conservation practitioners (e.g., natural park managers), will enable the identification of environmentally sensitive areas for more effective route planning.

Financing sustainable grid expansion

Leveraging funders' support is critical in trying to mainstream biodiversity considerations in grid development. Different national and international financial institutions are involved in financing grid expansion. Institutions should be required to link project funding to environmental sustainability compliance. The World Bank's Environmental and Social Framework (ESF), for instance, aims to reduce negative impacts from funded projects, including energy infrastructure, by focusing on flexible, outcome-based policies. While this approach allows for project-specific agreements, aligning with borrower

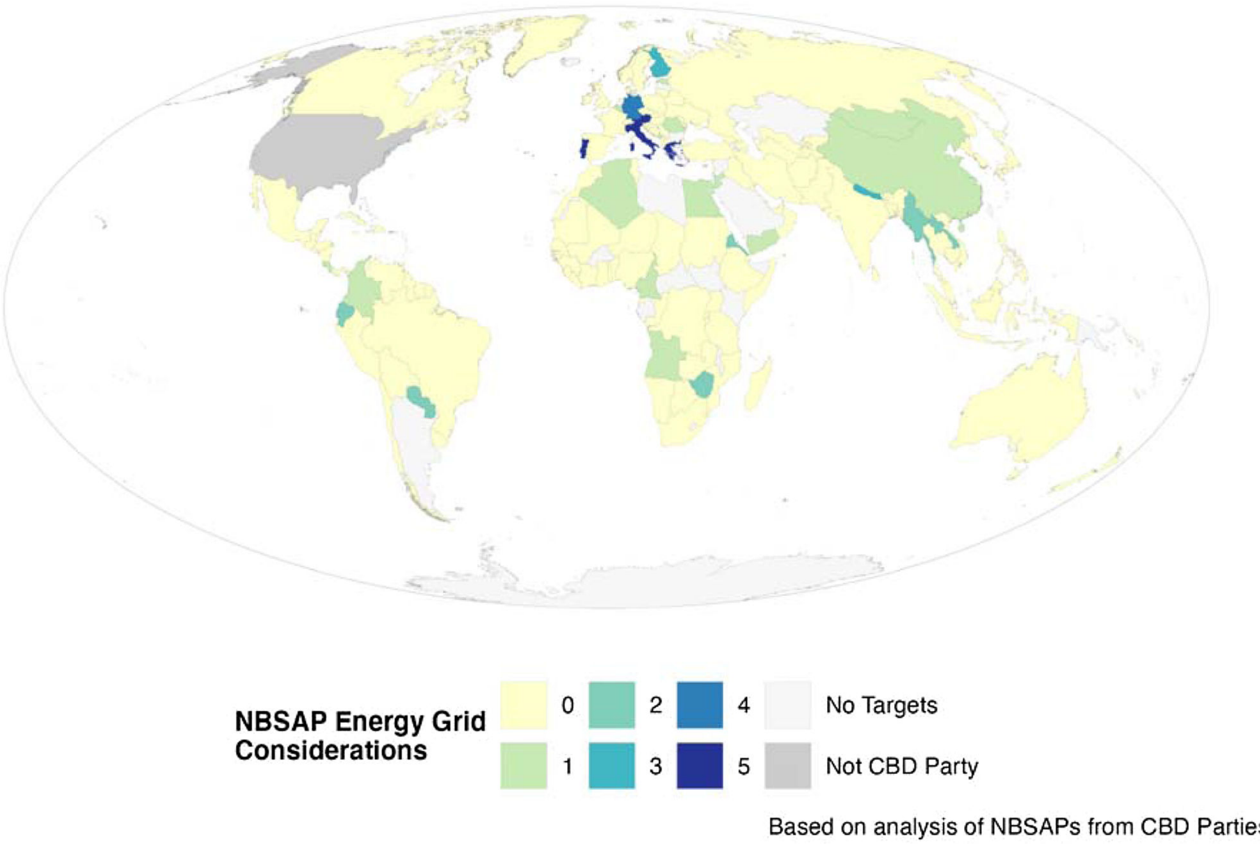

Fig. 2. Global assessment of energy grid considerations in pre-COP15 National Biodiversity Strategies and Action Plans (NBSAPs). The map shows the extent to which parties of the Convention on Biological Diversity (CBD) have incorporated energy grid-related issues into their national biodiversity strategies. Scores range from 1 (energy sector mentioned but no grid-specific considerations) to 5 (explicit avoidance and mitigation measures for grid impacts). A score of 0 represents a country where there is a list of targets available, but energy is not mentioned. Gray shading indicates countries that are not CBD parties or for which no list of national targets was available. The map reveals that 162 out of 193 CBD parties (84%) have not yet mentioned energy-related targets in their NBSAPs, highlighting a critical gap in mainstreaming biodiversity considerations into grid expansion policies. See Supplementary Material S1 for detailed methodology and country-by-country analysis.

countries' needs, it faces criticism over its vague requirements, use of biodiversity offsets, and reliance on borrower frameworks (Morley et al., 2021). Effective ESF implementation depends on adhering to the mitigation hierarchy and ensuring no net loss of biodiversity, which may not always be guaranteed under current guidelines. Concerns arise when flexibility benefits borrowers at the cost of biodiversity, as seen in China's Belt and Road grid projects, which often lack biodiversity safeguards (Narain et al., 2020). This highlights the need for clearer guidelines in the ESF to prevent projects with adverse environmental impacts. The World Bank should lead by example, setting stricter standards to ensure that biodiversity is a core consideration in all grid expansion initiatives. Establishing robust guidelines would help promote sustainable, responsible energy development while protecting ecosystems.

To ensure effective enforcement of biodiversity safeguards in financing mechanisms, a comprehensive and complementary set of measures should be implemented across projects and programs rather than in isolation. While many of these mechanisms have been applied in individual projects or incorporated into broader frameworks such as ESG rankings, the explicit integration of biodiversity remains limited or deficient in these frameworks (Zhu and Carrasco, 2025). Overcoming this gap requires developing, validating, and making available sector-specific biodiversity risk metrics and indicators

Pre-approval requirements could include mandatory biodiversity impact assessments using standardized metrics, third-party verification of mitigation hierarchy compliance, and baseline surveys. Conditional funding structures could incorporate staged disbursement tied to environmental performance milestones, escrow accounts for mitigation implementation, and financial penalties for non-compliance. Monitoring and accountability mechanisms could include independent audits, public disclosure of environmental performance data, and grievance mechanisms for affected communities and conservation organizations. In resource-limited settings, adaptations can maintain safeguards while acknowledging practical constraints. For example, capacity-building programs could be funded through project budgets to develop local institutional expertise. Technical assistance from international conservation organizations could supplement local capacity.

On the other hand, simplified assessment protocols for small-scale projects could use rapid biodiversity assessment methods focusing on indicator species or critical habitats. These complementary measures, when implemented systematically rather than selectively, can ensure biodiversity becomes central to financing decisions while providing practical implementation pathways across diverse economic contexts. However, their effectiveness depends on developing robust, sector-specific biodiversity metrics that move beyond current frameworks' limitations.

Increase awareness and education

Educational campaigns highlighting the impact of electric grids on biodiversity, along with the associated monetary costs of these negative impacts, are crucial. Such campaigns can foster public and institutional commitment to preserving both biodiversity and transitioning to carbon-free energy solutions. Key principles like 'Mitigation Hierarchy', and targets such as 'No Net Loss/Net Gain' need to be well understood not just by the general audience but also within the energy sector, investors, and environmental agencies. At least in principle, No Net Loss/Net Gain policies could have an important role to play in keeping humanity within a safe operating space (Steffen et al., 2015). However, this depends on many elements of policy design and implementation, starting with clearly defined and appropriate reference scenarios (Maron et al., 2018).

While regulatory frameworks play a significant role in mandating compliance, the adoption and commitment from companies are vital (White et al., 2023). Ultimately, decisions concerning biodiversity conservation within energy infrastructure are made by these entities, underscoring the importance of their understanding and integration of these principles into their practices. Importantly, learning and engagement with biodiversity commitments is strongly dependent on experience (Christofi et al., 2025), demonstrating the interdependence of the three lines of action proposed here – awareness and education cannot be divorced from practical implementation and financing mechanisms, as each reinforces the others. Aligning the objectives of energy planners, environmental agencies, and investors with public sentiment is hence indispensable.

Concluding remarks

The global expansion of electricity grids to meet rising energy demands and support renewable energy transition poses both challenges and opportunities for biodiversity conservation. Without careful planning, rapid network growth threatens biodiversity, ecosystem services, and human well-being. Integrating biodiversity considerations into every phase of grid development is crucial but often overlooked in international policies. Numerous frameworks and tools are already available to support this integration, making sustainable grid expansion feasible and essential. Balancing energy needs with biodiversity protection is key to achieving energy security. By adopting sustainable practices, leveraging innovative technologies, and fostering global cooperation, we can chart a path toward a greener, more resilient energy future while preserving the planet's rich biodiversity for generations to come.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.pecon.2025.11.003.

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