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Editorial

Sustainability – a concept that became a societal value

Marcel Bursztyn, Carlos Hiroo Saito, Frédéric Mertens e Patrícia Mesquita

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In science, concepts qualify situations or phenomena that catalyse attention and/or constitute objects of study. Concepts are words, like any others in our everyday lives. However, they translate generally complex content whose understanding requires many words. Concepts are, therefore, syntheses of ideas.

The same term is often used in different scientific contexts, expressing different contents. For instance, economists use the idea of *development* to refer to processes associated with improving a society's *well-being* and quality of life. Urban planners use the same word with another meaning: *development* as a way of organising and valuing a specific territorial space. This same word can have a more general meaning in medicine: developing resistance to a certain medication. In biology, *development* is a process of differentiation, growth and formation of living beings. What for one scientific field is a concept may be just a word for another.

In practice, concepts are words that summarise content that requires many words to describe. In her work, *Economic Philosophy*, Joan Robinson states that not everything understood by a word's meaning represents a concept. She argues that we cannot, for example, define what an elephant is but only describe it. An elephant has four legs, two ears and a trunk, but so does the tapir. Elephant is, therefore, not a concept.

Using concepts simplifies communication between scientists from the same area of knowledge. When a physicist refers to *quantum*, his peers know what he means. Nevertheless, when the same scientist seeks to present his ideas to uninitiated people, he must use many words to refer to the same term.

Some concepts popped up with the claim of universality as something that could (or should) be understood and assimilated by everyone, regardless of each person's speciality. Perhaps, because of this broad scope, these are sometimes fluid concepts, which sometimes require additional qualifications to be correctly understood. Well-being is one of these concepts. We are generally forced to point out what type of well-being we refer to, such as material, physical, social, spiritual, etc.

Universal and widely understood concepts tend to constitute values, which are beliefs and convictions defining what is important and is a priority for people and societies. Therefore, values also guide principles that determine individual and collective behaviour rules. Some examples are honesty, freedom, and respect for others. As derived from universal concepts, these values also inherit their fluidity and universality. Freedom, previously mentioned, was brilliantly portrayed by Cecília Meireles in her *Romanceiro da Inconfidência*: "Freedom, that word that the human dream feeds, that there is no one who explains and no one who does not understand...". However, specifying the term to not continue in a state of not explaining ourselves is increasingly fundamental for everyone to understand it in the same way so that, for example, this freedom is not used as an argument for carrying out coup acts or conveying denialist untruths. The same must apply to the term sustainability.

The concept of *sustainability* formally emerged at the end of the 1980s, when it was incorporated as the central axis of the *Our Common Future* report, prepared under the coordination of Gro Harlem

Brundtland. It is never too much to remember here the definition of *sustainability*, as stated in the Brundtland Report:

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

The document would serve as a reference for the debates that would take place at the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992. As a new idea which evoked the importance of the ecological dimension in consideration of economic development, the concept of *sustainability* launched in 1987 also brought a new and additional element: the consideration of future generations as an integral part of human decisions. This would mean notable changes in attitudes and even the need to review values until then considered the social ethos of modernity, such as freedom. After all, how far can some people's freedom go in the present, given the risks of compromising the right to exist (the imperative of the *continuity of life*) of someone who has not yet been born?

In a way, the formulation of what *sustainability* is should rescue the *imperative of responsibility*, launched by Hans Jonas in 1979, and which established the commandment "that there should be humanity" among the rights and duties to be considered in the social contract (Bartholo Jr.; Bursztyn, 2001). In this sense, even though it was launched as a concept, sustainability was already born as a principle proposal since it postulated changes in human behaviour, indicating how people should behave. It is worth saying that the concept was not quickly and deeply understood and assimilated.

For years, the difference between sustained growth and sustainable development pitted economists against environmentalists. The time scale of business management (an area of interest to economists) and political decisions (of interest to public managers) is very different from that of nature (of interest to geologists and biologists). Geological eras are measured in millions of years, while the economy's time is measured in years, and that of politicians is measured in legislatures of 4 or 5 years. It was necessary for phenomena such as the scarcity of raw materials, degradation of the seas, water pollution, climate change, and the energy crisis, among others, to emerge for an understanding that different time scales have a high degree of synergy. The economy affects nature, and nature affects the economy!

In this context, we can infer that sustainability is no longer simply a concept of interest to those interested in nature; it has become a value that concerns our society. As a human value, sustainability must guide the principles of attitudes and behaviours of all people, interest groups and categories of social actors everywhere on the planet.

It is from a societal value that SiD presents itself as an interdisciplinary academic space.

In this edition 14, number 3, SiD publishes ten articles, seven of which are from the Dossier "A Just Energy Transitions" and three more in the *Varia* section.

Firstly, Paulino *et al.* discuss the advances in wind energy in the Brazilian Northeast with a focus on the socio-environmental conflicts that affect the population living around the plants, followed by Araújo and Gorayeb, who address the problem of social acceptance of wind generator technology and the perception of members of a community on aspects that concern procedural and distributive injustices. González *et al.* present a comparative discussion on the consequences of different institutional arrangements for the advancement of "energy communities", and Baigorrotegui *et al.* address problems related to the maintenance of the energy network in Puerto Edén, the extreme south of Chilean Patagonia.

Finally, as the last articles in the "Just Energy Transitions" Dossier, Costa *et al.* discuss the relevance of transmission lines for promoting access to renewable energy sources within the scope of SDG 7. Araújo *et al.* seek to demonstrate the applicability of spatial modelling in the local planning of transmission

projects, and Wolffenbüttel talks about how individuals mobilise "functional and symbolic" values as criteria for the acquisition of electric cars.

In our *Varia* section, Zulkifli *et al.* present a financial viability study of a state-owned sugarcane company in Indonesia by employing a financial viability analysis approach. Canãr and Loor address the social and environmental repercussions on Amazonian communities from gold mining after the end of official concessions, emphasising the need to incorporate sustainability principles into concessions to prevent such effects. In the last article of this edition, Amaral *et al.* present a comparative study on air quality legislation, comparing the technical standards in force on air quality in Brazil to international standards.

We wish you all a good read and a new year of health and peace.

REFERENCES

BARTHOLO Jr.; R.; BURSZTYN, M. Prudência e Utopismo: ciência e educação para a sustentabilidade. *In*: BURSZTYN, M. (Ed.) **Ciência, Ética e Sustentabilidade**, Ed. Cortez/Unesco, São Paulo, 2001.

BRUNDTLAND, G. H. **Our Common Future**. World Commission on Environment and Development – UN, Oxford University Press, Oxford – UK, 1987.

JONAS, H. Zur ontologischen Grundlegung einer Zukunftsethik. *In*: **Philosophischen Untersuchungen und metaphysische Vermutungen**. Insel, Frankfurt am Main & Leipzig, 1992.

MEIRELES, C. **Romanceiro da Inconfidência**. Rio de Janeiro, Nova Fronteira, 1989.

ROBINSON, J. **Economic Philosophy**. Pelican Books, Middlesex – UK, 1962

Editorial

Sustentabilidade – um conceito que se tornou um valor societal

Marcel Bursztyn, Carlos Hiroo Saito, Frédéric Mertens e Patrícia Mesquita

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No âmbito das ciências, *conceitos* servem para qualificar situações ou fenômenos que catalisam atenções e/ou constituem objetos de estudo. Conceitos são palavras, como quaisquer vocábulos do nosso dia a dia. Mas são palavras que traduzem conteúdos geralmente complexos, cujo entendimento demanda, em suas definições, muitas palavras. Conceitos são, portanto, sínteses de ideias.

Muitas vezes um mesmo termo é usado em diferentes contextos científicos, expressando conteúdos diversos. Por exemplo, os economistas se valem da ideia de *desenvolvimento* para se referir a processos associados à melhoria do bem-estar e da qualidade de vida de uma sociedade. Os urbanistas usam a mesma palavra com outro significado: *desenvolvimento* como o modo de organizar e valorizar um determinado espaço territorial. Na medicina, a mesma palavra pode ter um significado bem mais geral: desenvolver resistência a um determinado medicamento. Em biologia, *desenvolvimento* é um processo de diferenciação, crescimento e formação dos seres vivos. O que para um campo científico é um conceito, para outro pode ser apenas uma palavra.

Na prática, conceitos são palavras que resumem conteúdos que demandam muitas palavras para serem descritos. Em sua obra *Economic Philosophy*, Joan Robinson afirma que nem tudo o que é entendido pelo sentido de uma palavra representa um conceito. Ela argumenta que não podemos, por exemplo, definir o que é um elefante, mas apenas descrever. Um elefante tem quatro patas, duas orelhas e uma tromba, mas o tapir também tem. Elefante não é, portanto, um conceito.

O uso de conceitos facilita a comunicação entre cientistas de uma mesma área do conhecimento. Quando um físico se refere ao termo *quântico*, seus pares sabem a que está se referindo. Mas quando o mesmo cientista busca apresentar suas ideias a pessoas não iniciadas na sua disciplina, terá de usar muitas palavras para se referir ao mesmo termo.

Alguns conceitos já nasceram com a pretensão de universalidade, como algo que pudesse (ou devesse) ser entendido e assimilado por todos, independentemente da especialidade de cada um. Talvez, por conta dessa abrangência, sejam conceitos por vezes fluidos, que às vezes demandam qualificações adicionais para serem devidamente entendidos. *Bem-estar* é um desses conceitos. Mas somos forçados, geralmente, a apontar a que tipo de bem-estar nos referimos: material, físico, social ou espiritual.

Conceitos universais e de amplo entendimento tendem a constituir *valores*, que são crenças e convicções que definem o que é importante e prioritário para as pessoas e a sociedade. Portanto, valores orientam também princípios que determinam regras de comportamento individual e coletivo. São exemplos a honestidade, a liberdade e o respeito ao próximo. Esses valores, ao se derivarem de conceitos universais, herdam também destes a sua fluidez e universalidade.

A liberdade, anteriormente exemplificada, foi brilhantemente retratada por Cecília Meireles, em seu *Romanceiro da Inconfidência*: "Liberdade, essa palavra que o sonho humano alimenta, que não há ninguém que explique e ninguém que não entenda…". Mas precisar o termo para não continuarmos no estado de não se explicar é cada vez mais fundamental para que as pessoas entendam, da mesma

maneira, para que, por exemplo, essa liberdade seja utilizada como argumento para a realização de atos golpistas ou veicular inverdades negacionistas. O mesmo deve valer para o termo *sustentabilidade*.

O conceito de *sustentabilidade* surgiu, formalmente, ao final dos anos 1980, quando foi incorporado como eixo central do relatório *Nosso Futuro Comum*, elaborado sob a coordenação de Gro Harlem Brundtland. Nunca é demais relembrar, aqui, a definição de *sustentabilidade*, conforme consta no Relatório Brundtland:

> "desenvolvimento que responde às necessidades do presente sem comprometer a capacidade de resposta das gerações futuras às suas próprias necessidades".

O documento serviria de referência para os debates que ocorreriam na conferência das Nações Unidas sobre Meio Ambiente e Desenvolvimento, realizada no Rio de Janeiro, em 1992. Como uma ideia nova, que evocava a importância da dimensão ecológica no contexto do desenvolvimento econômico, o conceito de *sustentabilidade* lançado em 1987 trouxe também um elemento novo e adicional: a consideração das futuras gerações como parte integrante, a ser acatada nas decisões humanas. Isso significaria mudanças notáveis em atitudes, e mesmo a necessidade de revisão de valores até então considerados como *ethos* sociais da modernidade, como é o caso da liberdade. Afinal, até aonde pode ir a liberdade de uns, no presente, diante dos riscos de comprometer o direito de existir (o imperativo da *perenidade da vida*) de alguém que ainda não nasceu?

De certa forma, a formulação do que deveria ser a *sustentabilidade* resgata o *princípio da responsabilidade*, lançado por Hans Jonas em 1979, e que estabelecia o mandamento "que exista a humanidade", entre os direitos e deveres a serem considerados no contrato social (Bartholo Jr; Bursztyn, 2001). Nesse sentido, ainda que tenha sido lançado como um conceito, a sustentabilidade já nasceu como uma proposta de princípio, já que postulava mudanças nas condutas dos humanos, indicando como deveriam se comportar. Vale dizer que o conceito não foi rápida e profundamente entendido e assimilado.

Por muitos anos, a diferença entre crescimento sustentado e desenvolvimento sustentável opôs economistas e ambientalistas. A escala temporal da gestão dos negócios (área de interesse de economistas) e das decisões políticas (de interesse dos gestores públicos) é bem diferente daquela da natureza (de interesse dos geólogos e biólogos). Eras geológicas se medem em milhões de anos, enquanto o tempo da economia se mede em anos e o dos políticos se mede em legislaturas de 4 ou 5 anos. Foi preciso que ficassem evidentes fenômenos como a escassez de matérias-primas, a degradação dos mares, a poluição das águas, as mudanças climáticas, a crise energética, entre outros, para que houvesse um melhor entendimento de que as diferentes escalas temporais têm alto grau de sinergia. A economia afeta a natureza e a natureza afeta a economia!

É nesse contexto que podemos inferir, hoje, que *sustentabilidade* deixa de ser simplesmente um *conceito*, que interessa a quem se interessa pela natureza, para se tornar um *valor*, que diz respeito a toda a sociedade. Como valor humano, a sustentabilidade deve guiar atitudes e comportamentos de todos os povos, grupos de interesse e categorias de atores sociais, em todos os lugares do planeta.

E é como valor societal que a SiD se apresenta como um espaço acadêmico interdisciplinar.

Esta edição da revista SiD, volume 14, número 3, traz 10 artigos, sendo sete do Dossiê "Transições Energéticas Justas" e mais três artigos na seção *Varia*.

Primeiramente, Paulino *et al.* discutem os avanços da energia eólica no Nordeste com enfoque nos conflitos socioambientais que afetam a população residente no entorno das usinas, sendo seguido por Araújo e Gorayeb que abordam o problema da aceitação social da tecnologia de geradores eólicos e a percepção dos membros de uma comunidade sobre aspectos que dizem respeito às injustiças

procedimental e distributiva. Já González *et al.* apresentam uma discussão comparativa sobre as consequências de diferentes arranjos institucionais para o avanço das "comunidades energéticas", e Baigorrotegui *et al.* abordam os problemas relativos à manutenção da rede de energia em Puerto Edén, extremo sul da Patagônia chilena.

Por fim, como últimos artigos do Dossiê "Transições Energéticas Justas", Costa *et al.* discorrem sobre a relevância das linhas de transmissão para a promoção do acesso a fontes renováveis de energia no âmbito do ODS 7, Araújo *et al.* procuram demonstrar a aplicabilidade da modelagem espacial no planejamento locacional de projetos de transmissão, e Wolffenbüttel dialoga sobre como os indivíduos mobilizam valores "funcionais e simbólicos" enquanto critérios para a aquisição de automóveis elétricos.

Em nossa seção Varia, Zulkifli *et al.*, empregando uma abordagem de análise de viabilidade financeira, apresentam um estudo de viabilidade financeira de uma empresa estatal de cana-de-açúcar na Indonésia, enquanto Canãr e Loor abordam as repercussões sociais e ambientais em comunidades amazônicas devido à mineração de ouro após o término das concessões oficiais, enfatizando a necessidade de incorporação de princípios de sustentabilidade nas concessões para prevenir tais efeitos. Como último artigo do ano, Amaral *et al.* apresentam um estudo comparativo sobre as legislações de qualidade do ar, comparando as normas técnicas vigentes sobre qualidade do ar no Brasil em relação a normas internacionais.

Desejamos a todos(as) uma boa leitura e um ano novo repleto de saúde e paz.

REFERÊNCIAS

BARTHOLO Jr.; R.; BURSZTYN, M. Prudência e Utopismo: ciência e educação para a sustentabilidade. *In*: BURSZTYN, M. (Ed.) **Ciência, Ética e Sustentabilidade**, Ed. Cortez/Unesco, São Paulo, 2001.

BRUNDTLAND, G. H. **Our Common Future**. World Commission on Environment and Development – UN, Oxford University Press, Oxford – UK, 1987.

JONAS, H. Zur ontologischen Grundlegung einer Zukunftsethik. *In*: Philosophischen Untersuchungen und metaphysische Vermutungen. Insel, Frankfurt am Main & Leipzig, 1992.

MEIRELES, C. **Romanceiro da Inconfidência**. Rio de Janeiro, Nova Fronteira, 1989.

ROBINSON, J. **Economic Philosophy**. Pelican Books, Middlesex – UK, 1962.

Dossier: Just energy transition

Dossiê: Transições energéticas justas

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ARTICLE – DOSSIER

The concept of *just energy transition* has as many definitions as there are interpretations of "justice" seeking to legitimise it. Initially, it emerged as an application of "environmental justice" to criticise the impacts of energy infrastructure projects on socially disadvantaged groups based on class, ethnicity, and/or gender, depending on the specific project (Cha, 2017). Subsequently, different categories were identified to describe and evaluate these processes, such as "restorative," "distributive," and "procedural," among others. In the case of procedural justice, for example, it was important to determine to what extent energy planning would allow the participation of various stakeholders (local communities, scientists, and energy company workers), replacing top-down approaches with inclusive deliberation processes (Kirsten *et al.*, 2016).

The history of economic expropriation and human rights violations by large energy conglomerates has led an increasing number of researchers and activists to include the decentralisation and self-management of energy production and consumption among the criteria guiding the energy transition. In different contexts and with a focus on local specificities, academic research in "Energy & Society" has contributed to the discussion of new regulatory arrangements and instruments capable of fostering the creation and development of "energy communities."

It is important to avoid automatic associations between 'just energy transition' and the mere statistical increase in renewable energy sources. The Paris Agreement includes just transition as a guiding principle in addressing climate change. However, it does not translate into a fixed set of rules but into processes based on dialogue and a common agenda of workers, industries, and governments, formulating projects to be negotiated and implemented in their specific geographical, political, cultural, and social contexts.

Although climate justice is generally at the centre of discussions on energy justice, there are numerous instances where individuals and communities feel affected by renewable energy companies. Technological innovations still follow a market-driven model and are appropriated by companies engaging in a trillion-dollar business, concentrating wealth and decision-making processes not always distinctly from fossil fuel corporations. On the other hand, the idea that the diversification of energy sources alone characterises a sustainable transition is also controversial. In their analysis of Indian energy policy, Roy & Schaffartzik (2021) argue that, despite increased investments in renewable sources, the country is not moving towards a gradual phase-out of thermal power plants but rather towards a greater dependence on coal in its energy matrix.

In recent years, the concept of "just energy transitions" has taken on a new dimension, as academics and policymakers have used it as a tool for energy planning. Some countries have even established departments for energy transition and inter-sectoral programs to promote it. Despite these institutional advances, this notion should not conceal the contradictions of energy policies but instead be critically evaluated as a whole process, from fuel and electricity production to consumption, regarding their social aspects (Goldemberg & Moreira, 2005).

Indeed, energy consumption analyses highlight injustices, such as the disparities between Northern and Southern countries and differences in per capita energy consumption within each country. It is a double injustice because populations with relatively low energy consumption are among the most vulnerable to climate change. In this context, discussions on just transitions closely relate to research and public policies dedicated to overcoming 'energy poverty.' As part of the Sustainable Development Goals (SDG 7), the UN has urged to '*leave no one behind*' – an unequivocal commitment of all UN Member States to eradicate poverty in all its forms. Currently, 733 million people still lack access to electricity, and more than 2.4 billion depend on solid biomass for cooking (UNDP, 2013). Thus, there is an opportunity to align the promotion of a renewable energy-based sector with the fight against poverty.

Ignacy Sachs (2004) attributed the persistence of poverty to government failures and the disassociation of market forces from the poorest, which often make them socially invisible. Banerjee & Duflo (2011) and Amartya Sen (2008) share the understanding that poverty is not limited to income deficiency but also includes health problems, poor quality of education, and a life deprived of dreams and freedoms. Regarding Brazil, Pereira *et al.* (2011) pointed out that, despite the successful experience of the '*Light for All*' Program, the impacts of access to electricity on the beneficiaries' quality of life have not been sufficiently analysed. Understanding these gaps could improve the program so that beneficiaries gain the right to use electricity for development as they conceive it.

Delving into academic discussions and the broader public debate on *just energy transitions* requires clarity on what each interlocutor considers 'just' or 'unjust', as well as the explanation of the premises that underlie their respective notions of 'justice' (Uffelen *et al.*, 2024). There is not always consensus; sometimes, divergent proposals may derive from two or more valid premises. For example, when taken to the extreme, the sense of climate urgency may not coincide with the democratic decision-making principles of energy planning. In the first case, there is a dramatic and accelerated temporality, while in the second, time must be all that is needed to reach a decision oriented by the pursuit of possible consensus. Distinct and somewhat competing concerns might be articulated, but promoting just transitions requires a dialogue in which actors are clear about the energy justice they aspire to while being able to identify the premises of 'justice' that other parties mobilise to legitimise their values and interests.

Reaffirming its commitment to plurality and interdisciplinarity, *Sustainability in Debate* offers its readers a dossier on *just energy transitions* with qualified academic production of researchers from Brazilian and Latin American universities. This edition contains seven articles. The first one, 'Socioenvironmental conflicts and the implementation of wind farms in northeastern Brazil', discusses

wind energy advances in the Brazilian Northeast, focusing on the socioenvironmental conflicts affecting the population around the plants. Sonia Regina Paulino and her co-authors present a typology of local conflicts around four axes: economic, water-related, land-related, and health/well-being of affected populations. Next, the article 'Perception of socioenvironmental impacts caused by wind generators in the state of Piauí, Northeast Brazil' consists of a case study on wind energy in Serra dos Pereiros (PI), in which Rômulo Araújo and Adryane Gorayeb address the problem of social acceptance of the technology and the perception of members of communities surrounding the plant regarding procedural and distributive injustices.

In 'Institutional conditions for the development of energy communities in Chile and Brazil', Poque-González and co-authors present a comparative discussion on the consequences of different institutional arrangements for the advancement of 'energy communities.' The study suggests that the cooperative model benefits the development of grid-connected energy communities. In another contribution focusing on the Chilean reality, Gloria Baigorrotegui and researchers from the University of Santiago de Chile publish 'Energy Communities of Repair in Remote Infrastructures,' an ethnographic research based on the *Social Studies of Science and Technology* that addresses problems related to the maintenance of the energy network in Puerto Edén, the southernmost part of Patagonia.

Following this, the dossier presents two articles highlighting the complexity of transmission network planning. In 'Predictive Model of the Outage of Transmission Lines Exposed to Wildfires', Vaz da Costa and partners from the University of Brasília demonstrate the relevance of transmission lines for promoting access to renewable energy sources within SDG 7, weighing the risks associated with wildfires and their impacts on power supply outages, as well as the need for predictive models in planning. The sixth article, 'Geographic intelligence to integrate data, roles, and actors in sustainable planning of transmission powerlines,' presents the potential of so-called 'geographic intelligence' for modelling corridors during the study phase to identify alternative locations for energy transmission lines. Felipe Araújo and co-authors seek to demonstrate the applicability of spatial modelling to the local planning of transmission projects.

In this dossier's seventh and final article, Rodrigo Wolffenbüttel presents the results of his research on electric vehicles. In 'Limits of sustainability in electric cars, qualification of goods based on symbolic values,' he investigates how individuals mobilise 'functional and symbolic' values as criteria for acquiring electric cars. The author deserves credit as one of the few Brazilian researchers dedicated to electric mobility in the field of social sciences.

We hope you enjoy reading this issue!

REFERENCES

BANERJEE, A. V.; DUFLO, E. **Poor Economics:** a radical rethinking of the way to fight global poverty. New York: Public affairs., 2011.

CHA, M. **A Just Transition**. Fordham Environmental Law Review, v. 29, n. 2, p. 196-220, 2017. Disponível em: https://www.jstor.org/stable/26413303.

GOLDEMBERG, J.; MOREIRA, J. R. Política energética no Brasil. **Estudos Avançados**, v. 19, n. 55, 2005. DOI: https://doi.org/10.1590/S0103-40142005000300015

KIRSTEN, J. *et al.* Energy justice: a conceptual review. **Energy Research & Social Sciences**, 2016. DOI: https://doi.org/10.1016/j.erss.2015.10.004.

PEREIRA, M. G.; FREITAS, M. A. V.; SILVA, N. F.Rural electrification and energy poverty: empirical evidences from Brazil. **Renewable and Sustainable Energy Reviews**, v. 14, p. 1229–1240, 2010.

ROY, B.; SCHAFFARTZIK, A. Talk renewables, walk coal: the paradox of India's energy transition. **Ecological Economics**, v. 180, 2021. DOI: https://doi.org/10.1016/j.ecolecon.2020.106871.

SACHS, I. **Desenvolvimento includente**, sustentável e sustentado. Rio de Janeiro: Garamond, 2004.

SEN, A. K. **Desenvolvimento como liberdade**. São Paulo: Companhia das Letras, 2008.

SOVACOOL, B. *et al.* Pluralizing energy justice: incorporating feminist, anti-racist, indigenous, and postcolonial perspectives. **Energy Research & Social Science**, 2023. Avaliable in: https://www.sciencedirect.com/science/article/pii/S2214629623000567.

UFFELEN, N. V.; TAEBI, B.; PESCH, U. Revisiting the energy justice framework: doing justice to normative uncertainties. **Renewable and Sustainable Energy Reviews**, 2024. DOI: https://doi.org/10.1016/j.rser.2023.113974.

UNDP website. Available in: https://www.undp.org/energy/our-work-areas/energy-access. Access: 14 nov. 2013.

Dossiê: Transições energéticas justas

Dossier: Just energy transition

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ARTICLE – DOSSIER

O conceito de transição energética justa possui tantas definições quantas forem as interpretações de "justiça" que busquem legitimá-lo. Inicialmente, surgiu como uma aplicação da noção de "justiça ambiental" para criticar os impactos de projetos de infraestrutura energética sobre grupos socialmente desfavorecidos em relação à classe, etnia e/ou gênero, a depender do empreendimento em questão (Cha, 2017). A partir disso, foram identificadas diferentes categorias para descrever e avaliar esses processos, como justiça "restaurativa", "distributiva", "procedimental", entre outras. No caso da justiça procedimental, por exemplo, importava saber até que ponto o planejamento energético permitiria a participação das diversas partes interessadas (comunidades do entorno, cientistas e trabalhadores das empresas de energia), substituindo as abordagens verticalizadas por processos de deliberação inclusivos (Kirsten *et al.*, 2016).

O histórico de expropriação econômica e violações dos direitos humanos por parte dos grandes conglomerados de energia levou um número crescente de pesquisadores e ativistas a incluírem a descentralização e autogestão da produção e consumo de energia entre os critérios que deveriam orientar a transição energética. Em diferentes contextos e com olhar atento às especificidades locais, a produção acadêmica em "Energia & Sociedade" contribuiu para a discussão de novos arranjos regulatórios e de instrumentos capazes de fomentar a criação e o desenvolvimento de "comunidades energéticas".

É preciso cuidado para evitar associações automáticas entre "transição energética justa" e o mero incremento estatístico das fontes renováveis. O Acordo de Paris inclui a transição justa como um princípio norteador do enfrentamento às mudanças climáticas. Contudo, ela não se traduz em um conjunto fixo de regras, mas em processos baseados no diálogo e numa agenda que deve ser partilhada entre trabalhadores, indústrias e governos, formulando projetos que precisam ser negociados e implementados nos seus contextos geográficos, políticos, culturais e sociais específicos.

Embora a justiça climática esteja, via de regra, no centro das discussões sobre justiça energética, não são poucos os registros em que indivíduos e comunidades sentem-se afetados por empresas de energia renovável. As inovações tecnológicas ainda seguem um modelo mercadológico e são apropriadas por companhias que movimentam um negócio de trilhões de dólares, concentrando a riqueza e os processos decisórios de maneira nem sempre distinta das corporações que exploram os combustíveis fósseis. Por outro lado, também é controversa a ideia de que a diversificação das fontes de energia caracterizaria, por si só, uma transição sustentável. Em sua análise sobre a política energética indiana, Roy e Schaffartzik (2021) argumentam que, apesar do aumento dos investimentos em fontes renováveis, o país não se encontra em vias de uma transição para eliminar gradativamente as termoelétricas, mas sim para uma dependência ainda maior do carvão em sua matriz energética.

Para além de seu valor descritivo e analítico, o conceito de "transições energéticas justas" assumiu um novo patamar nos últimos anos, uma vez que não apenas acadêmicos, mas também formuladores de políticas passaram a compreendê-lo como uma ferramenta para o planejamento energético. Alguns países já criaram, inclusive, departamentos para a transição energética e programas intersetoriais para promovê-la. Apesar desses avanços institucionais, é importante cautela para que essa noção não seja invocada para escamotear as contradições das políticas energéticas, as quais devem ser avaliadas criticamente em seu todo, desde a produção dos combustíveis e da eletricidade até os usos sociais que lhe são atribuídos (Goldemberg; Moreira, 2005).

Com efeito, as análises sobre o consumo de energia também assinalam injustiças, vide os desníveis entre os países do Norte e do Sul Global e as diferenças no consumo *per capita* de energia no interior de cada país. Trata-se, portanto, de uma dupla injustiça, porque as populações com baixos índices relativos de consumo de energia figuram justamente entre as mais vulneráveis às mudanças climáticas. Nesse contexto, as discussões sobre transições justas mantêm uma relação estreita com as pesquisas e as políticas públicas dedicadas à superação da "pobreza energética". Sob a divisa "*leave no one behind*", a ONU estabeleceu como parte da Agenda para o Desenvolvimento Sustentável (ODS 7) o esforço para fornecer energia universal limpa, acessível e resiliente aos fenômenos climáticos extremos. Isso porque 733 milhões de pessoas ainda não têm acesso à eletricidade, e mais de 2,4 bilhões dependem de biomassa sólida para cozinhar (UNDP, 2013). Percebe-se então uma janela de oportunidades para aliar a promoção de um setor energético calcado em fontes renováveis ao combate à pobreza.

Ignacy Sachs (2004) atribuiu a persistência da pobreza ao fracasso dos governos e à desconexão das forças de mercado em relação aos mais pobres, que muitas vezes contribuem para torná-los socialmente invisíveis. Amartya Sen (2008) e Banerjee e Duflo (2011) compartilham o entendimento de que a pobreza não se limita apenas à falta de rendimentos, incluindo também problemas de saúde, má qualidade da educação e uma vida de privação de sonhos e liberdades. No que diz respeito ao Brasil, Pereira *et al.* (2011) apontaram que, mesmo com a experiência exitosa do *Programa Luz para Todos*, os impactos do acesso à eletricidade na qualidade de vida da população beneficiária ainda não foram suficientemente analisados. A compreensão dessas lacunas poderia aprimorar o programa para que os beneficiários conquistem o direito de utilizar a eletricidade no sentido do desenvolvimento tal como eles mesmos o concebem.

Um mergulho nas discussões acadêmicas e no debate público mais amplo sobre "transições energéticas justas" demanda clareza sobre o que cada interlocutor considera "justo" ou "injusto", assim como a explicitação das premissas que consubstanciariam suas respectivas noções de "justiça" (Uffelen *et al.*, 2024). Nem sempre existe consenso, e, por vezes, propostas divergentes podem derivar de duas ou mais premissas reconhecíveis como legítimas. Imagine, por exemplo, que quando levado ao extremo, o sentimento de urgência climática pode não coincidir com os princípios de decisão democrática do planejamento energético.

No primeiro caso tem-se uma temporalidade dramática e acelerada, enquanto no segundo o tempo deve ser todo aquele que se necessita para chegar a uma decisão orientada pela busca do consenso possível. Não queremos dizer com isso que seja impossível encontrar uma posição capaz de articular preocupações distintas e em certa medida concorrentes, mas sim destacar que a promoção de transições justas requer um diálogo em que os atores deixem claro qual a justiça energética que almejam e ao mesmo tempo estejam capacitados a identificar quais as premissas de "justiça" que as demais partes mobilizam para legitimar seus valores e interesses.

Reafirmando seu compromisso com a pluralidade e a interdisciplinaridade, a *Sustainability in Debate* oferece a seus leitores um dossiê sobre "transições energéticas justas" que valoriza a produção acadêmica qualificada de pesquisadores situados em diferentes universidades brasileiras e da América Latina.

A presente edição contém sete artigos, sendo o primeiro "Conflitos socioambientais e a implantação de parques eólicos no Nordeste brasileiro", que discute os avanços da energia eólica no Nordeste, com enfoque nos conflitos socioambientais que afetam a população residente no entorno das usinas. Nele, Sônia Regina Paulino e seus coautores apresentam uma tipologia de conflitos locais em torno de quatro eixos: econômicos, hídricos, fundiários e saúde/bem-estar das populações afetadas.

Na sequência, o artigo "Percepção dos impactos socioambientais causados por geradores eólicos no estado do Piauí, Nordeste do Brasil" consiste num estudo de caso sobre a energia eólica na Serra dos Pereiros (PI), no qual Rômulo Araújo e Adryane Gorayeb abordam o problema da aceitação social da tecnologia e a percepção dos membros da comunidade no entorno da usina sobre aspectos que dizem respeito às injustiças procedimental e distributiva.

Em "Institutional conditions for the development of energy communities in Chile and Brazil", Poque González e coautores apresentam uma discussão comparativa sobre as consequências de diferentes arranjos institucionais para o avanço das "comunidades energéticas". O estudo aponta que o modelo de entidade cooperativa tende a beneficiar o desenvolvimento de comunidades energéticas conectadas à rede. Noutro aporte sobre a realidade chilena, Gloria Baigorrotegui e pesquisadores da Universidade de Santigo de Chile publicam "Energy Communities of Repair in Remote Infrastructures", um estudo etnográfico segundo a abordagem dos Estudos Sociais da Ciência e Tecnologia, no qual abordam os problemas relativos à manutenção da rede de energia em Puerto Edén, extremo sul da Patagônia chilena.

Em seguida, o dossiê apresenta dois artigos que destacam a complexidade do planejamento das redes de transmissão. Em "Predictive Model of the Outage of Transmission Lines Exposed to Wildfires", Vaz da Costa e parceiros da Universidade de Brasília abordam a relevância das linhas de transmissão para a promoção do acesso a fontes renováveis de energia no âmbito do ODS 7, ponderando os riscos associados a queimadas e seus impactos na queda de fornecimento de energia elétrica nas redes, assim como a necessidade de modelos preditivos no âmbito do planejamento.

O sexto artigo, "Geographic intelligence to integrate data, roles, and actors in sustainable planning of transmission powerlines", apresenta o potencial da assim chamada "inteligência geográfica" para a modelagem de corredores preferenciais durante a etapa de estudos voltada para a identificação de localizações alternativas para linhas de transmissão de energia. Assim, Felipe Araújo e coautores procuram demonstrar a aplicabilidade da modelagem espacial ao planejamento locacional de projetos de transmissão.

No sétimo e último artigo deste dossiê, Rodrigo Wolffenbüttel apresenta os resultados de sua pesquisa sobre veículos elétricos. Em "Limits of sustainability in electric cars, qualification of goods based on symbolic values", ele investiga como indivíduos mobilizam valores "funcionais e simbólicos" enquanto critérios para a aquisição de automóveis elétricos. O autor possui o mérito de ser um dos

ainda poucos pesquisadores brasileiros que se dedicam ao tema da eletromobilidade no campo das ciências sociais.

Desejamos uma ótima leitura!

REFERÊNCIAS

BANERJEE, A. V.; DUFLO, E. **Poor Economics:** a radical rethinking of the way to fight global poverty. New York: Public affairs., 2011.

CHA, M. **A Just Transition**. Fordham Environmental Law Review, v. 29, n. 2, p. 196-220, 2017. Disponível em: https://www.jstor.org/stable/26413303.

GOLDEMBERG, J.; MOREIRA, J. R. Política energética no Brasil. **Estudos Avançados**, v. 19, n. 55, 2005. DOI: https://doi.org/10.1590/S0103-40142005000300015

KIRSTEN, J. *et al.* Energy justice: a conceptual review. **Energy Research & Social Sciences**, 2016. DOI: https://doi.org/10.1016/j.erss.2015.10.004.

PEREIRA, M. G.; FREITAS, M. A. V.; SILVA, N. F.Rural electrification and energy poverty: empirical evidences from Brazil. **Renewable and Sustainable Energy Reviews**, v. 14, p. 1229–1240, 2010.

ROY, B.; SCHAFFARTZIK, A. Talk renewables, walk coal: the paradox of India's energy transition. **Ecological Economics**, v. 180, 2021. DOI: https://doi.org/10.1016/j.ecolecon.2020.106871.

SACHS, I. **Desenvolvimento includente**, sustentável e sustentado. Rio de Janeiro: Garamond, 2004.

SEN, A. K. **Desenvolvimento como liberdade**. São Paulo: Companhia das Letras, 2008.

SOVACOOL, B. *et al.* Pluralizing energy justice: incorporating feminist, anti-racist, indigenous, and postcolonial perspectives. **Energy Research & Social Science**, 2023. Avaliable in: https://www.sciencedirect.com/science/article/pii/S2214629623000567.

UFFELEN, N. V.; TAEBI, B.; PESCH, U. Revisiting the energy justice framework: doing justice to normative uncertainties. **Renewable and Sustainable Energy Reviews**, 2024. DOI: https://doi.org/10.1016/j.rser.2023.113974.

UNDP website. Available in: https://www.undp.org/energy/our-work-areas/energy-access. Access: 14 nov. 2013.

Socio-environmental conflicts and the implantation of wind farms in the Brazilian Northeast

Conflitos socioambientais e a implantação de parques eólicos no Nordeste brasileiro

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ARTICLE- DOSSIER

ABSTRACT

Wind energy is already quite relevant in the Brazilian electrical matrix, especially when analysing the country's Northeast region. This expansion of wind sources gained even more strength with the development of renewable sources in an international context of negotiations to reduce greenhouse gas emissions. However, the implementation and operation of wind farms generate significant socio-environmental impacts on the population around these large enterprises. This research analysed academic articles that portray negative socio-environmental impacts caused by the installation and operation of wind farms in the Northeast of Brazil to address the local conflicts resulting from them situations of environmental injustice. A typology of identified conflicts is presented, classified into four categories: economic, water, land and health and wellness, demonstrating a clear scenario of environmental injustice.

Keywords: Wind energy. Local communities. Environmental injustice. Energy crisis. Renewable energy.

RESUMO

A energia eólica já se mostra bastante relevante na matriz elétrica brasileira, sobretudo quando analisada a Região Nordeste do país. Essa expansão das fontes eólicas ganhou ainda mais força com o desenvolvimento das fontes renováveis, em um contexto internacional de negociações pela redução de emissões de gases de efeito estufa. Todavia, a implantação e o funcionamento de parques eólicos geram impactos socioambientais significativos na população residente no entorno desses grandes empreendimentos. A presente pesquisa analisou artigos acadêmicos que retratam impactos socioambientais negativos causados pela instalação e operação de parques eólicos no Nordeste brasileiro para então abordar os conflitos locais deles decorrentes em situação de injustiça ambiental. É apresentada uma tipologia dos conflitos identificados, classificados em quatro categorias, quais sejam econômicos, hídricos, fundiários, e saúde e bem-estar, demonstrando o nítido cenário de injustiça ambiental.

Palavras-chave: Energia eólica. Comunidades locais. Injustiça ambiental. Crise energética. Energia renovável.

1 INTRODUCTION

Most of the Brazilian electrical matrix comes from hydroelectric plants. However, wind sources represent 10.6% of the Brazilian electricity matrix (BEN, 2022), and the country leapt from 15th place in countries with the highest installed capacity in 2012 to 6th in 2021 (Abeeólica, 2022). Since 2001, a year in which there were several "blackouts", wind farm installations in Brazilian territory have been growing, with emphasis on the Northeast region.

Since the 1990s, in an attempt to reduce the region's energy shortage, especially for the population far from large urban centres, projects have been designed to generate decentralised energy in a more economically accessible way. Thus, Brazil established new political guidelines with the objectives of expanding and diversifying the Brazilian electrical matrix, ensuring security in the energy supply and increasing access to energy (Drummond; Ferraz; Ramos, 2022).

Furthermore, the increase in environmental concerns has also stimulated the search for new sources of energy production compatible with an electrical matrix that is increasingly less dependent on fossil sources and more sustainable. In this scenario, due to the favourable geographic position of the Northeast, wind energy production gained space in the region (Santana; Silva, 2021).

Although wind energy is considered a source of clean energy, based exclusively on greenhouse gas emissions criteria, and because it is obtained through the power of an inexhaustible resource, the wind, the installation of large farms also causes significant socio-environmental impacts, although little

explored when compared to the literature that deals with their positive attributes (Sobrinho Júnior *et al.*, 2022).

Based on studies conducted in the Northeast, mostly in the state of Ceará, the literature lists different impacts caused by the installation of wind farms, such as land invasions, weakening of subsistence activities, such as agriculture and fishing, erasure of the existence of traditional population, noise pollution, visual pollution, changes in bird behaviour and reproduction, burial of lagoons and disappearance of dunes (Sobrinho Júnior *et al.*, 2022). Therefore, given these impacts, the article aims to answer the following question: what are the main socio-environmental conflicts caused by wind farms in the Brazilian Northeast?

In this sense, the objective is to identify the main conflicts generated by installing and operating wind farms in the Northeast of Brazil. In order to achieve this general objective, two specific objectives were defined: identifying the environmental impacts of wind energy projects and building a typology of the main socio-environmental conflicts related to local populations.

This research is based on analysing the literature on wind farms installed in the Northeast and the conflicts presented.

The focus on the Northeast is justified, as the region is home to most of the wind farms installed in Brazil, which is responsible for 88.7% of the entire country's wind energy production (Abeeólica, 2022). Observing the bibliography analysed, a typology of socio-environmental impacts was identified, developed by Farias, Silva and Carvalho (2021), which served as a reference for categorising socio-environmental conflicts arising from these impacts. The article presents five sections. After this introduction, section 2 addresses environmental injustice. In section 3, the methodology is presented. The results and discussion are shown in section 4. Finally, in section 5, the conclusion is made.

2 THEORETICAL REFERENCES

This article uses the concepts of environmental justice and injustice. The first arises from the integration of the concept of social justice, associated with the extent to which the environment and natural assets must be accessible to the entire population fairly. Furthermore, it combines the search for everyone's right to live in a healthy environment and equity and respect for human rights in relation to environmental impacts, especially considering the most vulnerable and marginalised communities (Acselrad, 2010). On the other hand, when there is no guarantee of this accessibility, environmental injustice is used to describe the greater exposure to environmental damage to which marginalised groups are subjected (Porto; Finamore; Ferreira, 2013). Based on that, environmental injustice is present when the pros and cons of large enterprises - which use natural assets - occur unequally, and historically marginalised and vulnerable communities are the most negatively affected (Acselrad, 2008).

The positive impacts of wind energy and how they are seen on a global scale are undeniable. In Brazil, some of the most present arguments are the democratisation of electrical energy and the fact that it is renewable (Araújo *et al.*, 2020; Neri *et al.*, 2019; Paiva; Lima, 2019; Santana; Silva, 2021). In the Northeast, the exploitation of winds for energy generation is justified thanks to favourable geographical

characteristics, such as climate, latitude, relief, and wind speed, as shown in Figure 1 (Bezerra, 2021; Santana; Silva, 2021).

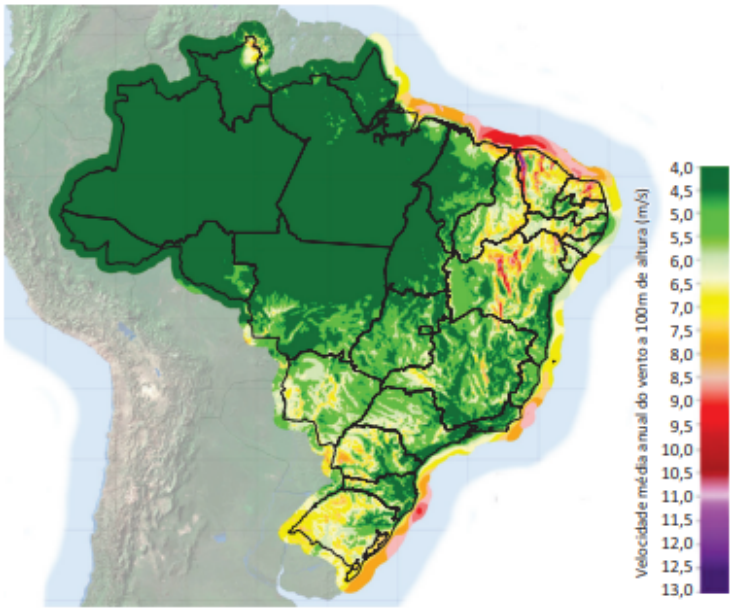

Figure 1 | Brazilian Wind Power Average annual wind speed at 100 meters high (m/s).
Source: Bezerra, 2021.

Therefore, large investments have been made in the region for wind exploration. Between 2009 and 2017, the region received 80% of the entire amount invested nationally in the sector, corresponding to an amount of BRL 80 billion (Santana; Silva, 2021). Despite the regionalist motivations that drove these investments, the benefits of energy generation have been directed to external groups without economically benefiting local communities, causing material and immaterial losses to those who have already been greatly neglected. (Farias; Silva; Carvalho, 2021; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021).

This negligence is shown when, for example, most of the implementation of wind farms in the Northeast occurs in regions where the local population remains without access to energy. This is often not considered in the planning and installation of farms, mainly due to studies that evaluate impacts superficially. Therefore, on a local scale, many of the consequences of such projects can harm the environment and the local population, generating a scenario of environmental injustice.

Therefore, focusing on the discussion on environmental (in)justice and conflicts, the environmental injustices arising from wind farm projects in the Northeast of Brazil are also linked to the suppression of the cultures and material and symbolic bonds of these populations by strongly impacting the territory in which they live. Therefore, for such groups, there is an intrinsic relationship with their productive environment that encompasses material, symbolic, and cultural aspects related to the land, common open areas, biodiversity, and ecosystems, where they build their identities and social bonds. However, these relationships are constantly threatened and unstructured by projects that call themselves development and clean energy (Araújo, 2016).

Environmental conflicts arise when negatively impacted communities demand greater access to natural resources and report the compromise of their activities as a result of large projects to appropriate space and the physical environment (Acselrad, 2004; Farias, 2023).

Given this fact, it is noted that the advancement of wind energy in Brazil, together with the rhetoric of development and the growing use of renewable energy, is closely linked to inequality and environmental

injustices in the Northeast of Brazil since the ruling elite in Brazil, in conjunction with the market, has demonstrated an especially selfish and insensitive stance, indiscriminately prioritising its interests and immediate profits (Acselrad, 2004). The economic benefits are concentrated in the hands of private companies, while local communities face the onus of the enterprises, often without access to basic resources and, in some cases, ironically, even electricity. (Gorayeb; Brannstrom, 2016).

3 METHODOLOGY

The literature review was conducted using searches in three databases: SciElo, Scopus and Web of Science. Data from academic articles collected in databases were used, as well as information from the official national database on Brazilian energy matrix (BEN) and data from the representative organisation of the Brazilian wind energy industry (*Associação Brasileira de Energia Eólica* – Abeeólica), which demonstrate the negative socio-environmental impacts caused to local communities living close to wind farms, focusing on the Northeast of Brazil.

In order to standardise data collection, the same keywords were used, and no additional filters were applied, as shown in Table 1.

Table 1 | Selection of articles

Database	*Terms*	
	Conflicts and "Wind Farm$"	Brazil, Conflicts and "Wind Farm$"
SciElo	1 result	6 results – 5 articles selected, after applying the exclusion criteria
Scopus	313 results	9 results – 5 articles selected, after applying the exclusion criteria
Web of Science	252 results	10 results – 2 articles selected, after applying the exclusion criteria

Source: Author's elaboration.

It can be observed that with each addition of keywords, the number of results changes, representing the search bottleneck. We mainly considered articles found with the keywords "Brazil" and "Conflicts" and "Wind Farm$" in the case of the SciElo database, and "Brazil" and "Conflict$" and "Wind Farm$" in the case of Scopus and the Web of Science.

Finally, searches were conducted according to relevance and number of citations on existing typologies of socio-environmental impacts to serve as an initial reference and demonstrate the still incipient typology of such impacts and their resulting conflicts within developing countries.

Once the bibliographical research was conducted, using the terms Brazil and Conflicts and "Wind Farm$", and the exclusion criteria were applied, 12 articles were selected. Articles that were repeated across different databases and those that were not relevant to the proposed topic were excluded.

The selected articles mainly address the states of Rio Grande do Norte, Pernambuco and Ceará, with the largest amount of information found being on the regions of São Cristóvão, in the municipality of Areia Branca (RN), in the municipality of Serra do Mel (RN), the community of Xavier, in the coastal area of Ceará, and the Communities of Galos and Galinhos in Rio Grande do Norte. These articles address the Caatinga biome, predominant in the Brazilian northeastern territory, and most of the wind farms in these regions are in the installation or operation phase. The articles address local contexts from

2001 onwards, the time frame used in the research, when the energy crisis gained strength, and the strengthening of an energy transition from fossil fuels to renewable energy began in Brazil.

From this, a schematic table was drafted about the main socio-environmental impacts identified in the literature, meaning those impacts that have directly generated local socio-environmental conflicts, based on the typology created by Farias Silva and Carvalho (2021). This work was chosen as the basis for the construction of this research because, among the bibliography analysed, it was the only one that presented a preliminary typology of negative impacts and potential generators of conflicts. The initial classification of these impacts was essential to understand and classify the resulting conflicts. Impacts identified only in the Northeast of Brazil were considered, as the research aims to create a local typology, unlike research already conducted based on developed countries (Bell; Gray; Haggett, 2005; Bell *et al.*, 2013; Pasqualetti, 2011). Furthermore, only articles that deal with wind farms located onshore were selected, and articles that deal with impacts that do not necessarily generate local conflicts were excluded. Considering that the objective of surveying the impacts is to relate them to the resulting conflicts caused, only negative impacts were considered.

From these impacts, the consequent conflicts caused at the location of the wind farms were raised, as mentioned in the articles analysed, classified into the following types: (i) economic, (ii) land, (iii) water, and (iv) health and wellness. This typology was established based on common elements in the 12 articles analysed. The partial arbitrariness in the choice of such types of conflicts is recognised (as is the case in any typology not yet sufficiently explored in the literature). However, the elaboration of the typology was based on conflicts identified by specialised literature so that they have a basis for their framing in the proposed form. Furthermore, detailed descriptions and captions for each type surveyed are explained in the discussion of the results. Finally, it is important to clarify that the present study intended to conduct the typology of conflicts and not of impacts, which are only the causes identified for those.

4 RESULTS AND DISCUSSION

Once the articles were reviewed, 21 conflicts caused by the implementation of wind farms in the Northeast were identified, resulting from the socio-environmental impacts of the enterprises, mentioned 40 times in the literature and organised in an Excel spreadsheet. These conflicts were classified into four different types, namely: "economic", "land", "water", and "health and wellness" (Figure 2 and Table 1), detailed in this section according to the different factors that highlight the situation of environmental injustice.

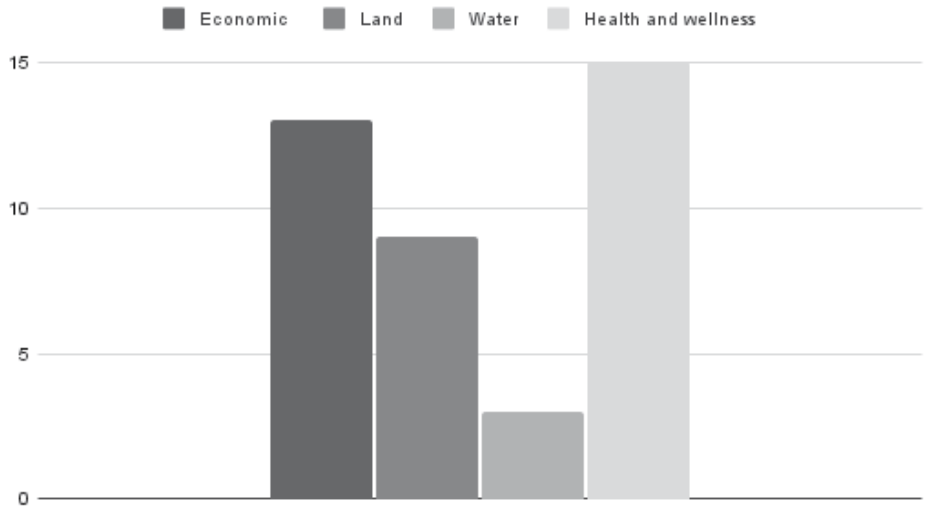

Figure 2 | Number of conflicts mentions.
Source: Author's elaboration.

It is evident that most conflict mentions (15) refer to those related to health and wellness, followed by mentions of economic conflicts (13), which will be exemplified and explained individually in the topics of this section. Furthermore, many mentions of conflicts identified as land (9) and only 3 related to water aspects. A detailed description of each of these types and a discussion of the results considering the concepts of environmental injustice and conflicts are provided below.

Table 2 | Conflicts arising from impacts

Impacts	Conflicts	Concept	Bibliography
Visual; degradation of the dune environment, soil and subsoils and the affected area; suppression of vegetation; fauna; local interference; noise and air pollution.	Economic	Generated by the restriction and reduction of local economic and subsistence activities.	BRANNSTROM et al. (2017) PINTO, MARTINS and PEREIRA (2017) FRATE et al. (2019) PAIVA and LIMA (2019) SANTANA and SILVA (2021) SOBRINHO JUNIOR et al. (2022)
Local interference and degradation of the affected area.	Land	Generated by disagreements between the local population and enterprises related to the use and occupation of land.	PORTO, FINAMORE and FERREIRA (2013) GORAYEB and BRANNSTROM (2016) BRANNSTROM et al. (2017) AVILA (2018) NERI et al. (2019) PAIVA and LIMA (2019) ARAÚJO et al. (2020) SANTANA and SILVA (2021)
Water pollution.	Water	Generated as a result of losses or compromise to the availability and/or quality of water in the region.	GORAYEB and BRANNSTROM (2016) BRANNSTROM et al. (2017) FRATE et al. (2019) ARAÚJO et al. (2020)
Local interference; air and noise pollution and visual impact.	Health and wellnes	Related to pathologies arising from the installation of the parks and/or interference with the feeling of comfort and safety of local residents.	GORAYEB et al. (2016) PINTO, MARTINS and PEREIRA (2017) BRANNSTROM et al. (2017) PAIVA and LIMA (2019) ARAÚJO et al. (2020) SANTANA and SILVA (2021) SOBRINHO JUNIOR et al. (2022)

Source: Author's elaboration.

The considered impacts repeatedly appeared in several articles in the literature analysed, which made it possible to classify impacts based on the typology developed by Farias, Silva and Carvalho (2021), important for differentiating such impacts into types such as water pollution, local interference, noise pollution, contributing to the consequent creation of a typology of conflicts.

Furthermore, counting and analysing conflict mentions made it possible to identify in which phase they occurred. Therefore, of the 40 conflicts mentioned, approximately 42.5% of them arose since the installation phase and remained during the operation of the farms (Figure 3).

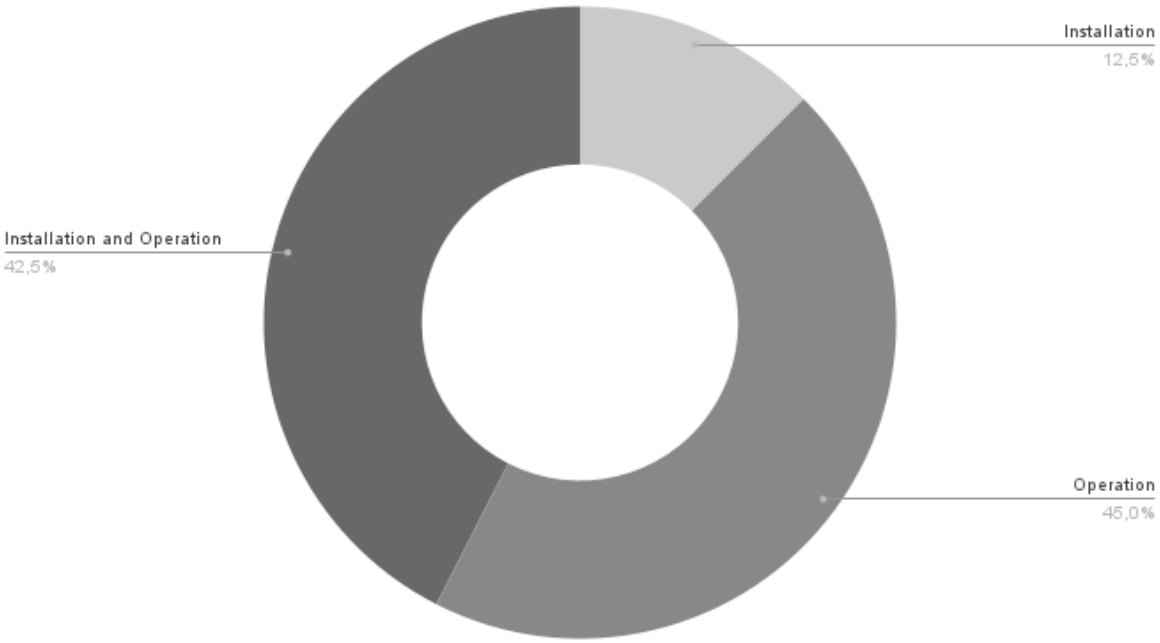

Figure 3 | Conflict phases.
Source: Author's elaboration.

The analysis is based on Acselrad's (2004) definition of socio-environmental conflicts. For the author, socio-environmental conflicts involve social groups with different ways of appropriating, using and significance of a territory, and they arise when at least one of the groups has its social forms of appropriation of the environment threatened by undesirable impacts, which may be related to soil, water, air or living systems, resulting from activities practised by other groups.

4.1 ECONOMIC CONFLICTS

Economic conflicts were defined as those generated by restricting and reducing local economic and subsistence activities. Of the total conflicts analysed, nine are in the economic category and were mentioned thirteen times in the bibliography. Within this classification, the thirteen conflicts arose from different impacts, namely: one from visual impact, one from degradation of the dune environment, two from vegetation suppression impacts, two from soil and subsoil degradation impacts, one fauna impact, one impact of degradation of the affected area, four impacts of local interference, one impact of noise pollution and one impact of air pollution, as characterised by Farias, Silva and Carvalho (2021).

Several economic conflicts related to losses caused to tourism were identified, causing the local economy to be strongly negatively impacted. One of the factors responsible for this is the change in the landscape caused by wind turbines during their operation phase (Frate *et al.*, 2019; Paiva; Lima, 2019; Pinto; Martins; Pereira, 2017; Sobrinho Júnior *et al.*, 2022). In some cases, residents have stated that the turbines are "mechanical monsters" that obstruct the view of the sunset (Frate *et al.*, 2019). In the northeastern context, they even affect coastal areas visited because they are considered vacation and leisure spots (Pinto; Martins; Pereira, 2017). In contrast, reports from residents were identified who, for example, consider the change in the landscape to be something positive and could contribute to wind turbine sighting tourism (Sobrinho Júnior *et al.*, 2022).

Another factor that alters landscapes is the earthworks of dunes. Due to the large movement of trucks and people, the sand on the ground levelled off, disappearing with the dunes in that region. For tourism and leisure in the region, this also makes some practices, such as kitesurfing, difficult, driving away tourists and harming local hotels (Brannstrom *et al.*, 2017).

Economic conflicts related to the income source generated by subsistence activities were also identified, harmed by changes in the land surface, drainage systems, and vegetation, and a reduction in environmental quality and biodiversity. Impacts such as the death of birds and bats, which contribute to the reproduction of vegetation, changes in the economy of communities close to the enterprises, such as shrimp farming and fishing in general, and the rural exodus caused by the impact on local agriculture are examples of causes of economic conflicts (Brannstrom *et al.*, 2017; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

Most of the conflicts generated during the installation and operation phases, and which interfered with sources of subsistence, resulted from the impact on local agriculture, harmed by the reduction of arable areas, suppression of native vegetation and reduction in food production due to traffic of heavy vehicles and the noise of turbines. In some cases, the impacts occurred on crops that were the basis of the local economy, as in the case of the municipality of Serra do Mel (RN), where cashew production was affected, and the communities of Larguinha and Pau Ferro, in the municipality of Caetés (PE), where there was a relevant change in the pace of corn production and a reduction in the supply of milk and eggs (Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

The issue of environmental injustice becomes evident in the economic conflicts described, given that affected communities face significant challenges due to the alteration of the natural environment, the basis of their economies. Such environmental impacts caused by the construction of wind farms can result in loss of income and rural exodus and even affect the subsistence of these communities, as previously demonstrated.

These factors highlight environmental injustices, as described by Porto, Finamore and Ferreira (2013), as they mainly harm already marginalised communities disproportionately affected by negative environmental impacts. In these cases, the profits from energy generating activities are not shared with local communities, who are left with only their costs and even their subsistence being compromised.

4.2 LAND CONFLICTS

Land conflicts were considered to be those caused by disagreements between the local population and enterprises related to the use and occupation of land. Four identified conflicts were classified as land conflicts, mentioned nine times in the bibliography analysed. Three of these conflicts resulted from local interference, and only one was from degradation of the affected area.

Several land conflicts were identified related to the restriction of access by the local population to spaces previously considered public (even though they were not) where wind farms were installed. In these cases, blocking access to roads previously used by the population, now fenced with bars and security gates with armed guards, generates access restrictions or increases travel time for the local population to essential public services such as schools, municipal waste collection and health units (Araújo *et al.*, 2020; Ávila, 2018; Brannstrom *et al.*, 2017; Gorayeb; Brannstrom, 2016; Porto; Finamore; Ferreira, 2013; Santana; Silva, 2021).

In the community of Xavier, in the municipality of Camocim (CE), the fencing of the wind farm area hindered the population's daily tasks, including subsistence activities, such as shellfish fishing, a source of income and food for the community. In 2013, through a term of commitment with the State Public Prosecutor's Office, the community's access to the road was released through control and, in addition, the entrepreneur responsible for the park built a refrigerated structure for storing fish and to serve as a community base for the local association (Brannstrom *et al.*, 2017).

Some authors also identify existing land conflicts that have intensified with the installation of wind farms due to the loss of political strength of traditional communities in the face of the enterprises.

In this sense, Ávila (2018) and Neri *et al.* (2019) indicate that the installation of wind farms, or the mere identification of the wind potential of a given location, leads to even greater difficulty for traditional people in having their lands recognised and demarcated, given the economic interest in such territories. This situation was also identified in Ponta do Tubarão State Reserve, located in the municipalities of Macau and Guamaré, in the state of Rio Grande do Norte, created after decades of social struggle by the local population and which, even though already protected, was the target of conflicts with the installation of a wind farm that politically weakened the protection of the conservation unit (Ávila, 2018).

In addition to land conflicts generated by local interference, Paiva and Lima (2019) mention land conflicts generated by the degradation of the area affected by the parks due to the destruction of archaeological sites and disrespect for the cultures of local people and their relations with the territory.

The land conflicts described above also make environmental injustice explicit. Generally installed in regions with populations that are already socially marginalised, these people find access to basic rights even more difficult and lose even more political power. In favour of a less polluting electrical matrix, the local population, who do not always benefit directly from such projects, has its fundamental rights curtailed, such as the installation of fences and the restriction of access to areas that were previously freely accessible. The case of the Xavier community illustrated above shows that, many times, some of these conflicts would be easily avoided and at no (or low) cost to the entrepreneur.

4.3 WATER CONFLICTS

Water conflicts were considered to occur due to losses or compromises in the region's availability and/or quality of water. This conflict occurs mainly due to the burial of rivers, lakes and lagoons. Of the total aspects analysed, the change in local water availability was mentioned three times in the bibliography and has "water pollution" as its causal impact.

The main cause of the burial of rivers, lakes and lagoons is the alteration of dunes, estuaries and beaches when the earthmoving of areas for the installation of turbines interrupts the flow of water between rivers and lakes existing between portions of dunes (Brannstrom *et al.*, 2017). In the bibliography analysed, this situation was identified in the installation and operation phases of wind farms in Ceará and Rio Grande do Norte.

In the community of Xavier, in the coastal area of Ceará, a wind farm buried interdune lagoons in the region, which impeded the population from accessing goods and services from outside the community and impeded subsistence fishing from being practised (Gorayeb; Brannstrom, 2016). Another example identified was the change in water availability due to interference in the water table due to the foundations of wind towers in the dunes in the coastal region of Ceará (Araújo *et al.*, 2020). In the communities of Galos and Galinhos, in Rio Grande do Norte, the region's river became shallower due to the movement of sand from the dunes, which resulted in restrictions on the population's navigability. Furthermore, the silting of rivers, lakes and ponds harms aquifers, aquatic fauna and flora in local regions, as by affecting the habitat, more sensitive beings die, and others emigrate, thus altering ecosystems (Frate *et al.*, 2019).

Thus, given the concept of environmental justice, water conflicts arise from the compromise of guaranteeing access to natural goods, a clear example of environmental injustice (Acselrad, 2010; Porto; Finamore; Ferreira, 2013). The affected local population is dissatisfied with no longer having access to water resources, such as lakes, ponds and rivers, which sometimes cease to exist for subsistence reasons and cultural values, often directly linked to these resources. For example, as they have different forms of interaction with bodies of water, these natural assets are considered sacred for many populations and linked to people's cultural identity (Gorayeb *et al.*, 2017). Therefore, when the installation of wind farms compromises water availability in a location, it is common for water conflicts to arise.

4.4 CONFLICTS RELATED TO HEALTH AND WELLNESS

Conflicts related to "health and wellness" were categorised as those related to pathologies resulting from the installation of farms and/or interference with the residents' feeling of comfort and safety. Following this description, it was possible to identify fifteen mentions of "health and wellness" conflicts, being the most mentioned type in the bibliography analysed. Seven of these conflicts were caused by impacts classified as "local interference", six by "noise pollution", and one by "visual impact".

Conflicts arising from the impact identified by local populations as a "territory of fear" stand out, resulting from the installation of signs that carry warnings (necessary for security reasons), such as "risk of death" and "escape routes" around the limits of wind farms. Although signage is mandatory in places where high voltage electrical cables are buried, it is possible to see them exposed on the surface, in areas with common access, in lakes, dunes, plantations and even fishing grounds, meaning a greater risk of accidents (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017). In the aforementioned community of Xavier, the territory of fear is even more present, as in addition to the road signs, in 2009, there was an accident in which one of the turbines caught fire (Gorayeb; Brannstrom, 2016).

Consequently, in addition to there being signs that lead residents to a constant state of alert in places that previously represented moments of leisure, the easy visibility of these cables only reinforces the possibility of accidents, causing disturbance, compromising their quality of life and offering risk of life for these residents. Given this, it is important to consider the interference these facilities cause in the psychological health of communities so that their wellness is guaranteed.

Pinto, Martins and Pereira (2017) identified conflicts related to wellness generated by local interference both in the installation phase and in the operation of wind farms. These conflicts arose with electromagnetic interference from wind turbines, causing disruptions in communications and data transmissions (radio, television, etc.) in communities close to wind farms. Such conflicts fit into the "health and wellness" type, considering that access to information and communication is a fundamental right linked to human rights to achieve the Sustainable Development Goals (ONU, 2023).

Another conflict identified is related to the intense traffic of large vehicles during the installation process of wind towers, which generates local interference and air pollution, being identified twice in the bibliography explored (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017). The clouds of sand and dust generated by this intense traffic impacted residential areas and schools, causing respiratory illnesses and affecting the health and wellness of communities near the wind farms.

According to Sette and Ribeiro (2011), any change in the composition of the air can constitute a real health problem for the individual. Therefore, in the case of intense heavy vehicle traffic, clouds of suspended particles significantly impact the population's health, as inhaling these particles can cause a series of respiratory problems, such as coughing, shortness of breath, and wheezing. and even the development of asthma in susceptible individuals, in addition to causing eye problems, such as eye irritation and, in more severe cases, even damage to the cornea.

During the operation phase, an impact that directly affects health and wellness can be observed in the case of the municipality of Caetés (PE), in the communities of Larguinha and Pau Ferro, in which Santana and Silva (2021) identified reports of residents experiencing severe discomfort, dizziness and nausea generated by the shadows produced by the propellers. Furthermore, the disruption caused by noise pollution from wind tower turbines is the impact that was most often cited in health and wellness conflicts, mentioned seven times (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017; Gorayeb; Brannstrom, 2016; Paiva; Lima, 2019; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

In all the works analysed, complaints from residents regarding noise from the turbines are very strong, complaining of great noise disturbance, further intensified by the proximity of the turbines in some cases. Many residents reported that, with the operation of the wind farms, they began to have severe and constant headaches. Children also find it difficult to adapt to noise, causing constant crying and discomfort in general.

To better understand the extent of the negative impact that this noise pollution causes on residents, one must consider the environment before installing wind farms in remote locations, normally calm and silent, close to nature. As a result, although noise levels in these locations are within the limits established by regulations, residents are strongly affected by the difference in the environment without the wind towers, with reports of residents considering the noise similar to a "helicopter that never lands". (Araújo *et al.*, 2020, p. 12). Therefore, it is clear that wind installations impact the health and wellness of residents, with some people experiencing sleep disturbances, stress or other health problems due to the constant noise.

Furthermore, although wind turbines transmit small vibrations considered insignificant, farmers in the interior of Ceará reported the perception of these vibrations emitted by wind turbines, but also due to the movement of heavy automobiles, the carrying out of geotechnical and hydrogeological studies, and compaction from the soil. In some cases, there was structural compromise in houses and buildings made with more fragile materials (Sobrinho Júnior *et al.*, 2022).

The relationship between environmental injustice and health is intrinsically linked, as the environment in which humans live plays a fundamental role in their health. However, when analysing the costs and bonuses generated by wind energy, it is clear that they are not being distributed fairly. Communities that are already poor and suffer social injustices – including less access to healthcare facilities, doctors and medicines – are the ones that have the onus of their health and wellness. In return, entrepreneurs receive profit bonuses and the prestige of contributing to the advancement of sustainable development by generating clean energy. This highlights the intertwining of environmental and social injustices and the contradictions of clean energy.

5 CONCLUSION

Although wind energy is currently one of the least polluting, there are many negative impacts generated by wind farms, especially during their installation and operation phase. From the bibliography analysed, it was possible to identify a gap in the elaboration of typology for conflicts caused by the implementation of wind farms in the context of the Northeast of Brazil, with only typologies being found for the impacts caused and, above all, in the context of developed countries. Thus, this article identifies the main socio-environmental conflicts in the Northeast region generated by wind farms and categorises them into four types.

Conflicts related to impacts on health and wellness and economic conflicts are those with the highest number of mentions in the bibliography. Among the different causes for such conflicts, the impacts on health and wellness caused by noise pollution from wind turbines stand out, as well as discomfort related to the constant shadows from wind blades. From a psychological point of view, there is still a constant fear and feeling of danger due to accidents, road signs and exposed high-voltage wires. Furthermore, there are impacts on health and wellness related to impacts on subsistence activities, hampered or hindered by interference with local space and biodiversity, also reflecting economic conflicts due to damage to agriculture, fishing and tourism.

In land conflicts, impacts related to the accessibility of local populations to territories previously considered and used as public stood out, hindering their access to essential and daily services. Furthermore, cases were identified in which lands were invaded, and communities were culturally

"erased". In conflicts related to the availability and quality of water, the main causes were the silting of lagoons, lakes and rivers, intervening in aquatic life, terrestrial animals and local communities.

It is possible to affirm that the identified and classified conflicts emerge as a result of repeated environmental injustices. The population directly affected by the installation and operation of wind farms in the Northeast of Brazil faces significant environmental injustices, as while the benefits of the enterprises are not properly passed on to them, they fully bear the onus, including environmental impacts and changes to their way of life.

In short, the article identifies the main socio-environmental conflicts generated by wind farms in the Brazilian Northeast during their installation and operation, presenting four types of conflicts. In an international scenario of energy transition to renewable sources and with lower greenhouse gas emissions, it is expected for Brazil to increase the share of sources such as wind in its electrical matrix. However, the transition must be made with environmental justice as a starting point, observing and respecting the local communities directly affected. Otherwise, conflicts of different natures will arise, making it difficult for the respective enterprises to be considered "clean" and effective in offering energy to the population. The typology of conflicts presented in this work can contribute to planning the implementation of wind farms, given that many of them can be avoided at low cost and, in some cases, at no cost.

REFERENCES

ACSELRAD, H. As práticas espaciais e o campo dos conflitos ambientais. *In*: **Conflitos Ambientais no Brasil.** ACSELRAD, H. (org), Rio de Janeiro: Relume Dumará: Fundação Heinrich Böll. São Paulo, p. 13-35, 2004.

ACSELRAD, H. Grassroots reframing of environmental struggles in Brazil. *In*: CARRUTHERS, D. V. (Ed.) **Environmental Justice in Latin America. Cambridge**: MIT Press, 2008. DOI: https://doi.org/10.7551/mitpress/9780262033725.003.0004. Available at: https://academic.oup.com/mit-press-scholarship-online/book/22802/chapter-abstract/183255158?redirectedFrom=fulltext. Accessed on: 31 jul. 2023.

ACSELRAD, H. Ambientalização das lutas sociais: o caso do movimento por justiça ambiental. **Estudos avançados**, São Paulo, v. 24, n. 68, p. 127-150, 2010. DOI: https://doi.org/10.1590/S0103-40142010000100010. Available at: https://www.scielo.br/j/ea/a/hSdks4fkGYGb4fDVhmb6yxk/?lang=pt. Accessed on: 26 jul. 2023.

ACSELRAD, H.; HERCULANO, S.; PÁDUA, J. A. **Justiça ambiental e cidadania**. Rio de Janeiro: Relume Dumará, 2004. ISBN: 85-7316-353-4. Available at: https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://edisciplinas.usp.br/mod/resource/view.php%3Fid%3D387079&ved=2ahUKEwjGyK-Q9rmAAxWNp5UCHRLPA5oQFnoECB8QAQ&usg=AOvVaw0hxhmk-Fez2CHdVyog3f-q. Accessed on: 31 jul. 2023.

ARAÚJO, J. C. H. Entre expropriações e resistências: a implementação de parques eólicos na zona costeira do Ceará, Brasil. **Cadernos do CEAS**, Salvador, n. 237, p. 327-346, 2016. ISSN: 2447-861X. Available at: https://cadernosdoceas.ucsal.br/index.php/cadernosdoceas/article/view/236/209. Accessed on: 31 jul. 2023.

ARAÚJO, J. C. H. *et al.* Sustainability challenges of wind power deployment in Coastal Ceará State, Brazil. **Sustainability**, v. 12, p. 5562, 2020. DOI: 10.3390/su12145562. Available at: https://www.mdpi.com/2071-1050/12/14/556. Accessed on: 31 jul. 2023.

ASSOCIAÇÃO BRASILEIRA DE ENERGIA EÓLICA E NOVAS TECNOLOGIAS. **Boletim anual 2021**. São Paulo: Abeeólica, 2022. Available at: https://abeeolica.org.br/energia-eolica/dados-abeeolica/?slug=boletim-anual. Accessed on: 31 mar. 2023.

ÁVILA, S. Environmental justice and the expanding geography of wind power conflicts. **Sustain. Sci**., v. 13, p. 599–616, 2018. DOI: https://doi.org/10.1007/s11625-018-0547-4. Available at: https://link.springer.com/article/10.1007/s11625-018-0547-4. Accessed on: 31 jul. 2023.

BALANÇO ENERGÉTICO NACIONAL. **Relatório Síntese 2022**. Ministério de Minas e Energia: Brasília, 2022. Availableat: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2022. Accessed on: 31 mar. 2023.

BELL, D.; GRAY, T.; HAGGETT, C. The 'Social Gap' in wind farm siting decisions: explanations and policy responses. **Environmental Politics**, v. 14, n. 4, 2005, p. 460-477. ISSN: 1743-8934. DOI: 10.1080/09644010500175833. Available at: https://www.tandfonline.com/doi/abs/10.1080/09644010500175833. Accessed on: 29 jul. 2023.

BELL, D. *et al.* Re-visiting the 'Social Gap': public opinion and relations of power in the local politics of wind energy. **Environmental politics**, v. 22, n. 1, 2013, p. 115-135. ISSN: 1743-8934. DOI: 10.1080/09644016.2013.755793. Available at: https://www.tandfonline.com/doi/abs/10.1080/09644016.2013.755793. Accessed on: 29 jul. 2023.

BEZERRA, F. D. **Energia eólica no Nordeste**. Banco do Nordeste, Fortaleza, dezembro, 2021. Available at: https://www.bnb.gov.br/s482-dspace/bitstream/123456789/1045/1/2021_CDS_200.pdf. Accessed on: 08 out. 2023.

BRANNSTROM, C. *et al.* Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state. **Renewable and Sustainable Energy**, v. 67, p. 62–71, 2017. ISSN: 1364-0321. DOI: http://dx.doi.org/10.1016/j.rser.2016.08.047. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1364032116304804?via%3Dihub. Accessed on: 27 jul. 2023.

BRASIL. Lei nº 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional do Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. **Diário Oficial da União**. Brasília, DF, 2 set. 1981. Available at: https://www.planalto.gov.br/ccivil_03/Leis/L6938.htm. Accessed on: 3 jun. 2023.

DRUMMOND, P.; FERRAZ, J. C.; RAMOS, L. Wind energy in Europe, Brazil and the UK. In: EEIST – Economics of Energy Innovation and System Transition. **The new economics of innovation and transition**: evaluating opportunities and risks.

EEIST, University of Exeter: Exeter, UK, 2022, p. 8-11. Available at: https://eeist.co.uk/eeist-reports/the-new-economics-of-innovation-and-transition-evaluating-opportunities-and-risks/. Accessed on: 14 out. 2023.

FARIAS, A. L. A. Impactos e conflitos socioambientais de grandes projetos na Amazônia: até quando Barcarena/PA será uma zona de sacrifício? **INTERthesis: Revista Internacional Interdisciplinar**, v. 20, p. 01-21, jan./dec. 2023. DOI: https://doi.org/10.5007/1807-1384.2023.e90583. Available at: https://orcid.org/0000-0002-0982-4212. Accessed on: 11 oct. 2023.

FARIAS, M. R. F. S.; SILVA, Í. H. M.; CARVALHO, R. G. Energias renováveis: o parque eólico de São Cristóvão, município de Areia Branca (RN), Brasil. **Revista de Geografia e Ordenamento do Território**, v. 22, p. 111-139, 2021. ISSN: 2182-1267. DOI: dx.doi.org/10.17127/got/2021.22.005. Available at: https://docplayer.com.br/229826305-Energias-renovaveis-o-parque-eolico-de-sao-cristovao-municipio-de-areia-branca-rn-brasil.html. Accessed on: 27 jul. 2023.

FRATE, C. A. *et al.* Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil. Energy Policy, v. 132, p. 185-195, 2019. DOI: https://doi.org/10.1016/j.enpol.2019.05.027. Available at: 10.1016/j.enpol.2019.05.027. Accessed on: 27 jul. 2023.

GORAYEB, A.; BRANNSTROM, C. Caminhos para uma gestão participativa dos recursos energéticos de matriz renovável (parques eólicos) no Nordeste do Brasil. **Mercator**, v. 15, n. 1, p. 101-115, jan./mar., 2016. DOI: 10.4215/RM2016.1501. 0008 Available at: https://www.scielo.br/j/mercator/a/JRtprDJJnXZT3kfDx3Dw8qy/?format=pdf&lang=ptAccessed on: 31 jul. 2023.

GORAYEB, A. *et al.* Wind power gone bad: critiquing wind power planning processes in northeastern Brazil. **Energy Research & Social Science**. v. 40, p. 82. Elsevier. 2017. DOI: https://doi.org/10.1016/j.erss.2017.11.027.

GORAYEB, A. *et al.* Wind-energy development causes social impacts in Coastal Ceará state, Brazil: the case of the Xavier Community. **Journal of Coastal Research**, v. 75, p. 383-387, 2016. DOI: 10.2112/SI75-077.1. Available at: http://www.observatoriodaenergiaeolica.ufc.br/wp-content/uploads/2019/08/Gorayebetal2016.pdf. Accessed on: 14 aug. 2023.

NERI, M. *et al.* Green versus green? Adverting potential conflicts between wind power generation and biodiversity conservation in Brazil. **Perspectives in Ecology and Conservation**, v. 17, n. 3. p 131-135, 2019. DOI: https://doi.org/10.1016/j.pecon.2019.08.004. Available at: https://www.sciencedirect.com/science/article/pii/S2530064419300537. Accessed on: 31 jul. 2023.

ORGANIZAÇÃO DAS NAÇÕES UNIDAS. **Objetivos de Desenvolvimento Sustentável**. Available at: https://brasil.un.org/pt-br/sdgs. Accessed on: 13 apr. 2023.

PAIVA, I. T. P.; LIMA, E. C. Conflitos socioambientais, energia eólica e justiça ambiental: contribuições para uma análise crítica. **Revista GeoUECE**, v. 08, n. 14, p. 294-xx, jan./jun. 2019, versão online. DOI: 10.37084. Available at: https://revistas.uece.br/index.php/GeoUECE/article/view/2105. Accessed on: 31 jul. 2023.

PASQUALETTI, M. J. Opposing wind energy landscape: a search for common cause. **Annals of the Association of American Geographers**, v. 101, n. 4, p. 907-917, 2011. ISSN 00045608. Available at: https://www.jstor.org/stable/27980237. Accessed on: 29 jul. 2023.

PINTO, L. I. C.; MARTINS, F. R.; PEREIRA, E. B. O mercado brasileiro da energia eólica, impactos sociais e ambientais. **Ambient. Água**, v. 12, n. 6. Taubaté – Nov. / Dec. 2017. DOI: https://doi.org/10.4136/ambi-agua.2064. Available at: https://www.scielo.br/j/ambiagua/a/5b77GB9j4yPTzkS4pjxyhvH/?lang=pt. Accessed on: 31 jul. 2023.

PORTO, F. S. P.; FINAMORE, R.; FERREIRA, H. Injustiças da sustentabilidade: conflitos ambientais relacionados à produção de energia "limpa" no Brasil. **Revista Crítica de Ciências Sociais**, n. 100, maio 2013, p. 37-64. DOI: https://doi.org/10.4000/rccs.5217. Available at: https://journals.openedition.org/rccs/5217. Accessed on: 29 jul. 2023.

SANTANA, A. O.; SILVA, T. A. A. Produção de energia eólica em Pernambuco e a injustiça ambiental sobre comunidades rurais. **R. Katál**., Florianópolis, v. 24, n. 1, p. 245-254, jan./apr. 2021. DOI: https://doi.org/10.1590/1982-0259.2021.e73663 Available at: https://www.scielo.br/j/rk/a/nsbqwxf8gzFshryZGqKJhDc/?lang=pt. Accessed on: 31 jul. 2023.

SARLET, I. W.; FENSTERSEIFER, T. **Curso de direito ambiental**. 2ª ed., revista, atualizada e ampliada. Rio de Janeiro: Forense, 2021. ISBN: 9788530990640.

SETTE, D. M.; RIBEIRO, H. Interações entre o clima, o tempo e a saúde humana. **Interfacehs** (Ed. português), v. 6, p. 3, 2011. ISSN 1980-0894. Available at: http://www3.sp.senac.br/hotsites/blogs/InterfacEHS/wp-content/uploads/2013/08/3_ARTIGO_vol6n2.pdf. Accessed on: 31 jul. 2023.

SOBRINHO JÚNIOR, M. F. *et al.* Perception of environmental impacts of wind farms in agricultural areas of Northeast Brazil. **Energies**, v. 15, n. 101, 2022. DOI: https://doi.org/10.3390/en15010101. Available at: https://www.mdpi.com/1996-1073/15/1/101. Accessed on: 31 jul. 2023.

Conflitos socioambientais e a implantação de parques eólicos no Nordeste brasileiro

Socio-environmental conflicts and the implantation of wind farms in the Brazilian Northeast

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RESUMO

A energia eólica já se mostra bastante relevante na matriz elétrica brasileira, sobretudo quando analisada a Região Nordeste do país. Essa expansão das fontes eólicas ganhou ainda mais força com o desenvolvimento das fontes renováveis, em um contexto internacional de negociações pela redução de emissões de gases de efeito estufa. Todavia, a implantação e o funcionamento de parques eólicos geram impactos socioambientais significativos na população residente no entorno desses grandes empreendimentos. A presente pesquisa analisou artigos acadêmicos que retratam impactos socioambientais negativos causados pela instalação e operação de parques eólicos no Nordeste brasileiro para então abordar os conflitos locais deles decorrentes em situação de injustiça ambiental. É apresentada uma tipologia dos conflitos identificados, classificados em quatro categorias, quais sejam econômicos, hídricos, fundiários, e saúde e bem-estar, demonstrando o nítido cenário de injustiça ambiental.

Palavras-chave: Energia eólica. Comunidades locais. Injustiça ambiental. Crise energética. Energia renovável.

ABSTRACT

Wind energy is already quite relevant in the Brazilian electrical matrix, especially when analysing the country's Northeast region. This expansion of wind sources gained even more strength with the development of renewable sources in an international context of negotiations to reduce greenhouse gas emissions. However, the implementation and operation of wind farms generate significant socio-environmental impacts on the population around these large enterprises. This research analysed academic articles that portray negative socio-environmental impacts caused by the installation and operation of wind farms in the Northeast of Brazil to address the local conflicts resulting from them situations of environmental injustice. A typology of identified conflicts is presented, classified into four categories: economic, water, land and health and wellness, demonstrating a clear scenario of environmental injustice.

Keywords: Wind energy. Local communities. Environmental injustice. Energy crisis. Renewable energy.

1 INTRODUÇÃO

A maior parte da matriz elétrica brasileira provém de usinas hidrelétricas. Porém, a fonte eólica representa 10,6% da matriz elétrica brasileira (BEN, 2022) e o país saltou da 15ª colocação em países com maior capacidade instalada, em 2012, para a 6ª, em 2021 (Abeeólica, 2022). Desde 2001, ano em que houve vários "apagões", as instalações de parques eólicos no território brasileiro vêm crescendo, com destaque para a Região Nordeste.

Desde a década de 1990, na tentativa de diminuir a carência energética da região, especialmente da população distante de grandes centros urbanos, foram elaborados projetos para a geração de energia descentralizada de forma mais acessível economicamente. Assim, o Brasil estabeleceu novas diretrizes políticas com os objetivos de expandir e diversificar a matriz elétrica brasileira, garantir a segurança no fornecimento de energia e aumentar o acesso a esta (Drummond; Ferraz; Ramos, 2022).

Ademais, o aumento das preocupações ambientais também estimulou a busca por novas fontes de produção de energia, compatíveis com uma matriz elétrica cada vez menos dependente de fontes fósseis e mais sustentável. Nesse cenário, devido à posição geográfica nordestina favorável, a produção de energia eólica ganhou espaço na região (Santana; Silva, 2021).

Apesar de a energia eólica ser considerada uma fonte de energia limpa, com base exclusivamente nos critérios de emissões de gases de efeito estufa, e por ser obtida por meio da força de um recurso inesgotável, o vento, a instalação de grandes parques causa também impactos socioambientais

significativos, embora pouco explorados quando comparados com a literatura que trata de seus atributos positivos (Sobrinho Júnior *et al.*, 2022).

A partir de estudos realizados no Nordeste, majoritariamente no Ceará, a literatura elenca diferentes impactos causados pela instalação dos parques eólicos, como invasões de terras, debilitação das atividades de subsistência, como a agricultura e a pesca, apagamento da existência de povos tradicionais, poluição sonora, poluição visual, alteração no comportamento e reprodução de aves, soterramento de lagoas e desaparecimento de dunas (Sobrinho Júnior *et al.*, 2022). Para tanto, diante desses impactos, o artigo propõe-se a responder a seguinte pergunta: quais são os principais conflitos socioambientais causados pelos parques eólicos no Nordeste?

Nesse sentido, tem-se como objetivo identificar os principais conflitos gerados pela instalação e operação de parques eólicos no Nordeste brasileiro. A fim de atingir esse objetivo geral, foram definidos dois objetivos específicos: identificar os impactos ambientais dos projetos de energia eólica e construir uma tipologia dos principais conflitos socioambientais relacionados às populações locais.

A presente pesquisa baseia-se na análise da literatura sobre parques eólicos instalados no Nordeste e os conflitos apresentados.

O enfoque no Nordeste justifica-se, por a região abrigar a maior parte dos parques eólicos instalados no Brasil, sendo essa região responsável por 88,7% da produção de energia eólica de todo o país (Abeeólica, 2022). Observando a bibliografia analisada, foi identificada uma tipologia de impactos socioambientais, elaborada por Carvalho, Farias e Silva (2021), a qual serviu de referência para a categorização dos conflitos socioambientais derivados desses impactos. O artigo apresenta cinco seções. Após esta introdução, a seção 2 aborda a injustiça ambiental. Na seção 3, é apresentada a metodologia. Os resultados e discussão são mostrados na seção 4. Por fim, na seção 5, é feita a conclusão.

2 REFERÊNCIAS TEÓRICAS

O presente artigo utiliza os conceitos de justiça e injustiça ambiental. O primeiro surge a partir da integração do conceito de justiça social, associado ao quanto o meio ambiente e os bens naturais devem ser acessíveis a toda a população de forma justa. Além disso, agrega a busca pelo direito de todos viverem em um ambiente saudável e a equidade e o respeito aos direitos humanos em relação aos impactos ambientais, considerando especialmente as comunidades mais vulneráveis e marginalizadas (Acselrad, 2010). Por outro lado, quando não há garantia dessa acessibilidade, o conceito de injustiça ambiental é usado para descrever a maior exposição a danos ambientais a qual grupos marginalizados são submetidos (Ferreira; Finamore; Porto, 2013). A partir disso, a injustiça ambiental se faz presente quando os ônus e bônus de grandes empreendimentos – que utilizam bens naturais – ocorrem de forma desigual e comunidades historicamente já marginalizadas e vulneráveis são as mais afetadas negativamente (Acselrad, 2008).

São inegáveis os impactos positivos da energia eólica e como eles são vistos na escala global. No Brasil, alguns dos argumentos mais presentes são a democratização da energia elétrica e o fato de ser renovável (Araújo *et al.*, 2020; Neri *et al.*, 2019; Paiva; Lima, 2019; Santana; Silva, 2021). Já no Nordeste, justifica-se a exploração dos ventos para geração de energia graças às características geográficas favoráveis, como o clima, latitude, relevo e a velocidade dos ventos, como demonstrado na Figura 1 (Bezerra, 2021; Santana; Silva, 2021).

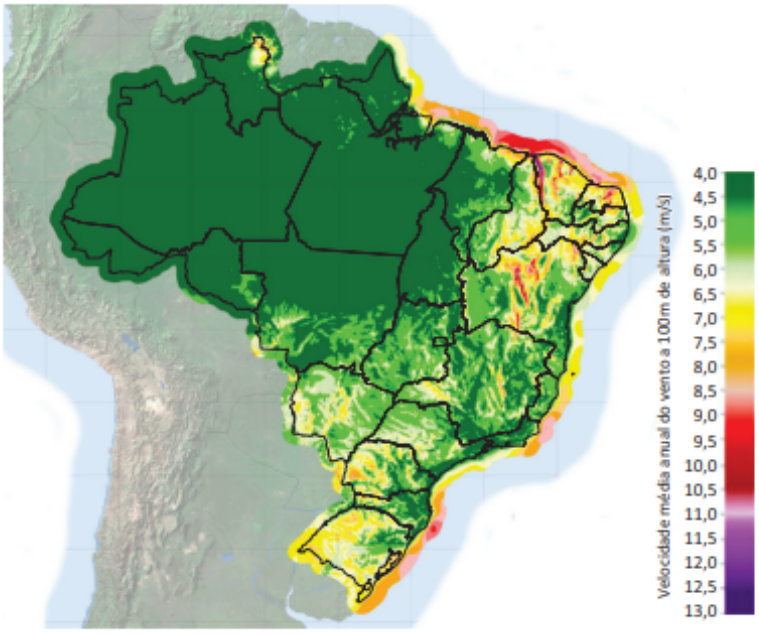

Figura 1 | Potencial eólico brasileiro.
Source: Bezerra, 2021.

Por isso, há grandes investimentos realizados na região para a exploração eólica. Entre 2009 e 2017, a região recebeu 80% de todo o valor investido nacionalmente no setor, correspondente a um montante de R$ 80 bilhões (Santana; Silva, 2021). Apesar das motivações regionalistas que impulsionaram esses investimentos, os benefícios da geração de energia têm sido direcionados a grupos externos, sem beneficiar economicamente as comunidades locais, causando prejuízos materiais e imateriais àqueles que já foram muito negligenciados (Farias; Silva; Carvalho, 2021; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021).

Essa negligência se mostra quando, por exemplo, a maior parte da implantação dos parques no Nordeste se dá em regiões onde a população local permanece sem acesso à energia. Isso, muitas vezes, não é considerado no planejamento e na instalação dos parques, devido, principalmente, aos estudos que avaliam impactos de forma superficial. Portanto, em escala local muitas das consequências geradas por tais empreendimentos podem ser prejudiciais ao meio ambiente e à população local, gerando um cenário de injustiça ambiental.

Portanto, colocando o foco na discussão sobre (in)justiça ambiental e conflitos, as injustiças ambientais advindas dos projetos de parques eólicos no Nordeste brasileiro também estão ligadas à supressão das culturas e vínculos materiais e simbólicos dessas populações ao impactar fortemente o território em que vivem. Sendo que, para tais grupos, há uma relação intrínseca com seu ambiente produtivo que abrange aspectos materiais, simbólicos e culturais relacionados à terra, a áreas livres comuns, à biodiversidade e aos ecossistemas, onde constroem suas identidades e redes de sociabilidade. Entretanto, essas relações são constantemente ameaçadas e desestruturadas por projetos que se autointitulam como de desenvolvimento e de energia limpa (Araújo, 2016).

Os conflitos ambientais surgem quando as comunidades impactadas negativamente reclamam maior acesso aos recursos naturais e denunciam o comprometimento de suas atividades em decorrência de grandes projetos de apropriação do espaço e do meio ambiente físico (Acselrad, 2004; Farias, 2023).

Diante disso, nota-se que o avanço da energia eólica no Brasil, junto à retórica do desenvolvimento e do crescente uso de energias renováveis, está intimamente ligado à desigualdade e às injustiças ambientais no Nordeste brasileiro, uma vez que a elite governante no Brasil, em conjunto com o

mercado, tem demonstrado uma postura especialmente egoísta e insensível, priorizando de maneira indiscriminada seus próprios interesses e lucros imediatos (Acselrad, 2004). Os benefícios econômicos ficam concentrados nas mãos de empresas privadas, enquanto as comunidades locais enfrentam os ônus dos empreendimentos, muitas vezes sem acesso a recursos básicos e, em alguns casos, ironicamente, inclusive de energia elétrica (Brannstrom; Gorayeb, 2016).

3 METODOLOGIA

A revisão da literatura foi realizada a partir de buscas em três bases de dados: SciElo, Scopus e Web of Science. Foram utilizados dados de artigos acadêmicos levantados nas bases de dados, bem como dados oficiais do Balanço Energético Nacional (BEN) e dados da Associação Brasileira de Energia Eólica (Abeeólica), que demonstram os impactos negativos socioambientais causados às comunidades locais que vivem próximoa parques eólicos, com enfoque no Nordeste brasileiro.

A fim de padronizar a coleta de dados, foram utilizadas as mesmas palavras-chave e não foi utilizado nenhum filtro adicional, conforme a Tabela 1

Tabela 1 | Seleção dos artigos

Base de dados	*Termos*	
	Conflitos and "Parque$ Eólico$"	Brasil and Conflitos and "Parque$ Eólico$"
SciElo	1 resultado	6 resultados – 5 artigos selecionados, após aplicação dos critérios de exclusão
Scopus	313 resultados	9 resultados – 5 artigos selecionados, após aplicação dos critérios de exclusão
Web of Science	252 resultados	10 resultados – 2 artigos selecionados, após aplicação dos critérios de exclusão

Fonte: Elaboração própria.

Observa-se que a cada adição de palavras-chave o número de resultados muda, representando o afunilamento da pesquisa. Foram considerados principalmente os artigos encontrados com as palavras-chave "Brasil" e "Conflitos" e "Parque$ Eólicos", no caso da base SciElo, e "Brazil" e "Conflict$" e "Wind Farm$" no caso da Scopus e da Web of Science.

Finalmente, foram feitas buscas conforme relevância e número de citações sobre tipologias existentes de impactos socioambientais, a fim de servir como referência inicial e demonstrar a ainda incipiente tipologia de tais impactos e de seus decorrentes conflitos no âmbito dos países em desenvolvimento.

Uma vez realizada a pesquisa bibliográfica, com os termos "Brasil and Conflitos and Parque$ Eólico$", e aplicados os critérios de exclusão, foram selecionados 12 artigos. Foram excluídos os artigos repetidos entre as diferentes bases e aqueles que não tinham pertinência com o tema proposto.

Os artigos selecionados abordam principalmente os estados do Rio Grande do Norte, Pernambuco e Ceará, sendo que a maior quantidade encontrada de informações foi sobre as regiões de São Cristóvão, em Areia Branca (RN), do município da Serra do Mel (RN), da comunidade de Xavier, na zona costeira do Ceará, e das Comunidades de Galos e de Galinhos no Rio Grande do Norte. Tais artigos abordam o bioma da Caatinga, predominante no território nordestino, e a maior parte dos parques eólicos nessas regiões, que se encontra em fase de instalação ou operação. Os artigos abordam contextos locais a partir

de 2001, recorte temporal utilizado na pesquisa, quando a crise energética ganhou força e teve início o fortalecimento de uma transição energética de combustíveis fósseis para energias renováveis no Brasil.

Com base nisso, elaborou-se um quadro esquemático sobre os principais impactos socioambientais identificados pela literatura, isto é, aqueles impactos que tenham gerado diretamente conflitos socioambientais locais, com base na tipologia criada por Farias, Silva e Carvalho (2021). Esse trabalho foi escolhido como base para a construção da presente pesquisa, pois entre a bibliografia analisada, foi o único que apresentou uma tipologia preliminar de impactos negativos, que são potenciais geradores de conflitos. A classificação inicial desses impactos foi essencial para compreender e classificar os conflitos decorrentes. Foram considerados impactos identificados apenas no Nordeste brasileiro, pois a pesquisa se propõe a criar uma tipologia local, diferentemente de análises já realizadas com base em países desenvolvidos (Bell; Gray; Haggett, 2005; Bell *et al.*, 2013; Pasqualetti, 2011). Além disso, foram selecionados artigos que tratam apenas de parques eólicos localizados em terra (onshore) e excluídos os artigos que tratam de impactos que não necessariamente geram conflitos locais. Como o objetivo do levantamento dos impactos é relacioná-los a consequentes conflitos causados, foram considerados apenas impactos negativos.

Desses impactos, foram levantados os consequentes conflitos ocasionados no local de implementação dos parques, conforme mencionados pelos artigos analisados, classificados nos seguintes tipos: (i) econômicos; (ii) fundiários; (iii) hídricos; e (iv) saúde e bem-estar. Essa tipologia foi estabelecida com base em elementos em comum presentes nos 12 artigos analisados. Reconhece-se a parcial arbitrariedade na escolha de tais tipos de conflitos (como o é em qualquer tipologia ainda não suficientemente explorada na literatura), mas a elaboração da tipologia se baseou em conflitos identificados pela literatura especializada, de modo que possuem fundamento para seu enquadramento na forma proposta. Além disso, as descrições e legendas pormenorizadas de cada tipo levantado estão explicadas na discussão dos resultados. Importante esclarecer, por fim, que o presente estudo pretendeu realizar a tipologia de conflitos e não de impactos, os quais são apenas as causas identificadas para aqueles.

4 RESULTADOS E DISCUSSÃO

Uma vez revisados os artigos, foram identificados 21 conflitos ocasionados pela implementação de parques eólicos no Nordeste, decorrentes de impactos socioambientais dos empreendimentos, mencionados 40 vezes na literatura e organizados em planilha Excel. Esses conflitos foram classificados em quatro diferentes tipos, quais sejam: “econômicos”, “fundiários”, “hídricos” e “saúde e bem-estar” (Figura 2 e Quadro 1), aprofundados nesta seção de acordo com os diferentes fatores que evidenciam a situação de injustiça ambiental.

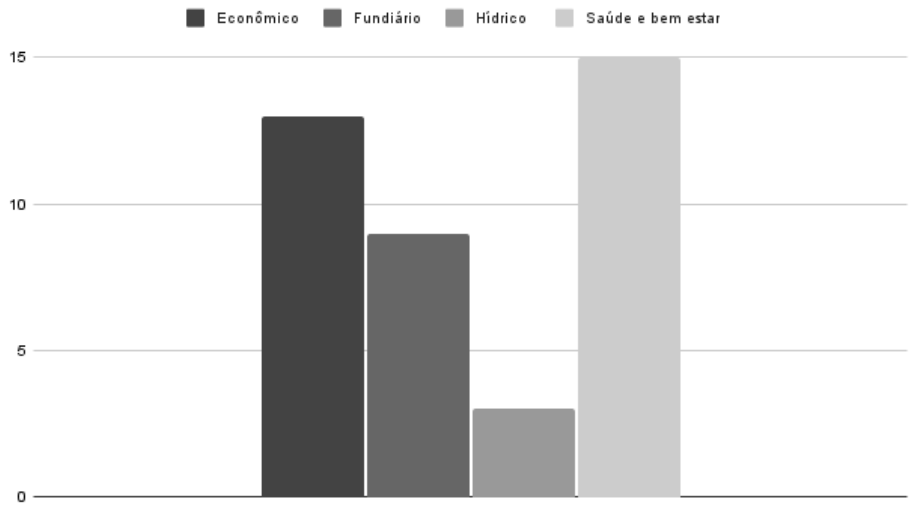

Figura 2 | Quantidade de menções dos conflitos
Fonte: Elaboração própria.

Nota-se que a maior parte das menções dos conflitos (15) se refere àqueles relacionados à saúde e bem-estar, seguidas pelas menções aos conflitos econômicos (13), que serão exemplificados e explicados individualmente nos tópicos desta seção. Ainda, há uma grande quantidade de menções sobre conflitos identificados como fundiários (nove) e apenas três relacionadas a aspectos hídricos. A descrição pormenorizada de cada um desses tipos, bem como a discussão dos resultados considerando os conceitos de injustiça ambiental e de conflitos, é feita a seguir.

Tabela 2 | Conflitos decorrentes dos impactos

Impactos	Conflitos	Conceito	Bibliografia
Visual; degradação do ambiente dunar, do solo e subsolos e da área afetada; supressão da vegetação; fauna; interferências locais; poluição sonora e atmosférica.	Econômico	Gerados pela restrição e diminuição das atividades econômicas e de subsistência locais.	BRANNSTROM et al. (2017) PINTO, MARTINS e PEREIRA (2017) FRATE et al. (2019) PAIVA e LIMA (2019) SANTANA e SILVA (2021) SOBRINHO JUNIOR et al. (2022)
Interferências locais e degradação da área afetada.	Fundiário	Gerados por divergências entre a população local e os empreendimentos relacionados ao uso e à ocupação da terra.	PORTO, FINAMORE e FERREIRA (2013) GORAYEB e BRANNSTROM (2016) BRANNSTROM et al. (2017) AVILA (2018) NERI et al. (2019) PAIVA e LIMA (2019) ARAÚJO et al. (2020) SANTANA e SILVA (2021)
Poluição Hídrica.	Hídrico	Gerados em decorrência de prejuízos ou comprometimento à disponibilidade e/ou da qualidade da água na região.	GORAYEB e BRANNSTROM (2016) BRANNSTROM et al. (2017) FRATE et al. (2019) ARAÚJO et al. (2020)
Interferências locais; poluição atmosférica e sonora e impacto visual.	Saúde e bem-estar	Relacionados a patologias decorrentes da instalação dos parques e/ou interferência na sensação de conforto e segurança dos moradores locais.	GORAYEB et al. (2016) PINTO, MARTINS e PEREIRA (2017) BRANNSTROM et al. (2017) PAIVA e LIMA (2019) ARAÚJO et al. (2020) SANTANA e SILVA (2021) SOBRINHO JUNIOR et al. (2022)

Fonte: Elaboração própria.

Os impactos considerados apareceram repetidas vezes em vários artigos da literatura analisada, o que possibilitou a classificação com base na tipologia elaborada por Carvalho, Farias e Silva (2021), importante por diferenciar tais impactos em tipos como poluição hídrica, interferências locais, poluição sonora, contribuindo para a conseguinte criação de uma tipologia de conflitos.

Além disso, a partir da contagem e análise de menções aos conflitos, foi possível identificar em que fase eles aconteceram. Diante disso, dos 40 conflitos mencionados, aproximadamente 42,5% deles surgiram desde a fase de instalação e permaneceram durante a operação dos parques (Figura 3).

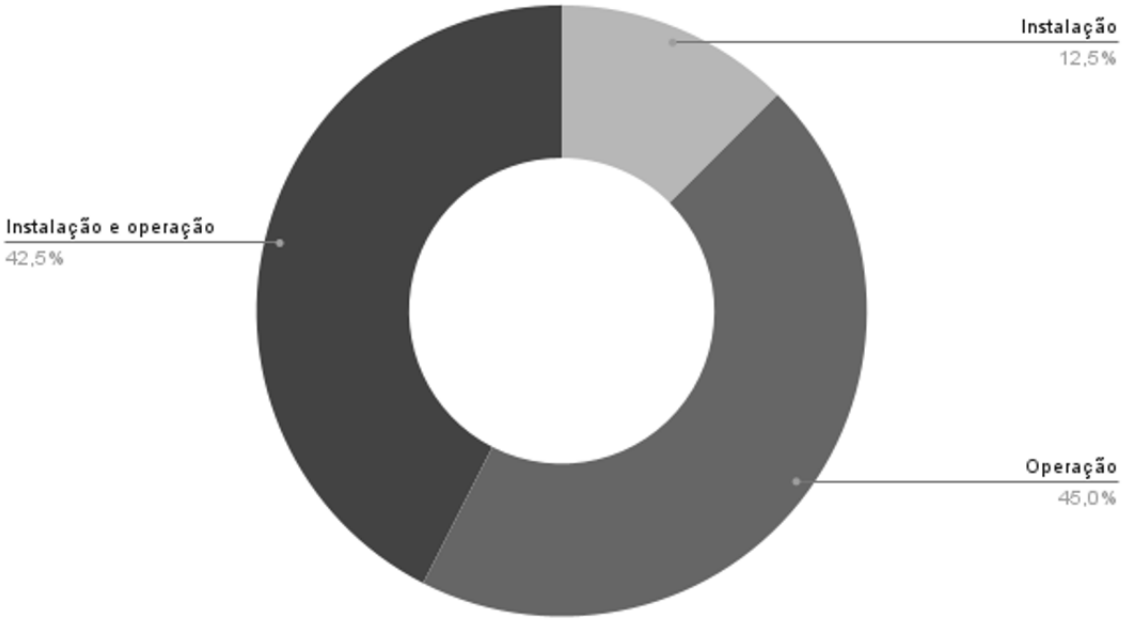

Figura 3 | Fases dos conflitos.
Fonte: Elaboração própria.

A análise apresentada é baseada na definição de Acselrad (2004) de conflitos socioambientais. Para o autor, conflitos socioambientais envolvem grupos sociais com diferentes modos de apropriação, uso e significação de um território e surgem quando pelo menos um dos grupos tem suas formas sociais de apropriação do meio ameaçadas por impactos indesejáveis, podendo ser relacionados ao solo, água, ar ou sistemas vivos, decorrentes de atividades exercidas por outros grupos.

4.1 CONFLITOS ECONÔMICOS

Foram definidos como conflitos econômicos aqueles gerados pela restrição e diminuição das atividades econômicas e de subsistência locais. Do total de conflitos analisados, nove estão na categoria econômicos e foram mencionados 13 vezes na bibliografia analisada. Dentro dessa classificação, os 13 conflitos surgiram a partir de diferentes impactos, sendo eles: um de impacto visual, um de impacto de degradação do ambiente dunar, dois de impactos de supressão da vegetação, dois de impactos de degradação do solo e subsolos, um de impacto de fauna, um de impacto de degradação da área afetada, quatro de interferências locais, um de impacto de poluição sonora e um de poluição da atmosfera, sendo esses impactos caracterizados por Carvalho, Farias e Silva (2021).

Foram identificados diversos conflitos econômicos relacionados a prejuízos causados ao turismo, fazendo com que a economia local fosse fortemente impactada negativamente. Um dos fatores responsáveis por isso é a alteração da paisagem, causada pelos aerogeradores durante sua fase de operação (Frate *et al.*, 2019; Paiva; Lima, 2019; Pinto; Martins; Pereira, 2017; Sobrinho Júnior *et al.*, 2022). Há casos em que os moradores locais afirmaram que as turbinas são "monstros mecânicos" que obstruem a visão do pôr do sol (Frate *et al.*, 2019). No contexto nordestino, afetam inclusive áreas litorâneas, visitadas por serem consideradas locais de veraneio e lazer (Pinto; Martins; Pereira, 2017). Em contraponto, foram identificados relatos de moradores que, por exemplo, consideram a alteração da paisagem como algo positivo e que pode contribuir para o turismo de avistamento dos aerogeradores (Sobrinho Júnior *et al.*, 2022).

Outro fator de alteração de paisagens é a terraplanagem de dunas. Devido ao grande movimento de caminhões e de pessoas, as areias do solo se nivelaram, fazendo desaparecer as dunas daquela região. Para o turismo e lazer, isso também dificulta algumas práticas como a de kitesurfing, afastando os turistas e prejudicando os hotéis locais (Brannstrom *et al.*, 2017).

Também foram identificados conflitos econômicos que se relacionam com a fonte de renda gerada por atividades de subsistência, prejudicadas pela alteração da superfície da terra, sistemas de drenagem e vegetação, redução na qualidade ambiental e da biodiversidade. Impactos como a mortandade de aves e morcegos, que contribuem para a reprodução da vegetação, a alteração na economia das comunidades próximas aos empreendimentos, como a carcinicultura e a pesca em geral, e o êxodo rural causado pelo impacto na agricultura local são exemplos de causadores de conflitos econômicos (Brannstrom *et al.*, 2017; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

A maior parte dos conflitos gerados durante as fases de instalação e operação, e que interferiram nas fontes de subsistência, decorreu do impacto sobre a agricultura local, prejudicada pela redução de áreas agricultáveis, supressão de vegetação nativa e diminuição da produção de alimentos devido ao tráfego de veículos pesados e ao ruído das turbinas. Em alguns casos, os impactos se deram sobre culturas que eram a base da economia local, como no município de Serra do Mel (RN), em que a produção de caju foi afetada, e das comunidades de Larguinha e de Pau Ferro, no município de Caetés (PE), onde houve relevante mudança no ritmo da produção de milho e redução da oferta de leite e ovos (Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

A questão da injustiça ambiental se torna evidente nos conflitos econômicos descritos, dado que as comunidades afetadas enfrentam desafios significativos devido à alteração do ambiente natural, base de suas economias. Tais impactos ambientais causados pela construção de parques eólicos podem resultar em perda de renda, êxodo rural e afetar até mesmo a subsistência dessas comunidades, conforme demonstrado anteriormente.

Esses fatores destacam as injustiças ambientais, como descrito por Ferreira, Finamore e Porto (2013), pois prejudicam principalmente as comunidades já marginalizadas, desproporcionalmente afetadas pelos impactos ambientais negativos. Nesses casos, os lucros decorrentes das atividades geradoras de energia não são repartidos com as comunidades locais, que ficam apenas com os seus ônus e até com sua subsistência comprometida.

4.2 CONFLITOS FUNDIÁRIOS

Foram considerados conflitos fundiários aqueles causados por divergências entre a população local e os empreendimentos relacionados ao uso e à ocupação da terra. Entre os diferentes conflitos identificados, quatro foram classificados como fundiários, mencionados nove vezes na bibliografia analisada. Três desses conflitos decorreram de interferências locais e apenas um de degradação da área afetada.

Foram identificados diversos conflitos fundiários relacionados à restrição de acesso da população local a espaços antes tidos como públicos (ainda que não o fossem), onde foram instalados parques eólicos. Nesses casos, o bloqueio de acesso a vias anteriormente utilizadas pela população, agora cercadas com grades e portões de segurança com guardas armados, gera restrições de acesso ou aumento do tempo de deslocamento da população local a serviços públicos essenciais, como escolas, coleta municipal de resíduos e unidades de saúde (Araújo *et al.*, 2020; Ávila, 2018; Brannstrom *et al.*, 2017; Gorayeb; Brannstrom, 2016; Porto; Finamore; Ferreira, 2013; Santana; Silva, 2021).

Na comunidade de Xavier, no município de Camocim (CE), o cercamento da área do parque eólico impedia tarefas cotidianas da população, inclusive atividades de subsistência, como a pesca de moluscos, fonte

de renda e de alimentação da comunidade. Em 2013, por meio de um termo de compromisso com o Ministério Público estadual, o acesso da comunidade à estrada foi liberado mediante controle e, ainda, o empreendedor responsável pelo parque construiu uma estrutura refrigerada para armazenamento de peixe e para servir de base comunitária para a associação local (Brannstrom *et al.*, 2017).

Alguns autores identificam também conflitos fundiários já existentes e intensificados com a instalação dos parques eólicos, em razão da perda de força política de comunidades tradicionais diante dos empreendimentos. Nesse sentido, Ávila (2018) e Neri *et al.* (2019) indicam que a instalação de parques eólicos ou a mera identificação de potencial eólico de determinado local levam a uma dificuldade ainda maior por parte de povos tradicionais em terem suas terras reconhecidas e demarcadas, dado o interesse econômico em tais territórios. Tal situação também foi identificada na Reserva Estadual Ponta do Tubarão, localizada nos municípios de Macau e de Guamaré, no estado do Rio Grande do Norte, criada após décadas de luta social da população local e que, mesmo já protegida, foi alvo de conflitos com a instalação de um parque eólico que enfraqueceu politicamente a proteção da unidade de conservação (Ávila, 2018).

Além dos conflitos fundiários gerados por interferências locais, Paiva e Lima (2019) mencionam conflitos fundiários gerados pela degradação da área afetada pelos parques, devido à destruição de sítios arqueológicos e desrespeito às culturas dos povos locais e de suas relações com o território.

Os conflitos fundiários descritos acima também deixam explícita a injustiça ambiental. Como os parques eólicos são geralmente instalados em regiões com populações já marginalizadas socialmente, essas pessoas têm o acesso a direitos básicos ainda mais dificultado, além de perder ainda mais poder político. Em prol de uma matriz elétrica menos poluente, a população local, que nem sempre se privilegia diretamente de tais empreendimentos, acaba tendo seus direitos fundamentais cerceados, como a instalação de cercas e a restrição de acesso a áreas que antes eram de livre acesso. O caso da comunidade de Xavier, ilustrado anteriormente, mostra que, muitas vezes, alguns desses conflitos seriam facilmente evitados e sem (ou com baixos) custos ao empreendedor.

4.3 CONFLITOS HÍDRICOS

Foram considerados como conflitos hídricos aqueles ocorridos em decorrência de prejuízos ou comprometimento da disponibilidade e/ou da qualidade da água na região. Esse conflito se dá principalmente pelo soterramento de rios, lagos e lagoas. Do total de aspectos analisados, a alteração na disponibilidade hídrica local foi mencionada três vezes na bibliografia e tem como impacto causal a "poluição hídrica".

O soterramento de rios, lagos e lagoas tem como causa principal a alteração nas dunas, estuários e praias, quando a terraplanagem de áreas para instalação das turbinas interrompe o fluxo de água entre rios e lagos existentes entre as porções de dunas (Brannstrom *et al.*, 2017). Na bibliografia analisada, essa situação foi identificada tanto na fase de instalação como de operação dos parques eólicos, nos estados do Ceará e do Rio Grande do Norte.

Na comunidade de Xavier, na zona costeira do Ceará, um parque eólico enterrou lagoas interdunares da região, o que impediu o acesso da população a bens e a serviços vindos de fora da comunidade e também que a pesca de subsistência fosse praticada (Gorayeb; Brannstrom, 2016). Outro exemplo identificado foi a alteração na disponibilidade hídrica devido a interferências no lençol freático, em decorrência das fundações das torres eólicas nas dunas na região costeira do Ceará (Araújo *et al.*, 2020). Nas comunidades de Galos e de Galinhos, no Rio Grande do Norte, o rio da região ficou mais raso devido à movimentação de areia das dunas, o que resultou em restrições na navegabilidade da população. Além disso, o assoreamento de rios, lagos e lagoas prejudica aquíferos, a fauna e a flora

aquáticas de regiões locais, pois ao afetar o habitat, seres mais sensíveis morrem e outros emigram, assim alterando os ecossistemas (Frate *et al.*, 2019).

Dessa forma, diante do conceito de justiça ambiental, os conflitos hídricos surgem do comprometimento da garantia do acesso a bens naturais, em claro exemplo de injustiça ambiental (Acselrad, 2010; Porto; Finamore; Ferreira, 2013). A população local afetada fica insatisfeita por deixar de possuir acesso a recursos hídricos, como lagos, lagoas e rios, que por vezes deixam de existir, tanto por questões de subsistência quanto por valores culturais, muitas vezes diretamente ligados a esses recursos. Por exemplo, ao possuírem diferentes formas de interação com os corpos-d'água, para muitas populações esses bens naturais são considerados sagrados, além de estarem ligados à identidade cultural de povos (Gorayeb *et al.*, 2017). Logo, quando a instalação de parques eólicos compromete a disponibilidade de água de um local é comum que surjam conflitos hídricos.

4.4 CONFLITOS RELACIONADOS À SAÚDE E AO BEM-ESTAR

Foram categorizados como conflitos de "saúde e bem-estar" aqueles que se relacionam a patologias decorrentes da instalação dos parques e/ou interferência na sensação de conforto e segurança dos moradores locais. Seguindo essa descrição, foi possível identificar 15 menções a conflitos de "saúde e bem-estar", sendo o tipo mais mencionado na bibliografia analisada. Sete desses conflitos foram causados por impactos classificados como "interferência local", seis por "poluição sonora" e um por "impacto visual".

Destacam-se os conflitos decorrentes do impacto apontado pelas populações locais como "território do medo", decorrente da instalação de placas que trazem alertas (necessários por questões de segurança), como "risco de morte" e "rotas de fuga", em volta dos limites dos parques eólicos. Apesar da sinalização ser obrigatória em locais onde há cabos elétricos de alta tensão enterrados, é possível vê-los expostos sobre a superfície, em ambientes de acesso comum, em lagoas, dunas, plantações e até mesmo em pesqueiros, significando maior risco a acidentes (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017). Na já mencionada comunidade de Xavier, o território do medo é ainda mais presente, pois além das placas de sinalização, em 2009, houve um acidente em que uma das turbinas pegou fogo (Brannstrom; Gorayeb, 2016).

Por consequência, além de existirem placas que levam os moradores a um constante estado de alerta em locais que anteriormente representavam momentos de lazer, a fácil visibilidade desses cabos só reforça a possibilidade de acidentes, causando perturbação, comprometendo a sua qualidade de vida e oferecendo risco de vida para esses moradores. Diante disso, é importante que haja a consideração da interferência que essas instalações causam na saúde psicológica das comunidades para que seu bem-estar seja garantido.

Martins, Pereira e Pinto (2017) identificaram conflitos relacionados ao bem-estar gerados por interferências locais tanto na fase de instalação quanto na operação de parques eólicos. Esses conflitos surgiram com interferências eletromagnéticas dos aerogeradores, causando perturbações nas comunicações e transmissões de dados (rádio, televisão, etc.) em comunidades próximas a instalações eólicas. Tais conflitos se encaixam no tipo "saúde e bem-estar", considerando que o acesso à informação e à comunicação é direito fundamental e está ligado aos direitos humanos para alcançar os Objetivos de Desenvolvimento Sustentável (ONU, 2023).

Outro conflito identificado está relacionado ao intenso tráfego de veículos de grande porte durante o processo de instalação das torres eólicas, que gera interferências locais e poluição atmosférica, sendo identificado duas vezes na bibliografia explorada (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017). As nuvens de areia e de poeira geradas por esse intenso tráfego impactaram áreas residenciais e escolas,

provocando doenças respiratórias e afetando a saúde e o bem-estar das comunidades próximas aos parques eólicos.

Segundo Sette e Ribeiro (2011), qualquer modificação na composição do ar pode constituir um verdadeiro problema de saúde para o indivíduo. Por isso, no caso do intenso tráfego de veículos pesados, as nuvens de partículas em suspensão têm um impacto significativo na saúde da população, pois a inalação dessas partículas pode causar uma série de problemas respiratórios, como tosse, falta de ar, chiado no peito e até mesmo o desenvolvimento de asma em indivíduos suscetíveis, além de causar problemas oculares, como irritação nos olhos e, em casos mais graves, até danos à córnea.

Já durante a fase de operação, um impacto que afeta diretamente a saúde e o bem-estar pode ser observado no caso do município de Caetés (PE), nas comunidades de Larguinha e Pau Ferro, nas quais Santana e Silva (2021) identificaram relatos de moradores com forte incômodo, tontura e enjoo gerados pelas sombras produzidas pelas hélices. Além disso, a perturbação causada pela poluição sonora das turbinas das torres eólicas é o impacto que foi mais vezes citado nos conflitos de saúde e bem-estar, mencionado sete vezes (Araújo *et al.*, 2020; Brannstrom *et al.*, 2017; Gorayeb; Brannstrom, 2016; Paiva; Lima, 2019; Pinto; Martins; Pereira, 2017; Santana; Silva, 2021; Sobrinho Júnior *et al.*, 2022).

Em todos os trabalhos analisados, as queixas por parte dos moradores locais quanto ao ruído das turbinas ocorrem de forma muito veemente, reclamando de grande perturbação sonora, intensificada ainda mais pela proximidade das turbinas em alguns casos. Muitos moradores relataram que, com o funcionamento dos parques eólicos, passaram a ter dores de cabeça fortes e constantes. Ainda é citada a dificuldade de adaptação das crianças com os ruídos, fazendo com que os choros e incômodos em geral sejam constantes.

Para melhor entendimento da dimensão do impacto negativo que essa poluição sonora causa aos moradores, deve-se considerar o ambiente anterior à instalação dos parques eólicos, em locais afastados, normalmente tranquilos e silenciosos, com proximidade à natureza. Com isso, embora os níveis de ruídos nesses locais estejam dentro dos limites estabelecidos por regulamentações, os moradores são fortemente afetados pela diferença do ambiente sem as torres eólicas, chegando a relatos de moradores que consideram o ruído semelhante a um "helicóptero que nunca pousa" (Araújo *et al.*, 2020, p. 12). Portanto, é evidente que as instalações eólicas geram impacto na saúde e no bem-estar de moradores locais, sendo que algumas pessoas podem experimentar distúrbios do sono, estresse ou outros problemas de saúde devido ao ruído constante.

Além disso, embora as turbinas eólicas transmitam pequenas vibrações consideradas insignificantes, foi relatada por agricultores no interior do Ceará a percepção dessas vibrações, emitidas pelos aerogeradores, mas também devido à movimentação de automóveis pesados, da realização de estudos geotécnicos e hidrogeológicos, e da compactação do solo. Em alguns casos, houve o comprometimento estrutural de casas e construções feitas com materiais mais frágeis (Sobrinho Júnior *et al.*, 2022).

A relação entre injustiça ambiental e saúde é intrinsecamente ligada, pois o ambiente em que o ser humano vive desempenha papel fundamental em sua saúde. Entretanto, ao analisar os ônus e bônus gerados pela energia eólica, nota-se que não estão sendo distribuídos de forma justa. Comunidades já pobres e que sofrem injustiças sociais – inclusive com menor acesso a instalações de saúde, médicos e medicamentos – são as que ficam com os ônus em sua saúde e bem-estar. Em contrapartida, os empreendedores ficam com os bônus dos lucros e com o prestígio de estarem colaborando para o avanço do desenvolvimento sustentável por meio da geração de energia considerada limpa. Com isso, nota-se o entrelaçamento de injustiças ambientais e sociais e das contradições da energia limpa.

5 CONCLUSÃO

Embora a energia eólica seja uma das menos poluentes atualmente, há muitos impactos negativos gerados por parques eólicos, especialmente durante sua fase de instalação e operação. A partir da bibliografia analisada, foi possível identificar uma lacuna de elaboração de tipologia para os conflitos causados pela implantação de parques eólicos no contexto do Nordeste brasileiro, sendo encontradas apenas tipologias para os impactos causados e, sobretudo, no contexto dos países desenvolvidos. Assim, o presente artigo identificou os principais conflitos socioambientais na Região Nordeste gerados pelos parques eólicos e os categoriza em quatro tipos.

Os conflitos relacionados a impactos na saúde e no bem-estar e os conflitos econômicos são os que possuem maior número de menções na bibliografia. Entre as diferentes causas para tais conflitos, destacam-se os impactos na saúde e no bem-estar causados pela poluição sonora dos ruídos das turbinas eólicas, bem como mal-estar relacionado às constantes sombras das pás eólicas. Do ponto de vista psicológico, há ainda um constante medo e sensação de perigo em decorrência de acidentes, placas de sinalização e fios de alta tensão expostos. Além disso, há impactos na saúde e no bem-estar relacionados a impactos nas atividades de subsistência, dificultadas ou impedidas por interferências no espaço e na biodiversidade local, refletindo também em conflitos econômicos, devido aos prejuízos à agricultura, à pesca e ao turismo.

Nos conflitos fundiários, destacaram-se impactos relacionados à acessibilidade das populações locais a territórios anteriormente tidos e utilizados como públicos, dificultando seu acesso a serviços essenciais e cotidianos. Além disso, foram identificados casos em que terras foram invadidas e comunidades "apagadas" culturalmente. Nos conflitos relacionados à disponibilidade e à qualidade da água, as causas principais foram o assoreamento de lagoas, lagos e rios, intervindo na vida aquática dos animais terrestres e das comunidades locais.

É possível afirmar que os conflitos identificados e classificados emergem em decorrência de reiteradas injustiças ambientais. A população diretamente afetada pela instalação e operação de parques eólicos no Nordeste brasileiro enfrenta injustiças ambientais marcantes, pois enquanto os benefícios dos empreendimentos não lhes são devidamente repassados, eles suportam integralmente os ônus, incluindo impactos ambientais e alterações em seu modo de vida.

Em suma, o artigo contribui para a identificação dos principais conflitos socioambientais gerados pelos parques eólicos no Nordeste durante sua instalação e operação, apresentando uma tipologia de quatro conflitos. Em um cenário internacional de transição energética para fontes renováveis e com menores emissões de gases de efeito estufa, é desejável que o Brasil aumente a participação de fontes como a eólica em sua matriz elétrica. Contudo, a transição deve ser feita tendo a justiça ambiental como ponto de partida, observando e respeitando as comunidades locais diretamente afetadas. Caso contrário, conflitos de diferentes naturezas surgirão, dificultando o esforço para que os respectivos empreendimentos possam ser considerados "limpos" e efetivos na oferta de energia para a população. A tipologia de conflitos apresentada no presente trabalho pode contribuir para o planejamento da implantação de parques eólicos, sendo certo que muitos deles podem ser evitados a baixo custo e, em alguns casos, sem que haja custo.

REFERÊNCIAS

ACSELRAD, H. As práticas espaciais e o campo dos conflitos ambientais. *In*: **Conflitos Ambientais no Brasil.** ACSELRAD, H. (org), Rio de Janeiro: Relume Dumará: Fundação Heinrich Böll. São Paulo, p. 13-35, 2004.

ACSELRAD, H. Grassroots reframing of environmental struggles in Brazil. *In*: CARRUTHERS, D. V. (Ed.) **Environmental Justice in Latin America. Cambridge**: MIT Press, 2008. DOI: https://doi.org/10.7551/mi-

tpress/9780262033725.003.0004. Available at: https://academic.oup.com/mit-press-scholarship-online/book/22802/chapter-abstract/183255158?redirectedFrom=fulltext. Accessed on: 31 jul. 2023.

ACSELRAD, H. Ambientalização das lutas sociais: o caso do movimento por justiça ambiental. **Estudos avançados**, São Paulo, v. 24, n. 68, p. 127-150, 2010. DOI: https://doi.org/10.1590/S0103-40142010000100010. Available at: https://www.scielo.br/j/ea/a/hSdks4fkGYGb4fDVhmb6yxk/?lang=pt. Accessed on: 26 jul. 2023.

ACSELRAD, H.; HERCULANO, S.; PÁDUA, J. A. **Justiça ambiental e cidadania**. Rio de Janeiro: Relume Dumará, 2004. ISBN: 85-7316-353-4. Available at: https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://edisciplinas.usp.br/mod/resource/view.php%3Fid%3D387079&ved=2ahUKEwjGyK-Q9rmAAxWNp5UCHRLPA5oQFnoECB8QAQ&usg=AOvVaw0hxhmk-Fez2CHdVyog3f-q. Accessed on: 31 jul. 2023.

ARAÚJO, J. C. H. Entre expropriações e resistências: a implementação de parques eólicos na zona costeira do Ceará, Brasil. **Cadernos do CEAS**, Salvador, n. 237, p. 327-346, 2016. ISSN: 2447-861X. Available at: https://cadernosdoceas.ucsal.br/index.php/cadernosdoceas/article/view/236/209. Accessed on: 31 jul. 2023.

ARAÚJO, J. C. H. *et al.* Sustainability challenges of wind power deployment in Coastal Ceará State, Brazil. **Sustainability**, v. 12, p. 5562, 2020. DOI: 10.3390/su12145562. Available at: https://www.mdpi.com/2071-1050/12/14/556. Accessed on: 31 jul. 2023.

ASSOCIAÇÃO BRASILEIRA DE ENERGIA EÓLICA E NOVAS TECNOLOGIAS. **Boletim anual 2021**. São Paulo: Abeeólica, 2022. Available at: https://abeeolica.org.br/energia-eolica/dados-abeeolica/?slug=boletim-anual. Accessed on: 31 mar. 2023.

ÁVILA, S. Environmental justice and the expanding geography of wind power conflicts. **Sustain. Sci**., v. 13, p. 599–616, 2018. DOI: https://doi.org/10.1007/s11625-018-0547-4. Available at: https://link.springer.com/article/10.1007/s11625-018-0547-4. Accessed on: 31 jul. 2023.

BALANÇO ENERGÉTICO NACIONAL. **Relatório Síntese 2022**. Ministério de Minas e Energia: Brasília, 2022. Availableat: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2022. Accessed on: 31 mar. 2023.

BELL, D.; GRAY, T.; HAGGETT, C. The 'Social Gap' in wind farm siting decisions: explanations and policy responses. **Environmental Politics**, v. 14, n. 4, 2005, p. 460-477. ISSN: 1743-8934. DOI: 10.1080/09644010500175833. Available at: https://www.tandfonline.com/doi/abs/10.1080/09644010500175833. Accessed on: 29 jul. 2023.

BELL, D. *et al.* Re-visiting the 'Social Gap': public opinion and relations of power in the local politics of wind energy. **Environmental politics**, v. 22, n. 1, 2013, p. 115-135. ISSN: 1743-8934. DOI: 10.1080/09644016.2013.755793. Available at: https://www.tandfonline.com/doi/abs/10.1080/09644016.2013.755793. Accessed on: 29 jul. 2023.

BEZERRA, F. D. **Energia eólica no Nordeste**. Banco do Nordeste, Fortaleza, dezembro, 2021. Available at: https://www.bnb.gov.br/s482-dspace/bitstream/123456789/1045/1/2021_CDS_200.pdf. Accessed on: 08 out. 2023.

BRANNSTROM, C. *et al.* Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state. **Renewable and Sustainable Energy**, v. 67, p. 62–71, 2017. ISSN: 1364-0321. DOI: http://dx.doi.org/10.1016/j.rser.2016.08.047. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1364032116304804?via%3Dihub. Accessed on: 27 jul. 2023.

BRASIL. Lei nº 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional do Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. **Diário Oficial da União**. Brasília, DF, 2 set. 1981. Available at: https://www.planalto.gov.br/ccivil_03/Leis/L6938.htm. Accessed on: 3 jun. 2023.

DRUMMOND, P.; FERRAZ, J. C.; RAMOS, L. Wind energy in Europe, Brazil and the UK. In: EEIST – Economics of Energy Innovation and System Transition. **The new economics of innovation and transition**: evaluating opportunities and risks.

EEIST, University of Exeter: Exeter, UK, 2022, p. 8-11. Available at: https://eeist.co.uk/eeist-reports/the-new-economics-of-innovation-and-transition-evaluating-opportunities-and-risks/. Accessed on: 14 out. 2023.

FARIAS, A. L. A. Impactos e conflitos socioambientais de grandes projetos na Amazônia: até quando Barcarena/PA será uma zona de sacrifício? **INTERthesis: Revista Internacional Interdisciplinar**, v. 20, p. 01-21, jan./dec. 2023. DOI: https://doi.org/10.5007/1807-1384.2023.e90583. Available at: https://orcid.org/0000-0002-0982-4212. Accessed on: 11 oct. 2023.

FARIAS, M. R. F. S.; SILVA, Í. H. M.; CARVALHO, R. G. Energias renováveis: o parque eólico de São Cristóvão, município de Areia Branca (RN), Brasil. **Revista de Geografia e Ordenamento do Território**, v. 22, p. 111-139, 2021. ISSN: 2182-1267. DOI: dx.doi.org/10.17127/got/2021.22.005. Available at: https://docplayer.com.br/229826305-Energias-renovaveis-o-parque-eolico-de-sao-cristovao-municipio-de-areia-branca-rn-brasil.html. Accessed on: 27 jul. 2023.

FRATE, C. A. *et al.* Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil. Energy Policy, v. 132, p. 185-195, 2019. DOI: https://doi.org/10.1016/j.enpol.2019.05.027. Available at: 10.1016/j.enpol.2019.05.027. Accessed on: 27 jul. 2023.

GORAYEB, A.; BRANNSTROM, C. Caminhos para uma gestão participativa dos recursos energéticos de matriz renovável (parques eólicos) no Nordeste do Brasil. **Mercator**, v. 15, n. 1, p. 101-115, jan./mar., 2016. DOI: 10.4215/RM2016.1501. 0008 Available at: https://www.scielo.br/j/mercator/a/JRtprDJJnXZT3kfDx3Dw8qy/?format=pdf&lang=ptAccessed on: 31 jul. 2023.

GORAYEB, A. *et al.* Wind power gone bad: critiquing wind power planning processes in northeastern Brazil. **Energy Research & Social Science**. v. 40, p. 82. Elsevier. 2017. DOI: https://doi.org/10.1016/j.erss.2017.11.027.

GORAYEB, A. *et al.* Wind-energy development causes social impacts in Coastal Ceará state, Brazil: the case of the Xavier Community. **Journal of Coastal Research**, v. 75, p. 383-387, 2016. DOI: 10.2112/SI75-077.1. Available at: http://www.observatoriodaenergiaeolica.ufc.br/wp-content/uploads/2019/08/Gorayebetal2016.pdf. Accessed on: 14 aug. 2023.

NERI, M. *et al.* Green versus green? Adverting potential conflicts between wind power generation and biodiversity conservation in Brazil. **Perspectives in Ecology and Conservation**, v. 17, n. 3. p 131-135, 2019. DOI: https://doi.org/10.1016/j.pecon.2019.08.004. Available at: https://www.sciencedirect.com/science/article/pii/S2530064419300537. Accessed on: 31 jul. 2023.

ORGANIZAÇÃO DAS NAÇÕES UNIDAS. **Objetivos de Desenvolvimento Sustentável**. Available at: https://brasil.un.org/pt-br/sdgs. Accessed on: 13 apr. 2023.

PAIVA, I. T. P.; LIMA, E. C. Conflitos socioambientais, energia eólica e justiça ambiental: contribuições para uma análise crítica. **Revista GeoUECE**, v. 08, n. 14, p. 294-xx, jan./jun. 2019, versão online. DOI: 10.37084. Available at: https://revistas.uece.br/index.php/GeoUECE/article/view/2105. Accessed on: 31 jul. 2023.

PASQUALETTI, M. J. Opposing wind energy landscape: a search for common cause. **Annals of the Association of American Geographers**, v. 101, n. 4, p. 907-917, 2011. ISSN 00045608. Available at: https://www.jstor.org/stable/27980237. Accessed on: 29 jul. 2023.

PINTO, L. I. C.; MARTINS, F. R.; PEREIRA, E. B. O mercado brasileiro da energia eólica, impactos sociais e ambientais. **Ambient. Água**, v. 12, n. 6. Taubaté – Nov. / Dec. 2017. DOI: https://doi.org/10.4136/ambi-agua.2064. Available at: https://www.scielo.br/j/ambiagua/a/5b77GB9j4yPTzkS4pjxyhvH/?lang=pt. Accessed on: 31 jul. 2023.

PORTO, F. S. P.; FINAMORE, R.; FERREIRA, H. Injustiças da sustentabilidade: conflitos ambientais relacionados à produção de energia "limpa" no Brasil. **Revista Crítica de Ciências Sociais**, n. 100, maio 2013, p. 37-64. DOI: https://doi.org/10.4000/rccs.5217. Available at: https://journals.openedition.org/rccs/5217. Accessed on: 29 jul. 2023.

SANTANA, A. O.; SILVA, T. A. A. Produção de energia eólica em Pernambuco e a injustiça ambiental sobre comunidades rurais. **R. Katál**., Florianópolis, v. 24, n. 1, p. 245-254, jan./apr. 2021. DOI: https://doi.org/10.1590/1982-0259.2021.e73663 Available at: https://www.scielo.br/j/rk/a/nsbqwxf8gzFshryZGqKJhDc/?lang=pt. Accessed on: 31 jul. 2023.

SARLET, I. W.; FENSTERSEIFER, T. **Curso de direito ambiental**. 2ª ed., revista, atualizada e ampliada. Rio de Janeiro: Forense, 2021. ISBN: 9788530990640.

SETTE, D. M.; RIBEIRO, H. Interações entre o clima, o tempo e a saúde humana. **Interfacehs** (Ed. português), v. 6, p. 3, 2011. ISSN 1980-0894. Available at: http://www3.sp.senac.br/hotsites/blogs/InterfacEHS/wp-content/uploads/2013/08/3_ARTIGO_vol6n2.pdf. Accessed on: 31 jul. 2023.

SOBRINHO JÚNIOR, M. F. *et al.* Perception of environmental impacts of wind farms in agricultural areas of Northeast Brazil. **Energies**, v. 15, n. 101, 2022. DOI: https://doi.org/10.3390/en15010101. Available at: https://www.mdpi.com/1996-1073/15/1/101. Accessed on: 31 jul. 2023.

Perception of the socio-environmental impacts caused by wind generators in the state of Piauí, Northeast of Brazil

Percepção dos impactos socioambientais causados por geradores eólicos no estado do Piauí, Nordeste do Brasil

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ABSTRACT

The expansion of wind energy in Brazil has brought benefits, but many conflicts have arisen around rural communities. The research involved understanding the community's responses regarding the acceptance or rejection of wind farms in the Serra dos Pereiros community in Piauí from the procedural and distributive justice view. A questionnaire with ten answers was applied, which added together 31 variables. In statical analyses, with a population sample of 69 people, the Likert scale, Cronbach's alpha coefficient, and Spearman's correlation coefficient (rs) were used. From the results, 5 responses presented moderate positive or strongly positive correlations: change in the landscape, opinion about wind farms, political process for implementing wind farms, fairness of the process, and compensation. The data show that the development of policies that do not include the direct participation of society generates conflicts between the different institutional levels and significant local environmental and social problems.

Keywords: Social impacts. Wind energy. Procedural justice and Distributive justice. Perception.

RESUMO

A expansão da energia eólica no Brasil trouxe benefícios, mas surgiram muitos conflitos no entorno de comunidades rurais. A pesquisa consistiu em entender as respostas da comunidade em relação à aceitação/rejeição da implantação de parques eólicos na ótica da justiça processual e distributiva, na comunidade Serra dos Pereiros no Piauí. Aplicou-se um questionário com dez respostas que somaram juntas 31 variáveis. Nas análises estatísticas, com amostra populacional de 69 pessoas, utilizou-se a escala de Likert, o coeficiente alfa de Cronbach e o coeficiente de correlação de Spearman (rs).

Dos resultados, cinco respostas apresentaram correlações moderadas positivas ou fortes positivas: mudança na paisagem, opinião sobre os parques eólicos, processo político de implantação dos parques eólicos, justiça do processo e compensação. Os dados mostram que o desenvolvimento de políticas que não incluam a participação direta da sociedade gera conflitos entre os diferentes níveis institucionais e problemas de ordem ambiental e social local graves.

Palavras-chave: Impactos sociais. Energia eólica. Justiça processual e Justiça distributiva. Percepção.

1 INTRODUCTION

Since the Industrial Revolution, the economic disputes of countries and the quality of life of their inhabitants have been influenced by several factors, including energy. Clean energy production is a dynamic concept in which new procedures and technologies constantly emerge, searching methods and practices to prevent environmental damage (Giannetti *et al.*, 2020).

Brazil is part of the Global South Countries, which stand out in the generation of renewable energy. Among them, wind energy stands out as an alternative plan to non-renewable sources (of fossil origin), helping to reduce the greenhouse effect and global warming while preserving the planet's natural resources (Montefusco; Santos; Santos, 2020).

Social and political responses to wind energy development are highly variable globally. Numerous cases of opposition to wind energy in North America and Europe provide evidence of the persistence of the social gap, defined as the difference between national public opinion in favour of wind energy in contradiction to local perception opposition (Bell *et al.*, 2005; Bell *et al.*, 2013). The conflict often results from "imposition" (Pasqualetti, 2011a; Pasqualetti, 2011b), when entrepreneurs and the government prioritise technical issues of efficiency and wind quality above social impasses. Rand and Hoen (2017) argue that, in North America, issues related to justice, participation and trust between parties during the development of a wind farm are determining factors in the social acceptance of the project. The authors summarise several factors that the bibliography points to as "acceptance" or "rejection".

However, the topic of social opposition is little discussed in the Brazilian context, despite wind energy having environmental impacts, especially at the community level, from implementation to operation. Gorayeb and Brannstrom (2016) suggest measures to manage wind farm implementation policies better. These measures provide goals and directions related to the implementation of wind energy projects through municipal planning plans, including establishing, in more detail, the suitability of the location of the turbines, the number of projects and the relevance of the visual impact on the landscapes. To this end, it is important to consider the population that lives in the location with regard to information about projects and negotiations regarding their geographic location and the size of the enterprise.

That implies that the planners and the population should decide if the Project is compatible with the existent use of the land and if it negatively modifies the global character of the area, harming established communities since residents are the most impacted (Gorayeb; Brannstrom, 2019).

Even with the impacts of the increase in wind power, it is necessary to rethink parks that work from a win-win perspective, a "situation where everyone wins" in the sense of benefiting their owners, the consumer population and the population residing close to the parks (Juárez *et al.*, 2014, p. 833). That is, the installation of wind farms must consider issues relating to procedural justice and distributive justice.

It is noticed that the development of politics that does not include the direct participation of Society generates conflicts between the different institutional levels and major environmental and social order problems, a proportion of which we may only have an exact idea of in a few decades (Gorayeb; Brannstrom, 2016).

The present research is part of this discussion, considering that few academic works address fair energy social justice from the perspective of the vision of residents who live close to wind turbines installed in the Northeast of Brazil, specifically in the interior of Piauí.

Piauí, a federal state in Brazil, stands out in the wind generation scenario. According to data released by the Brazilian Wind Energy Association (Abeeólica, 2021), Piauí was the third state that produced the most wind energy in Brazil in 2022 (10.29 TWh), behind Bahia (24.17 TWh) and Rio Grande do Norte (23.20 TWh) (Abeeólica, 2022). The State of Piauí stands out today in the wind generation scenario. According to data from SIGA (Aneel) from June 2023, the state occupied the third position in the number of wind farms (173) and also in supervised power (3,526.5 MW).

The objective of the research was to understand the community's responses in relation to the acceptance/rejection of the implementation of wind farms from the perspective of procedural and distributive justice. Here, the results of a face-to-face survey carried out in the Serra dos Pereiros community in the municipality of Caldeirão Grande do Piauí – PI were analysed. The results are presented from the 31 questions referring to the answers to the variables impact on daily life, landscape changes, visibility, opinion on wind farms, political process of implementing wind farms, fairness of the process, compensation, noise nuisance, sensitivity to noise and perception of background noise. Results with moderate and strong correlations with statistical significance were discussed. These correlations are carried out between two variables with the same response, or in cases where the response has a single variable, correlation is carried out between variables with different responses that are identical to each other.

2 ENERGETIC SOCIAL JUSTICE

Procedural justice in the renewable energy project location is achieved by sharing information, participating in decision-making opportunities, and having the capacity to influence results and relations with project developers (Frate *et al.*, 2019). Information strongly influences feelings of procedural justice and local acceptance of renewable energy. For Walker (2017), procedural justice tends to concentrate on the participation of the residents in wind energy planning and the conditions of this participation, and for justice in these processes to be considered fair, the meetings must be accessible, the decision makers must recognise the legitimate contributions of local citizens, and the public opinion must have some influence on the final decisions.

People's participation is the main axis for achieving procedural justice. It refers to the representation and decision-making power of the local population, which will be satisfactory only through dialogue, transparency in actions and transfer of information and, mainly, the starting from the construction of a relationship of trust between the parties (Leite, 2019).

Corroborating the idea of Hall *et al.* (2013) and Leite (2019) demonstrate that three principles emerged from participants about how the wind company could maintain procedural fairness during its engagement with the local community: honesty and transparency, complete and unbiased information, and ensuring that donations of funds for infrastructure or community programs do not were perceived as tacit support.

To facilitate the development of these principles, Frate *et al.* (2019) observe the inclusion of defenders and opponents of wind energy in the decision-making process. This permanently improves local and regional acceptance.

As noted by several authors, the acceptance of wind energy must be directly linked to people's participation in the decision-making process. Yun *et al.* (2022) argue that the involvement of local communities in the development process is a key component in leading communities to have

positive attitudes towards wind farms. Hall *et al.* (2013) observed that public consultations following announcements about the implementation of wind farms are more of a trigger for opposition than an incentive for the adequate design of acceptable projects. In summary, Byrne *et al.* (2017, p.48) argue that community members want "partnership in decision-making processes" rather than being treated as "consumers at the end of the line".

For Simcock (2016), procedural justice has multiple 'dimensions', where the basic criteria by which the fairness of a decision-making process is judged must be understood. The general evaluations of a decision process are shaped by the fact that justice should be reached in these different dimensions, which for him are: inclusion, influence and information, as shown in Board 1.

Board 1 | Multiple Dimensions

Dimension	*Concept*	*Description*	*Application*
Inclusion	It refers to the question of who is present and has a voice in decision-making.	Everyone affected by a decision must be involved to some degree in that decision. Also pertinent are questions about the responsibility to ensure presence and participation while people may have a 'right' to be included and to what extent different actors are responsible for ensuring this right is exercised.	Call the community in a wide manner, democratic and universal way, to dialogue with the company, including residents and people interested in the process.
Influence	It is related to the extent to which different participants' opinions, suggestions and concerns shape the outcomes of decisions.	A person or collective can exercise different degrees of influence in a decision-making process, which broadly categorises here as "listening as a spectator", "consultative influence", and "direct authority". "Bystander listening" refers to a situation in which a stakeholder receives information about a decision but has no influence. If a stakeholder has "consultative influence," they can give their opinion on an issue, but others make the final decision. Finally, "direct authority" refers to the situation in which a stakeholder can formally shape the outcome of the decision, either by making the decision individually or by sharing power with others in a democratic process (such as voting).	Open the possibility for residents' associations to have their resolutions in a 'deliberative' and not just 'consultative' character, that is, to be able to give their opinion and intervene in the projects from the first moment.
Information	Adequate, sufficient and accurate information for all participants in a decision-making process is often considered crucial to procedural justice, helping to ensure transparency, participation and informed consent.	Constitutes 'adequate', 'sufficient' and 'accurate' information, such as how much detail should be included and how it should be communicated (e.g. in writing or verbally?) – so it is not evasive or disputed.	Proceed with well-planned protocols and the idea of revealing the truth about issues relating to the project, especially concerning negative aspects, and not a version that the community can easily approve.

Source: Adapted from Simcock (2016).

Distributive justice focuses on the local community's perception of equity in the distribution of costs, risks and benefits associated with the wind farm. Besides that, distributive justice also considers conflicts created within communities due to the distribution of benefits (Leite, 2019).

Endorsing Leite (2019) and Walker and Baxter (2017b), distributive justice is the perception of equity in relation to the introduction and benefit distribution, such as tax revenues, lease payments, and compensation for negative results from the wind farm. Brannstrom (2022) comments based on studies focused on concepts of distributive justice (Bell *et al.*, 2005, 2013; Devine-Wright, 2005, 2011; Gross, 2007; Wolsink, 2000, 2007; Wustenhagen *et al.*, 2007) that these authors aim to understand how the distribution of costs and benefits of wind farms influence acceptance and opposition. This

understanding builds on the analytical turn to the multidimensional understanding of the host community's acceptance of renewable energy infrastructure.

According to Anchustegui (2020), the responsible company for implementing the wind farm offers some form of retribution for the externalities imposed on the host Community, such as noise or visual impact, and brings direct benefits in addition to the positive effects of renewable energy benefits play a key role when it comes to fostering the acceptance and, ultimately, approval of renewable energy projects, serving a utilitarian purpose that goes beyond pure financial compensation to specific individuals, such as those arising from tort or non-contractual liability.

Distributive justice approaches how the benefits (primarily financial) are introduced and shared within communities; that is to say, distributive justice in renewable energy is defined as the perceived justice of the introduction and distribution of benefits such as tax revenues and individualised lease payments or shared (Frate *et al.*, 2019; Walker, 2017). Supporting these authors, Brannstrom and Gorayeb (2022) refer to distributive justice as a damage distribution and benefits between the affected people, focusing on the energetical Injustice location.

The absence of processes that meet these justices often creates economic inequalities and power asymmetries in the communities hosting wind farms, causing economic losses and disruptions in the routine of a significant portion of the population (Frate *et al.*, 2019).

3 METHODOLOGY

This chapter presents the work methodology and the adopted phases of the research development.

3.1 LOCATION OF THE STUDY AREA

Piauí stands out in the onshore wind Generation scenario. One of the largest wind complexes in Latin America is located in an Environmental Protection Area (APA) in the west of "Chapada do Araripe" (an area of elevated land with a relatively flat top, located in the interior of the State of Ceará) on the border between the states of Pernambuco and Piauí (Abeeólica, 2017). The wind complex has 585 wind turbines, distributed over 14,543.2 há with a total installed power of 1,212.5 MW (Sigel, 2022). It was installed in 2015 with 50 parks, of which 45 are in the state of Piauí and 5 in Pernambuco, according to Figure 1.

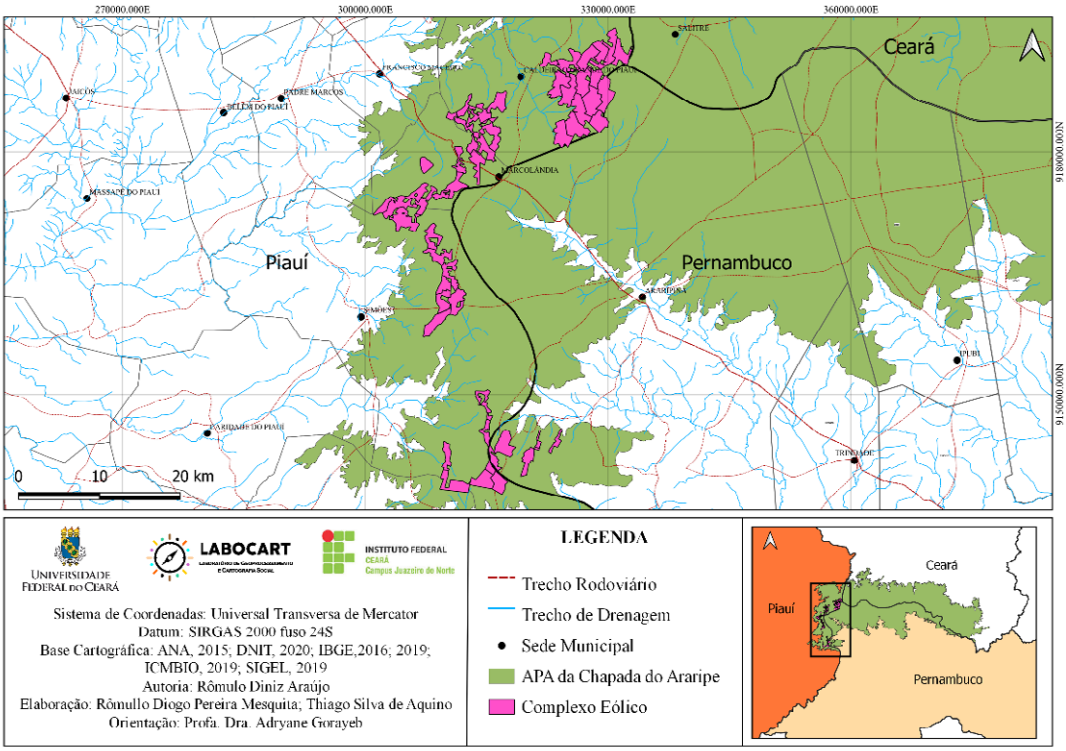

Figure 1 | Wind farms installed in the Chapada do Araripe region

Source: Prepared by the authors (2022).

Given the large number of wind farms in this complex, there was a need to select parks with many residences close to the wind turbines. So, parks were chosen in Caldeirão Grande do Piauí, in the Serra dos Pereiros Community, as they have these characteristics.

In this community, there are 149 families, distributed in 144 residences, totalising 433 residents, according to the data of the Health Secretary of the city of Caldeirão Grande do Piauí of 2022, August, obtained through community health agents in Serra dos Pereiros.

3.2 PREPARATION OF THEMATIC CARTOGRAPHY

For the study, it was made a mapping of the residences of Serra dos Pereiros community using the Google Earth Pro software. The information was collected in images from August 9, 2020. A bibliographical survey was also carried out to acquire data relating to wind turbines via the Sigel platform - Georeferenced Information System for the Electrical Sector.

Based on these data, it was observed that 7 residences are located at a distance between 150 and 200m, 30 residences are located between 200 and 300m, and 35 residences are between 300 and 400m away from the wind turbine tower (Figure 2), verifying densification of residences within the perimeter of up to 400m from the wind turbine towers, that is, around 50% of residences are within this perimeter, which justifies the choice of the community for the study under Conama resolution 462 (Brasil, 2014), which establishes procedures for the environmental licensing of projects generating electricity from wind sources.

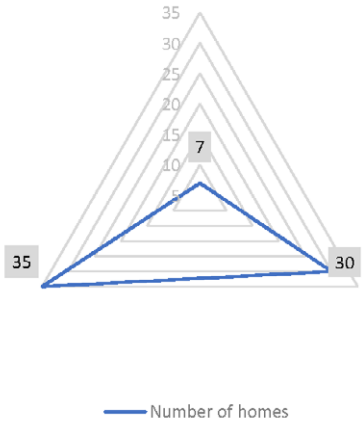

Figure 2 | Residential quantity and distances, in meters, in relation to wind turbine towers

Source: Prepared by the authors (2023).

The research has an *ex-post-facto* research nature; in other words, it investigates the hosts' perception of the impacts of a wind farm installed in the community since 2015. Primary data collection took place through four field activities, February/2021, June/2021, August/2022 and June/2023, in order to get to know the study area through conversations with community members, health agents and associations to diagnose the interviewees' perceptions regarding the acceptance/rejection of the implementation of wind farms from the perspective of procedural and distributive justice.

3.3 DEVELOPMENT AND APPLICATION OF THE QUESTIONNAIRE

The objective of the research was to understand the community's responses in relation to the acceptance/rejection of the implementation of wind farms from the perspective of procedural and distributive justice. Here, the results of a face-to-face survey carried out in the Serra dos Pereiros community in the municipality of Caldeirão Grande do Piauí – PI were analysed. The results are presented from the 31 questions referring to the variables for the answers: impact on daily life, landscape change, visibility, opinion on wind farms, political process of implementing wind farms, fairness of the process, compensation, noise nuisance and noise sensitivity.

Questionnaires were adapted from research carried out in Brazil and South Korea, based on Brannstrom *et al.* (2022), Leite (2019), and Yun *et al.* (2022). This questionnaire consists of identifying the interviewee and 10 answers that add up to 31 variables that measure the factors used for the analysis. Board 2 presents the objectives of the responses and the number of questions used in the questionnaire.

Board 2 | Description of responses

Nº	*Responses*	*Objective*	*Number of questions*
1	Impact on daily life	Understand the day-to-day relationships of the community with wind farms.	3
2	Change in the landscape	Understanding the relationships established between individuals and the environment experienced over time which can contribute to understanding the idea of protecting the landscape and the relationship with the territory.	3
3	Visibility	Understand the relationships established between individuals and wind turbines.	1
4	Opinion about wind farms	Effectively present participants' views regarding implementing and expanding wind energy projects at local, state and national levels.	4

Nº	Responses	Objective	Number of questions
5	Political process for implementing wind farms	Understand community participation with governmental and non-governmental bodies regarding implementing wind farms.	10
6	Fairness of the process	Understand whether there was any community influence in the wind farm design stage.	4
7	Compensation	Understand the positive and negative impacts of installing a wind farm in terms of financial and economic compensation.	3
8	Noise nuisance	Understand the impacts of noise on the community	1
9	Noise sensitivity	Understanding the impacts of noise on the community	1
10	Background noise perception	Understand the impacts of noise on the community	1

Source: Prepared by the first author (2023).

As this research used subjective data collection through interviews with human beings, it was necessary to submit it for consideration by the Research Ethics Committee – CEP, through Plataforma Brasil (Brazilian Base of Data of the registry of research involving human beings). The CEP's consolidated opinion confirmed the ethical approval of the research under opinion number 6,034,815 on May 2, 2023.

3.4 STATISTICAL ANALYSIS AND DATA PROCESSING

Population data were provided by health agents from the Serra dos Pereiros community. The sample was calculated considering the total number of inhabitants: 433 people.

The following statistical formula was applied to calculate the sample (Devore, 2018).

$$n = \frac{Z^2.p.q.N}{e^2(N-1)+Z^2.p.q} \qquad (1)$$

Where:

- n: is the sample value;
- Z: adopted a significance level of 10% (1.64), which gives a confidence of 90%;
- p: proportional value of the population analysed in relation to the municipality, where the population of the community (433) was divided in relation to the population of the municipality (5671), resulting in p = 0.0763;
- q: complementary value, q = 1 - p, which resulted in the value 0.9236;
- N: population size;
- e: the non-sampling error was adopted at 5%.

The sample size calculated according to equation 1 to apply the questionnaire was 65 (n = 64.6) people, men and women over 18 years old.

To measure the level of agreement with each statement, the participant chose a response according to the gradient of the Likert scale of satisfaction with 5 levels: completely disagree (1), disagree (2), indifferent (3), agree (4) and totally agree (5). This scale consists of taking a construct and developing

a set of statements related to its definition to which respondents express their degree of agreement (Júnior; Costa, 2014).

To measure the degree of relationship between the variables, a correlation test was conducted with a reliability degree of 95% and, consequently, a statistical significance level of 5%.

Data tabulation was carried out using the Microsoft Excel program. The information in the questionnaire was entered into Excel, calculating the percentages of each response obtained through the agreement used on the Likert scale.

After, the software R (*Language and Environment for Statistical Computing*) was used. The data were imported from Microsoft Excel to perform the statistical analyses. In R, Cronbach's alpha coefficient was calculated to evaluate the reliability and internal consistency of measuring instruments. It is a statistical tool that quantifies, on a scale from 0 to 1, the reliability of a questionnaire, with the minimum acceptable value being 0.70 (Almeida; Santos; Costa, 2010; Gaspar; Shimoya, 2017).

Next, another statistical method, the Spearman correlation coefficient (rs), was applied. This coefficient indicates the intensity degree of the correlation between two variables with the same response or, in cases where the response has a single variable, performs there is a correlation between different response variables, but they identify with each other.

The direction of the correlation can be positive or negative. If the correlation between two variables is perfect and positive, then rs = (+1). If rs = (-1), there is a perfect and negative correlation between the variables, and if there is no correlation between the variables, then rs = (0).

Results with moderate and strong correlations with statistical significance were discussed. In the research, the proposal by Santos (2007) was used to indicate the degree of intensity of the correlation between two variables. According to the author, moderate correlation has a correlation coefficient between ($0.5 \leq rs < 0.8$), and strong correlation has a correlation coefficient between ($0.8 \leq rs < 1$).

4 RESULTS

This chapter summarises the results obtained from the questionnaires applied in the Serra dos Pereiros community.

4.1 COMMUNITY OPINION ABOUT THE INSTALLATION OF WIND TURBINES IN SERRA DOS PEREIROS

According to the data processing analysis procedure determined in the methodology, the results presented in Tables 1, 2, 3 and 4 express the percentages of each response obtained through the agreement used on the Likert scale.

Table 1 presents the results of the variables' impact on daily life, landscape change and visibility.

Table 1 | Responses about impact on daily life, change in landscape and visibility

Response	*q*	*Variable*	*Level of agreement*				
			1	*2*	*3*	*4*	*5*
Impact on daily life	1.1	I have good feelings about the wind farms in my community.	11,59%	17,39%	20,29%	39,13%	11,59%
	1.2	The community where I live is a good place to live	0,00%	0,00%	0,00%	55,07%	44,93%
	1.3	My life was affected by the installation of the wind farm	14,49%	30,43%	17,39%	11,59%	26,09%
Change in the landscape	2.1	The changing landscape caused by wind turbines around my community affects my daily life.	7,25%	27,54%	43,48%	15,94%	5,80%
	2.2	I consider the presence of wind turbines in the landscape to be beautiful.	7,25%	30,43%	10,14%	43,48%	8,70%
	2.3	I like the landscape of my community with wind farms	2,90%	24,64%	15,94%	47,83%	8,70%
Visibility	3.1	I can see the wind turbines from my house	1,45%	0,00%	0,00%	26,09%	72,46%

Source: Prepared by the authors (2023).

Regarding the variables' impact on daily life (1.1 – 1.3), for the existence of wind farms in the community, just over 50% reported that they had a good feeling about them. All residents interviewed stated that the community is a good place to live, and around 37% reported that their lives were negatively affected by the installation of the park. Half of the community was in favour of the existing wind energy project in the community. Concerning the feeling of belonging, all interviewees stated that the community is a good place to live, even considering that around 37% had their lives negatively affected by the wind farm installation.

As for the variables relating to the feeling of changing the landscape (2.1 – 2.3), almost half of the residents interviewed (43.5%) were indifferent to the change in the landscape caused by the installation of wind farms, 43.5% of those interviewed they consider the presence of wind turbines to be beautiful and 47.8% agree that they like the landscape with wind farms. In addition, the variable visibility (3.1) of wind turbines shows that almost 99% of residents interviewed can see the wind turbines from their homes. This demonstrates that the community does not consider the change in the landscape to be a problem caused by the wind energy project. In general, these results are in line with those presented by Leite (2019), who reports that the population's responses possibly did not consider this interrelationship (environmental dynamics and landscape), which can be explained by the educational level and superficial provision of information about this renewable energy, or even the short time during an interview to interpret information in depth.

The results of the variables about opinions on wind farms and the political process for implementing wind farms are presented in Table 2.

Table 2 | Responses about opinion and political process for implementing wind farms

Response	q	Variable	Level of agreement				
			1	2	3	4	5
Opinion about wind farms	4.1	I support the existing wind energy project in my community	13,04%	20,29%	5,80%	53,62%	7,25%
	4.2	I support installing more wind turbines in my community	18,84%	18,84%	13,04%	26,09%	23,19%
	4.3	I support wind energy projects in other locations in Piauí	1,45%	4,35%	30,43%	34,78%	28,99%
	4.4	I support the use of wind energy to meet Brazil's energy needs	1,45%	4,35%	23,19%	33,33%	37,68%
Political process for implementing wind farms	5.1	My community was consulted on the wind farm implementation project	5,80%	33,33%	5,80%	46,38%	8,70%
	5.2	I have knowledge about the wind energy project in my community	33,33%	49,28%	5,80%	8,70%	2,90%
	5.3	I participated in the public hearings for approval of the wind farm	86,96%	10,14%	0,00%	0,00%	2,90%
	5.4	I had a great opportunity to express my concerns and clarify doubts before the project was approved	88,41%	8,70%	0,00%	0,00%	2,90%
	5.5	The community consultation process was transparent to local residents	62,32%	24,64%	0,00%	11,59%	1,45%
	5.6	The municipal government helps clarify doubts and concerns about wind farms in the community	94,20%	2,90%	1,45%	0,00%	1,45%
	5.7	The wind company clarifies doubts and concerns about wind energy in the community	44,93%	34,78%	2,90%	17,39%	0,00%
	5.8	The Public Prosecution helps clarify doubts and concerns about wind farms in the community	92,75%	4,35%	1,45%	1,45%	0,00%
	5.9	The land title (land ownership document) facilitated the installation of the wind farm	2,90%	8,70%	43,48%	36,23%	8,70%
	5.10	The land title (ownership document) helped define the wind farm installation areas	4,35%	10,14%	40,58%	33,33%	11,59%

Source: Prepared by the authors (2023).

Regarding the variables related to the opinion on wind farms (4.1 – 4.4), just over 60.0% of those interviewed agreed or completely agreed with the existing wind farm project in the community, and

approximately 50.0% support the installation of more wind turbines on site. The community expressed acceptance of the wind farm project, and similarly, there was support for this energy generation projects at the state (64.8%) and national (71%) levels

Concerning the variables related to the political process (5.1 – 5.10) of implementing wind farms, around 55% of those interviewed expressed that the community was consulted about the installation of the park. However, 82.6% reported that they did not know about the project. In the variable "I participated in the public hearings to approve the wind farm", only 2.9% of those interviewed stated that they participated, highlighting the lack of community involvement. This becomes clearer when analysing the percentage of people interviewed (97.1%) who could not express their concerns and clarify doubts before the project was approved.

Still, 86.9% stated there was no transparency for local residents regarding the community consultation process. 92.1% totally disagreed or disagreed with the possibility of collaboration with the municipal government to clarify doubts and concerns about wind farms in the community. Similarly, this same question was asked to clarify doubts and concerns about wind farms in the community for the company and the Public Prosecutor's Office, obtaining percentages of 79.7% and 97.1%, disagreeing completely or disagreeing, respectively. It is believed that these high percentages of disagreements in relation to these entities in clarifying doubts and concerns about wind farms in the community may be because, often, there is no direct contact with people in the community but instead with representatives and public bodies involved.

Regarding the land title, respondents responded that 44.93% agreed or completely agreed that the land ownership document facilitated the wind farm installation and that this title helped define the wind farm installation areas.

The results of the variables related to justice in the process and compensation are presented in Table 3.

Table 3 | Responses about the fairness of the process and compensation

Response	*q*	*Variable*	*Level of agreement*				
			1	*2*	*3*	*4*	*5*
Fairness of the process	6.1	The community development process after the installation of wind farms was fair	11,59%	26,09%	11,59%	49,28%	1,45%
	6.2	The wind project developer acted openly and transparently throughout the process	8,70%	60,87%	7,25%	23,19%	0,00%
	6.3	My community was able to influence the outcome of the wind project, for example, the location or number of turbines	42,03%	50,72%	1,45%	5,80%	0,00%
	6.4	During the development process of wind farms, the interests of residents were considered	30,43%	56,52%	4,35%	8,70%	0,00%

Response	q	Variable	Level of agreement				
			1	2	3	4	5
Compensation	7.1	I and/or my family received compensation for the wind farm implementation project	71,01%	7,25%	0,00%	15,94%	5,80%
	7.2	I am satisfied with the compensation for leasing the land for installing the turbine	82,61%	5,80%	0,00%	8,70%	2,90%
	7.3	I believe that the community is satisfied with the improvements made by the wind project developer	1,45%	20,29%	18,84%	59,42%	0,00%

Source: Prepared by the authors (2023).

Concerning the variables related to the fairness of the process (6.1 – 6.4) in the implementation of wind farms in the community, around 50% of those interviewed agreed or completely agreed that development occurred in the community after the installation of the parks. They cite, as an example, the construction and paving of roads. However, more than 70% reported that the project developer did not act transparently, the community could not influence the project and the interests of residents were not considered.

Regarding the variables related to financial compensation (7.1 – 7.3), more than 70% of the residents interviewed did not receive financial compensation with the implementation of the park. However, around 60% believe that the community is satisfied with the improvements made by the project.

The results of the variables related to noise annoyance, noise sensitivity and perception of background noise are presented in Table 4.

Table 4 | Responses about the fairness of the process and compensation

Response	q	Variable	Level of agreement				
			1	2	3	4	5
Noise nuisance variable	9.1	I am bothered by wind turbine noise in my community	5,80%	10,14%	55,07%	14,49%	14,49%
Variable Noise sensitivity	10.1	In general, I am sensitive to noise	1,45%	17,39%	43,48%	23,19%	14,49%
Variable Perception of background noise	11.1	The area where I'm living was initially quiet	0,00%	1,45%	0,00%	17,39%	81,16%

Source: Prepared by the authors (2023).

Regarding the variable related to noise nuisance (9.1), more than half of the residents interviewed are indifferent regarding noise nuisance. Regarding the noise sensitivity variable (10.1), around 37% of residents interviewed agree or completely agree that they are sensitive to noise. Regarding the variable perception of background noise (11.1), almost 100% of the residents reported that the community was quiet before installing the wind farms. These results show that wind farms can generate environmental problems, with noise incompatible with the local lifestyle.

4.2 CORRELATIONS BETWEEN VARIABLES REFERRING TO THE QUESTIONNAIRE APPLIED IN THE SERRA DOS PEREIROS COMMUNITY

From the data tabulation, results were identified where there were moderate or strong correlations with statistical significance, based on the 31 questions referring to the variables' impact on daily life, landscape change, visibility, opinion on wind farms, political process of implementation of wind farms, fairness of the process, compensation, noise nuisance, noise sensitivity and perception of background noise, collected when applying the questionnaire. The correlation matrix between the variables was analysed using the R software, which was also used to determine the level of reliability of the questionnaire with a sample of 69 people living in Serra dos Pereiros. The result obtained a Cronbach Coefficient of 0.805, representing high reliability.

In cases where the response has a single variable, such as visibility, a correlation was made between the variables visibility and change in the landscape, which are identified with each other. The variables noise annoyance, noise sensitivity and perception of background noise were also correlated with each other.

Only five presented moderate and strong correlations with statistical significance from ten analysed responses in Tables 1, 2, 3, and 4. Responses to landscape change have a moderate positive correlation between q2.2 and q2.3 ($r_s = 0,74$; $p < 0,001$). These data indicate a moderate tendency for those who consider the presence of wind turbines in the landscape beautiful and like the landscape of their community with wind farms to be more supportive of wind projects. These results corroborate the results of Leite (2019).

The variables related to the response to opinions about wind farms present moderately positive correlations between the variables q4.1 and q4.2 ($r_s = 0,76$; $p < 0,001$), q4.1 and q4.3 ($r_s = 0,74$; $p < 0,001$), q4.1 and q4.4 ($r_s = 0,73$; $p < 0,001$) and q4.2 and q4.4 ($r_s = 0,70$; $p < 0,001$). According to the data obtained through moderated correlations in relation to support for the existing wind farm project in the community, they indicate that there is a direct relationship between support for the installation of more turbines in the community and also in other locations in Piauí, with the purpose to satisfy the needs of wind energy in Brazil. Between the variables q4.2 and q4.3 ($r_s = 0,86$; $p < 0,001$), and q4.3 and q4.4 ($r_s = 0,86$; $p < 0,001$) there is a strong positive correlation. The same support relationship as the previous ones can be seen regarding these variables. However, they demonstrated greater support in installing more turbines in the community and other locations in Piauí to meet the needs of wind energy in Brazil.

The variables regarding responses to the political process of implementing wind farms have a moderate positive correlation between q5.3 and q5.6 ($r_s = 0,64$; $p < 0,001$) and q5.3 and q5.8 ($r_s = 0,56$; $p < 0,001$). These data suggest a direct trend in the responses among those who did not participate in the public hearings, stating that the municipal government and the Public Prosecution did not clarify doubts and concerns regarding wind farms in the community. The variables q5.3 and q5.4 ($r_s = 0,94$; $p < 0,001$) have a strong positive correlation. This trend is even stronger in the responses among those who did not participate in the public hearings and the opportunity to express concerns and clarify doubts before the project is approved.

Regarding the variables for the response fairness in the process, there is a moderate positive correlation between the variables q6.1 and q6.2 ($r_s = 0,57$; $p < 0,001$) and q6.3 and q6.4 ($r_s = 0,63$; $p < 0,001$). These data show, through moderate correlations, that the responses regarding justice in the community development process after the installation of the park and how the developer acted during this process are directly related, as well as the community's responses regarding the capacity to influence the outcome of the wind project and the interest of residents are directly related.

The variables relating to the compensation response have a moderate positive correlation between q7.1 and q7.2 (r_s = 0,64; p < 0,001). This data has a tendency in the answers directly between the compensation received by people and the compensation received regarding the land lease.

5 CONCLUSION

The analysis of the Serra dos Pereiros community's responses concerning wind farms shows that 50% of interviewers are in favour of the wind energy project. However, 37.0% were negatively impacted by the installation of the park.

These impacts are related to the visibility of wind turbines, considering that almost 99.0% of interviewed residents see the wind turbines in their homes, nor with the change in the landscape, considering that 78.27% agree or are indifferent to this statement.

Just over 60.0% of respondents expressed acceptance of the wind farm project in the community, and similarly, there was also support for energy generation projects at the state (64.8%) and national (71.0%) levels.

It was verified that for 55% of those interviewed, there was an initial consultation about the wind energy project in the community; however, 82.6% reported that they did not have knowledge about the project, and 97.1% were unable to express their concerns and clarify doubts before the approving of the project. Only 2.9% participated in a public hearing, confirming the community's low participation and ability to interfere in the local project. These data show that according to Gorayeb and Brannstrom (2016), the development of policies that do not include the direct participation of society generates conflicts between different institutional levels and severe environmental and social problems, the proportion of which we may only have an accurate idea only in some decades.

Regarding procedural justice, about 50% of the interviewed stated that development occurred in the community after the installation of the parks. It is quoted, as an example, the construction and paving of the roads. However, more than 70% reported that the project developer did not act transparently, did not consider the community's interests, and did not allow the community to influence the project development. Regarding distributive justice, 70% of the interviewees did not receive financial compensation for the park implantation. However, about 60% believe that the community is satisfied with the improvements made by the project. Even carrying the conception that the wind parks could generate environmental issues, noise being the main one, it is clear when almost 100% of the interviewed residents informed that the community used to be quiet before the installation of wind farms.

Through the Spearman Correlation Coefficient, it was possible to confirm that the related variables to the referred answers to changes in the landscape, the opinion about the wind farms, the political process of implanting the wind farms, the fairness of the process and compensation have a moderate positive correlation and also the variables related to the responses referred to the opinion about wind farms and the political process of the implementation of wind farms have a strong positive correlation, which always shows a directly proportional relationship between these variables.

Walker and Baxter's research (2017 a, b) reveals that accepting wind energy projects raises when people have a role in the decision-making, which would be procedural justice. The question about justice in the planning and licensing (procedural justice) and the benefits and harms distribution (distributive justice) are essential in this process.

Gorayeb and Brannstrom (2016) bring proposals to adequate the implementation of wind energy parks in the Northeast, such as payment of monthly amounts related to productivity and rents to community associations, reduction of energy bills for residents, creation of permanent education programs and promotion of good practices aimed at the local community; construction of legal provisions that

regulate the implementation of wind energy at the state and municipal level, based on the drafting of municipal laws and plans; preparation of environmental impact studies that are based on public awareness, broad information and communication strategies about the benefits and possible damages to the natural and social environment and human health; and construction of a state zoning that identifies levels of compatibility of the state's regions with the implementation of wind farms, with broad social participation.

The research has limitations related to the sample size, which, when presented in a small number, allows for considering the results found only for the population in question. Another limitation was the low education level of the interviewees, who often did not fully understand the questions in the questionnaire.

Therefore, new research is suggested to deepen these discussions, which aims to understand the criteria for installing new wind farms and enabling a fairer distribution of benefits.

Based on these guidelines, the research contributed to developing more detailed normative instruments that preserve the well-being of local communities in or around wind farms, assisting in policies linked to fair energy and social justice.

REFERENCES

ABEEÓLICA – Brazilian Wind Energy Association. **'No sertão do Nordeste, Casa dos Ventos inaugura um dos maiores complexos eólicos da América Latina**'. June 12, 2017. Available in: https://abeeolica.org.br/no-sertao--do-nordeste-casa-dos-ventos-inaugura-um-dos-maiores-complexos-eolicos-da-america-latina/. Access in: February 23, 2020.

ABEEÓLICA – Brazilian Wind Energy Association. **'Energia Eólica**: os bons ventos do Brasil'. October 22, 2020. Available in: http://abeeolica.org.br/wp-content/uploads/2020/10/Infovento-18.pdf. Access in: February 23, 2021.

ABEEÓLICA – Brazilian Wind Energy Association **'Boletim anual 2022'**. Available in: https://abeeolica.org.br/wp--content/uploads/2023/06/Boletim-de-Geracao-Eolica-2022.pdf. Access in: August 10, 2023.

ANCHUSTEGUI, I. H. **Distributive justice, community benefits and renewable energy**: the case of offshore wind projects. University of Bergen, Faculty of Law. October 29, 2020.

ANEEL. **'Sistema de Informações Geográficas do Setor Elétrico'.** SIGEL, 2022. Available in: https://sigel.aneel.gov.br/portal/home/. Access in: September 10, 2022.

BELL, D.; GRAY, T.; HAGGETT, C. The 'social gap' in wind farm siting decisions: explanations and policy responses. **Environ. Politics**, v. 14, n. 4, p. 460-477, 2005.

BELL, D. *et al.* Re-visiting the 'social gap': public opinion and relations of power in the local politics of wind energy. **Environ. Politics**, v. 22, n. 1, p.115-135, 2013.

BRANNSTROM, C. *et al.* What explains the community acceptance of wind energy? Exploring benefits, consultation, and livelihoods in coastal **Brazil. Energy Research & Social Science**, v. 83, p. 1-13, 2022.

BRANNSTROM, C. 'Distribuição com Justiça? Conceitos e Abordagens. **Descarbonização na América do Sul:** conexões entre o Brasil e a Argentina'. Editions EERN, Mossoró, RN. 2022.

BRASIL. National Council of the Environment. **'Resolução 462, de 24 de julho de 2014'**. Available in: https://www.ibama.gov.br/component/legislacao/?view= legislacao& legislacao=133565#:~:text=Estabelece%20procedimen-

tos%20para%20o %20licenciameto,fonte%20e%C3%B3lica%20em%20superf%C3%ADcie%20terrestre.Access in: May 30, 2020.

DEVINE-WRIGHT, P. Beyond NIMBYism: toward an integrated framework for understanding public perceptions of wind energy. **Wind Energy**, v. 8, p.125–191, 2005. DOI: https://doi.org/10.1002/we.124.

DEVINE-WRIGHT, P. Public engagement with large-scale renewable energy technologies: breaking the cycle of NIMBYism. **WIREs, Clim. Change**, v. 2, n. 1, p. 19–26, 2011. DOI: https://doi.org/10.1002/wcc.v2.110.1002/wcc.89.

DEVORE, J. L. **'Probabilidade e Estatística para Engenharia e Ciências'**. Editor Cengage. 9º edit. 656 p. 2018.

FRATE, C. A. *et al.* Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil. **Energy Policy**, v. 132, p. 185–195, 2019.

GASPAR, I. DE. A.; SHIMOYA, A. **'Avaliação da Confiabilidade de uma Pesquisa utilizando o Coeficiente Alfa de Cronbach'.** Production Engineering Symposium. Universidade Federal de Goiás – Regional Catalão. Catalão, Goiás, Brasil. From 09 to 11, August, 2017.

GIANNETTI, B. F. Cleaner production for achieving the sustainable development goals. 2020. **J. Clean. Prod**., v. 271 DOI: https://doi.org/10.1016/j.jclepro.2020.122127, 122127.

GORAYEB, A.; BRANNSTROM, C. 'Licenciamento Ambiental e Oposição Social à Energia Eólica: estudo de caso com foco no social gap em comunidade litorânea do Ceará, Brasil'. **Magazine of Geography (Recife)**. v. 37, nº. 3, 2020.

GORAYEB, A.; BRANNSTROM, C. **'Impactos socioambientais da implantação dos parques de energia eólica no Brasil**. Diretrizes para o Planejamento Socialmente Justo com Vistas à Implantação de Parques Eólicos no Brasil'. Fortaleza: Editions UFC, 2019.

GORAYEB, A.; BRANNSTROM, C. 'Caminhos para uma Gestão Participativa dos Recursos Energéticos de Matriz Renovável (Parques Eólicos) no Nordeste do Brasil'. **Mercator**, Fortaleza, v.15, n.1, p. 101-115, jan./mar., 2016.

GROSS, C. Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. **Energy Policy,** v. 35, p. 2727–2736, 2007. DOI: https://doi.org/10.1016/j.enpol.2006.12.013.

HALL, N.; WRIGHT, P. D. Societal acceptance of wind farms: analysis of four common themes across. **Australian case studies**, v. 58, July 2013, p. 200-208. DOI: https://doi.org/10.1016/j.enpol.2013.03.009.

LEITE, N. S. **'Respostas de Comunidades ao Desenvolvimento da Energia Eólica no Litoral do Ceará, Brasil'**. 2019. 257 f. Thesis (Doctorate in Geography) – Universidade Federal do Ceará, Fortaleza, 2019.

MONTEFUSCO, C.; SANTOS, M. J.; SANTOS, J. R. C. 'Energia Eólica e ODS: uma análise dos níveis de evidenciação socioambiental no Rio Grande do Norte/Brasil'. **Socioeconomic Development in Debate Magazine – RSSD**. RDSD v. 6 n. 3 (2020), Special Number IV CRIARS 03-17p.

PASQUALETTI, M. J. Opposing wind energy landscapes: a search for common cause. **Ann. Assoc. Am. Geogr**., v. 101, n. 4, p. 907-917, 2011a.

PASQUALETTI, M. J. Social barriers to renewable energy landscapes. **Geogr. Rev**., v. 101, n. 2, p. 201-223, 2011b.

RAND, J.; HOEN, B. Thirty years of North American wind energy acceptance research: what have we learned? **Energy Res. Soc. Sci**, v. 29, p. 135-148, 2017.

SILVA JÚNIOR, S. D.; COSTA, F. J. Measurement and Verification Scales: a comparative analysis between the likert and phrase completion scales. **Revista Brasileira de Pesquisas de Marketing**, Opinião e Mídia, 2014.

SIMCOCK, N. Procedural justice and the implementation of community windenergy projects: a case study from South Yorkshire, UK. **Land Use Policy**, v. 59, p. 467–477, 2016.

WALKER, C. J. R. **Wind energy policy, development, and justice in Ontario and Nova Scotia, Canada**: a comparison of technocratic and community-based siting processes" (2017). Electronic Thesis and Dissertation Repository. 4696.

WALKER, C.; BAXTER, J. "It's easy to throw rocks at a corporation": wind energy development and distributive justice in Canada. **J. Environ. Policy Plan**., v. 19, n. 6, p. 754-768, 2017a.

WALKER, C.; BAXTER, J. Procedural justice in Canadian wind energy development: a comparison of community-based and technocratic siting processes. **Energy Res. Soc. Sci**., v. 29, p. 160-169, 2017b.

WOLSINK, M. Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support. **Renew. Energy**, v. 21, p. 49–64, 2000. DOI: https://doi.org/10.1016/S0960-1481(99)00130-5.

WOLSINK, M. Wind power implementation: the nature of public attitudes: equity and fairness instead of 'backyard motives'. **Renew. Sustain. Energy Rev**., v. 11, p. 1188–1207, 2007. DOI: https://doi.org/10.1016/j.rser.2005.10.005.

WÜSTENHAGEN, R.; WOLSINK, M.; BÜRER, M. J. Social acceptance of renewable energy innovation: an introduction to the concept. **Energy Policy**, v. 35, p. 2683–2691, 2007. DOI: https://doi.org/10.1016/j.enpol.2006.12.001.

YUN, S. J. *et al.* Local residents' attitudes about wind farms and associated noise annoyance in South Korea. **Energy Policy**, v. 163, p. 112847, 2022.

Percepção dos impactos socioambientais causados por geradores eólicos no estado do Piauí, Nordeste do Brasil

Perception of the socio-environmental impacts causedby wind generators in the state of Piauí, Northeast of Brazil

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ARTICLE- DOSSIER

RESUMO

A expansão da energia eólica no Brasil trouxe benefícios, mas surgiram muitos conflitos no entorno de comunidades rurais. A pesquisa consistiu em entender as respostas da comunidade em relação à aceitação/rejeição da implantação de parques eólicos na ótica da justiça processual e distributiva, na comunidade Serra dos Pereiros no Piauí. Aplicou-se um questionário com dez respostas que somaram juntas 31 variáveis. Nas análises estatísticas, com amostra populacional de 69 pessoas, utilizou-se a escala de Likert, o coeficiente alfa de Cronbach e o coeficiente de correlação de Spearman (rs). Dos resultados, cinco respostas apresentaram correlações moderadas positivas ou fortes positivas: mudança na paisagem, opinião sobre os parques eólicos, processo político de implantação dos parques eólicos, justiça do processo e compensação. Os dados mostram que o desenvolvimento de políticas que não incluam a participação direta da sociedade gera conflitos entre os diferentes níveis institucionais e problemas de ordem ambiental e social local graves.

Palavras-chave: Impactos sociais. Energia eólica. Justiça processual e Justiça distributiva. Percepção.

ABSTRACT

The expansion of wind energy in Brazil has brought benefits, but many conflicts have arisen around rural communities. The research involved understanding the community's responses regarding the acceptance or rejection of wind farms in the Serra dos Pereiros community in Piauí from the procedural and distributive justice view. A questionnaire with ten answers was applied, which added together 31 variables. In statical analyses, with a population sample of 69 people, the Likert scale, Cronbach's alpha coefficient, and Spearman's correlation coefficient (rs) were used. From the results, 5 responses

presented moderate positive or strongly positive correlations: change in the landscape, opinion about wind farms, political process for implementing wind farms, fairness of the process, and compensation. The data show that the development of policies that do not include the direct participation of society generates conflicts between the different institutional levels and significant local environmental and social problems.

Keywords: Social Impacts. Wind Energy. Procedural Justice and Distributive Justice. Perception.

1 INTRODUÇÃO

Desde a Revolução Industrial, a disputa econômica dos países e a qualidade de vida de seus habitantes são influenciadas por diversos fatores, entre eles a energia. A produção de energia limpa é um conceito dinâmico no qual novos procedimentos e tecnologias surgem constantemente, buscando métodos e práticas para prevenir danos ao meio ambiente (Giannetti *et al.*, 2020).

O Brasil faz parte dos países do Sul Global, os quais se destacam na geração de energia renovável. Entre elas, a energia eólica se destaca como um plano alternativo às fontes não renováveis (de origem fóssil), colaborando para reduzir o efeito estufa e o aquecimento global, preservando, ao mesmo tempo, os recursos naturais do planeta (Montefusco; Santos, M. J.; Santos, J. R. C., 2020).

As respostas sociais e políticas ao desenvolvimento da energia eólica são altamente variáveis em nível mundial. Numerosos casos de oposição à energia produzida pelo vento na América do Norte e na Europa fornecem evidências de persistência do social gap, definido como a diferença entre a opinião pública nacional favorável à energia eólica, em contradição à oposição da percepção local (Bell *et al.*, 2005; Bell *et al.*, 2013). Em muitos casos, o conflito é resultado da "imposição" (Pasqualetti, 2011a; Pasqualetti, 2011b), quando os empreendedores e o governo priorizam questões técnicas de eficiência e qualidade dos ventos acima dos impasses sociais. Rand e Hoen (2017) argumentam que, na América do Norte, as questões relacionadas à justiça, participação e confiança entre as partes durante o desenvolvimento de um parque eólico são determinantes na aceitação social do empreendimento. Os autores sumarizam vários fatores que a bibliografia aponta como "aceitação" ou "rejeição".

Todavia, a temática de oposição social é pouco discutida no contexto brasileiro, apesar de a energia eólica trazer impactos ambientais, especialmente em âmbito comunitário, desde a implantação até a operação. Brannstrom e Gorayeb (2016) sugerem medidas para um melhor gerenciamento das políticas de implantação de parques eólicos. Essas medidas fornecem metas e direcionamentos relacionados à implementação de projetos de energia eólica através dos planos de planejamento municipal, inclusive estabelecendo, de forma mais detalhada, a adequação da localização das turbinas, quantidade de empreendimentos e relevância do impacto visual nas paisagens. Para tanto, é importante que seja considerada a população que habita a localidade, no que concerne às informações acerca dos projetos e negociações sobre a sua localização geográfica e porte do empreendimento.

Isso significa que os planejadores e a população devem decidir se o projeto é compatível com o uso existente da terra e se vai modificar negativamente o caráter global da área, prejudicando as comunidades estabelecidas, uma vez que os moradores locais são os mais impactados (Brannstrom; Gorayeb, 2019).

Mesmo com os impactos com o aumento da fonte eólica, é necessário repensar em parques que trabalhem na perspectiva *win-win*, "situação em que todos saem ganhando" no sentido de beneficiar seus proprietários, a população consumidora e a população que reside próxima aos parques (Juárez *et al.*, 2014, p. 833), isto é, a instalação de parques eólicos deve prever questões referentes à justiça processual e à justiça distributiva.

Percebe-se que o desenvolvimento de políticas que não incluam a participação direta da sociedade gera conflitos entre os diferentes níveis institucionais e problemas de ordem ambiental e social graves, cuja proporção talvez tenhamos noção exata somente em algumas décadas (Brannstrom; Gorayeb, 2016).

A presente pesquisa insere-se nesta discussão, considerando-se que existem parcos trabalhos acadêmicos que abordam a justiça social energética justa na perspectiva da visão dos moradores que residem próximos às turbinas eólicas instaladas no Nordeste do Brasil, especificamente, no interior do Piauí.

O Piauí é destaque no cenário da geração eólica. De acordo com os dados divulgados pela Associação Brasileira de Energia Eólica (Abeeólica, 2021), o Piauí foi o terceiro estado que mais produziu energia eólica do Brasil no ano de 2022 (10,29 TWh), ficando atrás da Bahia (24,17 TWh) e do Rio Grande do Norte (23,20 TWh) (Abeeólica, 2022). O estado do Piauí destaca-se hoje no cenário da geração eólica. Segundo dados do Sistema de Informações de Geração, da Aneel, , de junho de 2023, o estado ocupou a terceira posição em quantidade de parques eólicos (173), e também em potência fiscalizada (3.526,5 MW).

O objetivo da pesquisa consistiu em entender as respostas da comunidade em relação à aceitação/rejeição da implantação de parques eólicos na ótica da justiça processual e distributiva. Aqui, analisaram-se os resultados de uma pesquisa presencial aplicada na comunidade Serra dos Pereiros, no município de Caldeirão Grande do Piauí – PI. São apresentados os resultados a partir das 31 perguntas referentes às respostas das variáveis impacto na vida diária, mudança da paisagem, visibilidade, opinião sobre os parques eólicos, processo político de implantação dos parques eólicos, justiça do processo, compensação, incômodo com o ruído, sensibilidade ao ruído e percepção do ruído de fundo. Foram discutidos os resultados onde existiam correlações moderadas e fortes, com significância estatística. Essas correlações são realizadas entre duas variáveis de mesma resposta, ou nos casos em que a resposta possui uma única variável realiza-se a correlação entre as variáveis de respostas diferentes, mas que se identificam entre si.

2 JUSTIÇA SOCIAL ENERGÉTICA

A justiça processual na localização de empreendimentos de energia renovável é alcançada pelo compartilhamento de informações, participação em oportunidades de tomada de decisões, e capacidade de influenciar resultados e relações com desenvolvedores de projetos (Frate *et al.*, 2019). A informação influencia fortemente os sentimentos de justiça processual e a aceitação local da energia renovável. Já para Walker (2017), a justiça processual tende a se concentrar sobre a participação dos moradores no planejamento da energia eólica e nas condições desta participação, sendo que, para que a justiça nesses processos seja considerada justa, as reuniões devem ser acessíveis, as pessoas que tomam as decisões devem reconhecer as contribuições legítimas de cidadãos locais, e a opinião pública deve ter alguma influência nas decisões finais.

A participação das pessoas é o eixo principal para alcançar a justiça processual e refere-se à representatividade e ao poder de decisão da população local, que será satisfatório somente por meio do diálogo, da transparência nas ações e repasse de informações e, principalmente, a partir da construção de uma relação de confiança entre as partes (Leite, 2019).

Corroborando a ideia de Leite (2019), Hall *et al.* (2013) mostram que três princípios emergiram dos participantes sobre como a empresa eólica poderia manter a justiça processual durante seu envolvimento com a comunidade local: honestidade e transparência, informações completas e imparciais, e garantia de que as doações de fundos para infraestrutura ou programas comunitários não fossem percebidas como apoio tácito.

Para facilitar o desenvolvimento desses princípios, Frate *et al.* (2019) atentam para que haja inclusão de defensores e opositores da energia eólica no processo decisório, isso melhora permanentemente a aceitação local e regional.

A aceitação da energia eólica deve estar diretamente ligada à participação das pessoas no processo de tomada de decisão como constatado por vários autores. Yun *et al.* (2022) argumentam que o envolvimento das comunidades locais no processo de desenvolvimento é componente-chave para levar as comunidades a terem atitudes positivas em relação aos parques eólicos. Hall *et al.* (2013) observaram que as consultas públicas após os anúncios da implantação de parques eólicos é mais um gatilho para a oposição do que um incentivo para o desenho adequado de projetos aceitáveis. Em síntese, Byrne *et al.* (2017, p.48) argumentam que os membros da comunidade desejam "parceria nos processos de tomada de decisão", em vez de serem tratados como "consumidores no final da linha".

Para Simcock (2016), a justiça processual tem múltiplas "dimensões", em que devem ser compreendidos os critérios básicos pelos quais a justiça de um processo de tomada de decisão é julgada. As avaliações gerais de um processo de decisão são moldadas pelo fato de que a justiça seja alcançada nessas diferentes dimensões, que para ele são: inclusão, influência e informação, como mostrado no Quadro 1.

Quadro 1 | Múltiplas dimensões

Dimensão	*Conceito*	*Descrição*	*Aplicação*
Inclusão	Refere-se à questão de quem está presente e tem voz em um processo de tomada de decisão.	Todos os afetados por uma decisão devem estar envolvidos em algum grau nessa decisão. Também são pertinentes questões sobre a responsabilidade de garantir presença e participação enquanto as pessoas podem ter o "direito" de serem incluídos e em que medida os diferentes atores são responsáveis por assegurar que esse direito seja exercido.	Chamar a comunidade, de modo amplo, democrático e universal, ao diálogo com a empresa, incluindo moradores e pessoas interessadas no processo.
Influência	Está relacionada na medida em que as opiniões, sugestões e preocupações de diferentes participantes moldam os resultados das decisões.	Uma pessoa ou o coletivo podem exercer diferentes graus de influência em um processo decisório que categorize amplamente aqui "ouvir como espectador", "influência consultiva" e "autoridade direta". Ouvir como espectador" refere-se a uma situação em que uma parte interessada recebe informações sobre uma decisão, mas não tem influência sobre esta. Se uma parte interessada tem "influência consultiva", ela é capaz de dar sua opinião sobre uma questão, mas a decisão final é tomada por outros. Finalmente, "autoridade direta" refere-se à situação em que uma parte interessada é capaz de moldar formalmente o resultado da decisão, seja tomando a decisão individualmente ou compartilhando o poder com outros em um processo democrático (como votação).	Abrir a possibilidade das associações de moradores para que tenham suas resoluções em caráter "deliberativo" e não somente "consultivo", ou seja, que possam opinar de fato e intervir nos projetos, desde o primeiro momento.
Informação	Informações adequadas, suficientes e precisas para todos os participantes em um processo de decisão são, muitas vezes, consideradas cruciais para a justiça processual, ajudando a garantir a transparência, participação e consentimento informado.	O que constitui informação "adequada", "suficiente" e "precisa" como a quantidade de detalhes que devem ser incluídos e como deve ser comunicada (por exemplo, por escrito ou verbalmente) para que não seja algo evasivo ou contestado.	Proceder com protocolos bem planejados e com a ideia de revelar a verdade sobre as questões referentes ao projeto, especialmente em relação aos aspectos negativos, e não uma versão passível de fácil aprovação pela comunidade.

Fonte: Adaptado de Simcock (2016).

A justiça distributiva se concentra na percepção da comunidade local sobre a equidade na distribuição dos custos, riscos e benefícios associados ao empreendimento eólico. Além disso, a justiça distributiva também considera os conflitos criados dentro das comunidades em virtude da distribuição dos benefícios (Leite, 2019).

Corroborando as ideias de Leite (2019) e de Baxter e Walker (2017b), a justiça distributiva é a percepção da equidade em relação à introdução e distribuição de benefícios, tais como receitas fiscais, pagamento de arrendamento e compensação de resultados negativos do parque eólico. Brannstrom (2022) comenta, com base em estudos centrados em conceitos de justiça distributiva (Bell *et al.*, 2005, 2013; Devine-Wright, 2005, 2011; Gross, 2007; Wolsink, 2000, 2007; Wustenhagen *et al.*, 2007), que esses autores visam compreender como a distribuição dos custos e dos benefícios dos parques eólicos influencia a aceitação e a oposição. Esse entendimento baseia-se na virada analítica para a compreensão multidimensional da aceitação pela comunidade anfitriã em relação à infraestrutura de energia renovável.

De acordo com Anchustegui (2020), a empresa responsável pela implantação do parque eólico oferece alguma forma de retribuição pelas externalidades impostas à comunidade anfitriã, como ruído ou impacto visual, e trazem benefícios diretos além dos efeitos positivos das energias renováveis. Os benefícios desempenham um papel fundamental quando se trata de fomentar a aceitação e, em última análise, a aprovação de projetos de energia renovável, servindo a um propósito utilitário que vai além da compensação financeira pura para indivíduos específicos, como aquelas decorrentes de responsabilidade civil ou responsabilidade extracontratual.

A justiça distributiva trata de como os benefícios (principalmente financeiros) são introduzidos e compartilhados dentro das comunidades, ou seja, a justiça distributiva em energia renovável é definida como a justiça percebida da introdução e distribuição de benefícios, como receitas fiscais e pagamentos de arrendamento individualizados ou compartilhados (Frate *et al.*, 2019; Walker, 2017). Corroborando a afirmação, Brannstrom e Gorayeb (2022) referem-se à justiça distributiva como a distribuição de danos e benefícios entre as pessoas afetadas, com foco na localização de injustiças energéticas.

Muitas vezes, a ausência de processos que atendam a essas justiças cria desigualdades econômicas e assimetrias de poder nas comunidades anfitriãs dos parques eólicos, causando prejuízos econômicos e transtornos na rotina de uma parcela significativa da população (Frate *et al.*, 2019).

3 METODOLOGIA

Este capítulo apresenta a metodologia de trabalho e as etapas adotadas para o desenvolvimento da pesquisa.

3.1 LOCALIZAÇÃO DA ÁREA DE ESTUDO

O Piauí é destaque no cenário da geração eólica *onshore*. Um dos maiores complexos eólicos da América Latina encontra-se inserido em uma Área de Proteção Ambiental (APA) no oeste da Chapada do Araripe, na fronteira entre os estados de Pernambuco e Piauí (Abeeólica, 2017). O complexo eólico possui 585 aerogeradores distribuídos em 14.543,2 ha com potência total instalada de 1.212,5 MW (Sigel, 2022). Instalou-se a partir de 2015, composto por 50 parques, dos quais 45 estão no estado do Piauí, e 5 em Pernambuco, de acordo com a Figura 1.

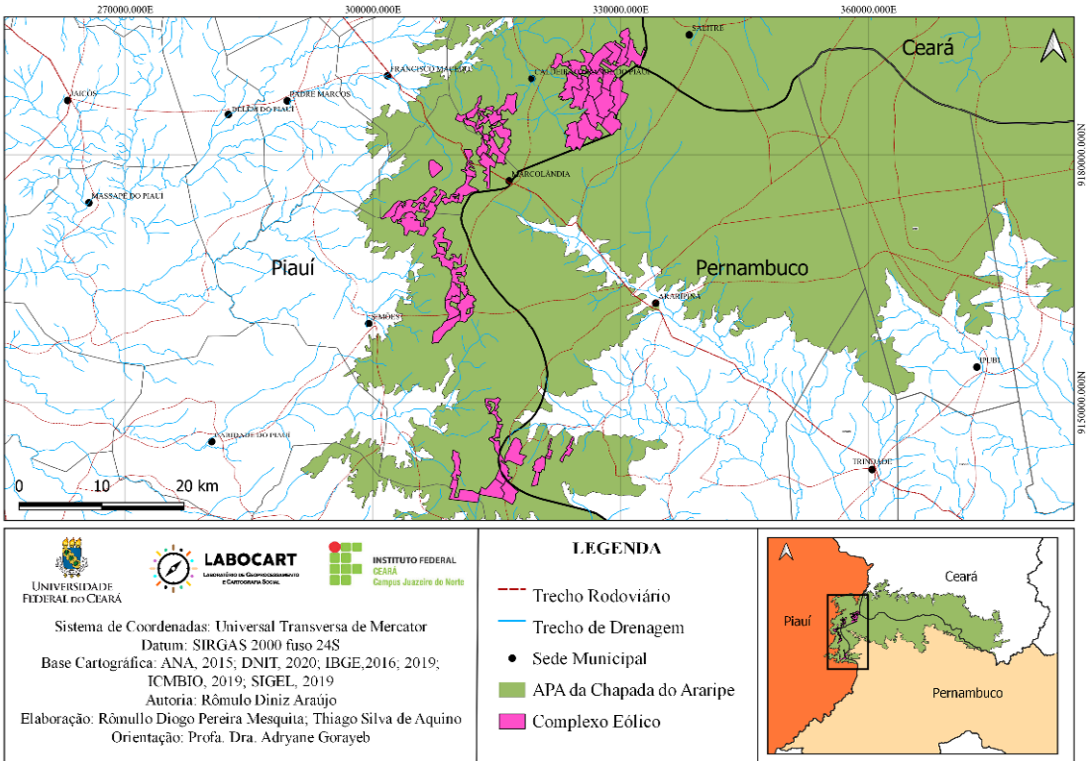

Figura 1 | Parques eólicos instalados na região da Chapada do Araripe

Fonte: Elaborada pelos autores (2022).

Diante da grande quantidade de parques eólicos existentes neste complexo, verificou-se a necessidade de selecionar parques onde havia um número elevado de residências nas proximidades das turbinas eólicas. Então, foram escolhidos parques no município de Caldeirão Grande do Piauí, na comunidade Serra dos Pereiros, por possuir essas características.

Nessa comunidade existem 149 famílias distribuídas em 144 residências, totalizando 433 habitantes, de acordo com dados da Secretaria Municipal de Saúde de Caldeirão Grande do Piauí, de agosto de 2022, obtidos por intermédio de agentes de saúde da comunidade Serra dos Pereiros.

3.2 ELABORAÇÃO DA CARTOGRAFIA TEMÁTICA

Para o estudo, realizou-se o mapeamento das residências da comunidade Serra dos Pereiros, utilizando o *software* Google Earth Pro. As informações foram coletadas em imagens do dia 9 de agosto de 2020. Realizou-se também um levantamento bibliográfico para aquisição de dados referentes aos aerogeradores pela plataforma do Sistema de Informações Georreferenciadas do Setor Elétrico (Sigel).

Com base nesses dados, observou-se que sete residências estão a uma distância entre 150 m e 200 m, 30 residências localizam-se entre 200 m e 300 m e 35 residências estão entre 300 m e 400 m de distância da torre do aerogerador (Figura 2). Verifica-se um adensamento de residências no perímetro de até 400 m das torres dos aerogeradores, ou seja, cerca de 50% das residências estão dentro desse perímetro, o que justifica a escolha da comunidade para o estudo conforme a resolução Conama 462 (Brasil, 2014), que estabelece procedimentos para o licenciamento ambiental de empreendimentos geradores de energia elétrica a partir de fonte eólica.

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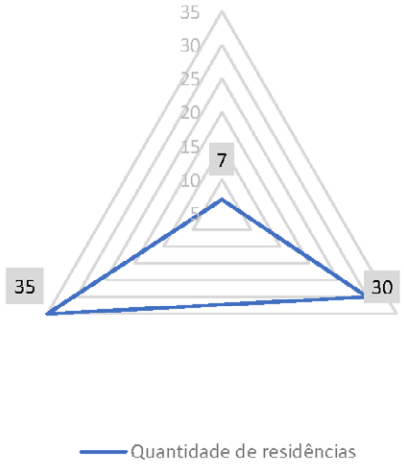

Figura 2 | Quantitativo residencial e distâncias, em metros, em relação às torres de aerogeradores

Fonte: Elaborada pelos autores (2023).

A pesquisa tem caráter de pesquisa *ex-post-facto*, ou seja, investiga a percepção dos anfitriões acerda dos impactos de um parque eólico que já está instalado, desde 2015, na comunidade. A coleta de dados primários ocorreu por meio de quatro atividades de campo, sendo fevereiro/2021, junho/2021, agosto/2022 e junho/2023, a fim de conhecer a área de estudo, realizar conversas com membros da comunidade, agentes de saúde e associações, com o objetivo de diagnosticar a percepção dos entrevistados em relação à aceitação/rejeição da implantação de parques eólicos na ótica da justiça processual e distributiva.

3.3 DESENVOLVIMENTO E APLICAÇÃO DO QUESTIONÁRIO

O objetivo da pesquisa consistiu em entender as respostas da comunidade em relação à aceitação/rejeição da implantação de parques eólicos na ótica da justiça processual e distributiva. Aqui, analisaram-se os resultados de uma pesquisa presencial aplicada na comunidade Serra dos Pereiros no município de Caldeirão Grande do Piauí – PI. São apresentados os resultados a partir das 31 perguntas referentes às variáveis para as respostas: impacto na vida diária, mudança da paisagem, visibilidade, opinião sobre os parques eólicos, processo político de implantação dos parques eólicos, justiça do processo, compensação, incômodo com o ruído e sensibilidade ao ruído.

Foram adaptados questionários de pesquisas realizadas no Brasil e na Coreia do Sul, a partir de Brannstrom *et al.* (2022), Leite (2019) e Yun *et al.* (2022). O questionário é composto pela identificação do entrevistado e por 10 respostas que somam juntas 31 variáveis que mensuram os fatores utilizados para a análise. O Quadro 2 apresenta os objetivos das respostas e o quantitativo de perguntas utilizadas no questionário.

Quadro 2 | Descrição das respostas

Nº	*Respostas*	*Objetivos*	*Número de perguntas*
1	Impacto na vida diária	Entender as relações do dia a dia da comunidade junto aos parques eólicos.	3
2	Mudança na paisagem	Entender as relações estabelecidas entre os indivíduos e o ambiente vivido ao longo do tempo, podendo contribuir para entender a ideia de proteção da paisagem e a relação com o território.	3
3	Visibilidade	Compreender as relações estabelecidas entre os indivíduos e as turbinas eólicas.	1

Nº	Respostas	Objetivos	Número de perguntas
4	Opinião sobre os parques eólicos	Apresentar efetivamente a opinião dos participantes em relação à implantação e expansão de projetos de energia eólica em nível local, estadual e nacional.	4
5	Processo político de implantação dos parques eólicos	Compreender a participação da comunidade junto aos órgãos governamentais e não governamentais quanto ao processo de implantação dos parques eólicos.	10
6	Justiça do processo	Entender se houve alguma influência da comunidade na etapa de projeto dos parques eólicos.	4
7	Compensação	Entender os impactos positivos e negativos da instalação do parque eólico no que se refere às compensações financeiras e econômicas.	3
8	Incômodo com o ruído	Entender os impactos dos ruídos na comunidade.	1
9	Sensibilidade ao ruído	Compreender os impactos dos ruídos na comunidade	1
10	Percepção do ruído de fundo	Perceber os impactos dos ruídos na comunidade	1

Fonte: Elaborado pelo primeiro autor (2023).

Por se tratar de uma pesquisa que utilizou a coleta de dados subjetivos mediante entrevistas com seres humanos, fez-se necessária a submissão para apreciação do Comitê de Ética em Pesquisa – CEP, através da Plataforma Brasil. O parecer consubstanciado do CEP confirmou a aprovação ética da pesquisa sob número de parecer 6.034.815 na data de 2 de maio de 2023.

3.4 ANÁLISE ESTATÍSTICA E TRATAMENTO DOS DADOS

Dados populacionais foram fornecidos por agentes de saúde da comunidade Serra dos Pereiros. A amostra foi calculada considerando-se o número total de habitantes: 433 pessoas.

Foi aplicada a seguinte fórmula estatística para o cálculo da amostra (Devore, 2018).

$$n = \frac{Z^2.p.q.N}{e^2(N-1)+Z^2.p.q} \qquad (1)$$

Onde:

- n: é o valor da amostra;
- Z: nível de significância adotado de 10% (1,64), o que causa uma confiança de 90%;
- p: valor proporcional da população analisada em relação ao município, onde foi realizada a divisão da população da comunidade (433) em relação à população do município (5.671) resultando em p = 0,0763;
- q: valor complementar, q = 1 - p que resultou o valor 0,9236;
- N: tamanho da população;
- e: o erro não amostral adotou-se o valor de 5%.

O tamanho da amostra calculado de acordo com a equação 1 para aplicação do questionário foi 65 (n = 64,6) pessoas, sendo homens e mulheres acima de 18 anos.

Para medir o nível de concordância de cada afirmação, o participante escolheu uma resposta de acordo com o gradiente da escala Likert de satisfação com 5 níveis: discordo totalmente (1), discordo (2), indiferente (3), concordo (4) e concordo totalmente (5). Essa escala consiste em tomar um constructo e desenvolver um conjunto de afirmações relacionadas à sua definição para os quais os respondentes emitem seu grau de concordância (Silva Júnior; Costa, 2014).

Para medir o grau de relacionamento entre as variáveis, realizou-se um teste de correlação com um grau de confiabilidade de 95% e, consequentemente, nível de significância estatística de 5%.

A tabulação dos dados foi realizada por meio do programa Microsoft Excel. As informações constantes no questionário foram inseridas no Excel, calculando-se os percentuais de cada resposta obtida através da concordância utilizada na escala Likert.

Em seguida, utilizou-se o software R (*Language and Environment for Statistical Computing*). Os dados foram importados do *Microsoft Excel* com o intuito de realizar as análises estatísticas. No R calculou-se o coeficiente alfa de *Cronbach*, que é uma técnica utilizada para avaliação da confiabilidade e consistência interna de instrumentos de medição, ou seja, é uma ferramenta estatística que quantifica, numa escala de 0 a 1, a confiabilidade de um questionário, sendo o valor mínimo aceitável de 0,70 (Almeida; Santos; Costa, 2010; Gaspar; Shimoya, 2017).

Na sequência, aplicou-se um outro método estatístico, o coeficiente de correlação de *Spearman* (rs), esse coeficiente indica o grau de intensidade da correlação entre duas variáveis de mesma resposta ou, nos casos em que a resposta possui uma única variável, realiza-se a correlação entre as variáveis de respostas diferentes, mas que se identificam entre si.

O sentido da correlação pode ser positivo ou negativo. Se a correlação entre duas variáveis for perfeita e positiva, então rs = (+1), já se rs = (-1) há uma correlação perfeita e negativa entre as variáveis, e se não existe correlação entre as variáveis, então rs = (0).

Foram discutidos os resultados nos quais existiam correlações moderadas e fortes, com significância estatística. Na pesquisa, utilizou-se a proposta de Santos (2007) para indicar o grau de intensidade da correlação entre duas variáveis. Segundo o autor, a correlação moderada possui coeficiente de correlação entre ($0,5 \leq rs < 0,8$), e a correlação forte possui coeficiente de correlação entre ($0,8 \leq rs < 1$).

4 RESULTADOS

Este capítulo sintetiza os resultados obtidos com os questionários aplicados na comunidade Serra dos Pereiros.

4.1 OPINIÃO DA COMUNIDADE ACERCA DA INSTALAÇÃO DE TURBINAS EÓLICAS NA SERRA DOS PEREIROS

Segundo o procedimento de análise de tratamento de dados determinado na metodologia, os resultados apresentados nas Tabelas 1, 2, 3 e 4 expressam os percentuais de cada resposta obtida através da concordância utilizada na escala Likert.

A Tabela 1 apresenta os resultados das variáveis “impacto na vida diária”, “mudança da paisagem” e “visibilidade”.

Tabela 1 | Respostas sobre impacto na vida diária, mudança na paisagem e visibilidade

Resposta	*q*	*Variável*	*Nível de concordância*				
			1	*2*	*3*	*4*	*5*
Impacto na vida diária	1.1	Possuo bom sentimento em relação aos parques eólicos existentes em minha comunidade.	11,59%	17,39%	20,29%	39,13%	11,59%
	1.2	A comunidade onde moro é um bom lugar para viver.	0,00%	0,00%	0,00%	55,07%	44,93%
	1.3	Minha vida foi afetada com a instalação do parque eólico.	14,49%	30,43%	17,39%	11,59%	26,09%
Mudança na paisagem	2.1	A mudança na paisagem causada pelas turbinas eólicas ao redor de minha comunidade afeta minha vida diária.	7,25%	27,54%	43,48%	15,94%	5,80%
	2.2	Considero bonita a presença das turbinas eólicas na paisagem.	7,25%	30,43%	10,14%	43,48%	8,70%
	2.3	Gosto da paisagem da minha comunidade com parques eólicos.	2,90%	24,64%	15,94%	47,83%	8,70%
Visibilidade	3.1	Eu consigo ver as turbinas eólicas de minha casa.	1,45%	0,00%	0,00%	26,09%	72,46%

Fonte: Elaborada pelos autores (2023).

Em relação às variáveis sobre o “impacto na vida diária” (1.1 – 1.3), no que se refere à existência dos parques eólicos na comunidade, pouco mais de 50% informaram que possuem um bom sentimento. Todos os moradores entrevistados afirmaram que a comunidade é um bom lugar pra se viver e cerca de 37% informam que sua vida foi afetada de forma negativa com a instalação do parque. Metade da comunidade demonstrou-se favorável ao projeto de energia eólica existente na comunidade. Em relação ao sentimento de pertencimento, todos os entrevistados afirmaram que a comunidade é um bom lugar para se viver, mesmo levando-se em consideração que cerca de 37% tiveram sua vida afetada de forma negativa com a instalação do parque eólico.

Já as variáveis referentes ao “sentimento na mudança da paisagem” (2.1 – 2.3), quase metade dos moradores entrevistados (43,5%) se mostraram indiferentes à mudança na paisagem ocasionada pela instalação dos parques eólicos, da mesma forma 43,5% dos entrevistados consideram bonita a presença dos aerogeradores e 47,8% concordam que gostam da paisagem com os parques eólicos. Complementando, a variável “visibilidade” (3.1) das turbinas eólicas mostra que quase 99% dos moradores entrevistados enxergam os aerogeradores de suas residências. Isso demonstra que a comunidade não considera a mudança na paisagem um problema causado pelo projeto de energia eólica. De modo geral, esses resultados estão em consonância com os apresentados por Leite (2019), que relata que as respostas da população, possivelmente, não consideraram esta inter-relação (dinâmica ambiental e paisagem), o que pode ser explicado pelo nível educacional e disponibilização superficial às informações sobre essa energia renovável, ou mesmo pelo pouco tempo durante uma entrevista de interpretar uma informação de forma aprofundada.

Os resultados das variáveis “opinião sobre os parques eólicos” e “processo político de implantação dos parques eólicos” são apresentados na Tabela 2.

Tabela 2 | Respostas sobre opinião e processo político de implantação dos parques eólicos

Resposta	*q*	*Variável*	*Nível de concordância*				
			1	*2*	*3*	*4*	*5*
Opinião sobre os parques eólicos	4.1	Eu apoio o projeto de energia eólica existente na minha comunidade.	13,04%	20,29%	5,80%	53,62%	7,25%
	4.2	Eu apoio a instalação de mais turbinas eólicas na minha comunidade.	18,84%	18,84%	13,04%	26,09%	23,19%
	4.3	Eu apoio projetos de energia eólica em outros locais do Piauí.	1,45%	4,35%	30,43%	34,78%	28,99%
	4.4	Eu apoio o uso da energia eólica para satisfazer as necessidades de energia do Brasil.	1,45%	4,35%	23,19%	33,33%	37,68%
Processo político de implantação dos parques eólicos	5.1	A minha comunidade foi consultada sobre o projeto de implantação do parque eólico.	5,80%	33,33%	5,80%	46,38%	8,70%
	5.2	Eu tenho conhecimento sobre o projeto de energia eólica em minha comunidade.	33,33%	49,28%	5,80%	8,70%	2,90%
	5.3	Participei das audiências públicas para aprovação do parque eólico.	86,96%	10,14%	0,00%	0,00%	2,90%
	5.4	Tive grande oportunidade de expressar minhas preocupações e esclarecer dúvidas antes do projeto ser aprovado.	88,41%	8,70%	0,00%	0,00%	2,90%
	5.5	O processo de consulta da comunidade foi transparente para os moradores locais.	62,32%	24,64%	0,00%	11,59%	1,45%
	5.6	O governo municipal ajuda a esclarecer dúvidas e preocupações sobre as eólicas na comunidade.	94,20%	2,90%	1,45%	0,00%	1,45%
	5.7	A empresa eólica esclarece dúvidas e preocupações sobre a energia eólica na comunidade.	44,93%	34,78%	2,90%	17,39%	0,00%
	5.8	O Ministério Público ajuda a esclarecer dúvidas e preocupações sobre as eólicas na comunidade.	92,75%	4,35%	1,45%	1,45%	0,00%
	5.9	O título da terra (documento de posse da terra) facilitou a instalação do parque eólico.	2,90%	8,70%	43,48%	36,23%	8,70%
	5.10	O título da terra (documento de posse) ajudou a definir as áreas de instalação do parque eólico.	4,35%	10,14%	40,58%	33,33%	11,59%

Fonte: Elaborada pelos autores (2023).

Em relação às variáveis relacionadas à "opinião sobre os parques eólicos" (4.1 – 4.4), pouco mais de 60,0% dos entrevistados concordaram ou concordaram totalmente com o projeto do parque eólico existente na comunidade, e aproximadamente 50,0% apoiam a instalação de mais aerogeradores no local. A comunidade expressou aceitação ao projeto do parque eólico e, de forma semelhante, também houve apoio para projetos dessa geração de energia em nível estadual (64,8%) e nacional (71%).

No que se refere às variáveis referentes ao "processo político" (5.1 – 5.10) de implantação dos parques eólicos, cerca de 55% dos entrevistados expressaram que a comunidade foi consultada sobre a instalação do parque, porém 82,6% informaram que não dispunham de conhecimento sobre o projeto. Na variável "participei das audiências públicas para aprovação do parque eólico", apenas 2,9% dos entrevistados afirmaram que participaram, evidenciando a falta de envolvimento da comunidade. Isso fica mais claro quando se analisa o percentual de pessoas entrevistadas (97,1%) que não conseguiram expressar suas preocupações e esclarecer dúvidas antes do projeto ser aprovado.

Ainda no que se refere ao processo de consulta da comunidade, 86,9% afirmam que não houve transparência para os moradores locais. Já 92,1% discordaram totalmente ou discordaram para a possibilidade de colaboração do governo municipal para esclarecer dúvidas e preocupações sobre os parques eólicos na comunidade. De modo similar, realizou-se esse mesmo questionamento em relação ao esclarecimento de dúvidas e preocupações sobre os parques eólicos na comunidade para a empresa e para o Ministério Público, obtendo-se os percentuais de 79,7% e 97,1%, discordando totalmente ou discordando, respectivamente. Acredita-se que esses altos percentuais de discordâncias em relação a essas entidades em esclarecer dúvidas e preocupações sobre os parques eólicos na comunidade, podem ser pelo fato de, muitas vezes, não existir um contato direto com as pessoas da comunidade, mas sim com representantes e órgãos públicos envolvidos.

Em relação ao título da terra, 44,93% concordaram ou concordaram totalmente que o documento de posse da terra facilitou a instalação do parque eólico e que esse título ajudou a definir as áreas de instalação do parque eólico.

Os resultados das variáveis relacionadas à "justiça no processo" e "compensação" são apresentados na Tabela 3.

Tabela 3 | Respostas sobre justiça do processo e compensação.

Resposta	*q*	*Variável*	*Nível de concordância**				
			1	*2*	*3*	*4*	*5*
Justiça do processo	6.1	O processo de desenvolvimento da comunidade após a instalação dos parques eólicos foi justo.	11,59%	26,09%	11,59%	49,28%	1,45%
	6.2	O desenvolvedor do projeto eólico atuou de forma aberta e transparente durante todo o processo.	8,70%	60,87%	7,25%	23,19%	0,00%
	6.3	A minha comunidade foi capaz de influenciar o resultado do projeto eólico, por exemplo, a localização ou o número de turbinas.	42,03%	50,72%	1,45%	5,80%	0,00%
	6.4	Durante o processo de desenvolvimento dos parques eólicos, foram considerados os interesses dos moradores.	30,43%	56,52%	4,35%	8,70%	0,00%

Resposta	q	Variável	Nível de concordância*				
			1	2	3	4	5
Compensação	7.1	Eu e/ou minha família recebemos compensação pelo projeto de implantação do parque eólico.	71,01%	7,25%	0,00%	15,94%	5,80%
	7.2	Eu estou satisfeito com a compensação referente ao arrendamento da terra para a instalação da turbina.	82,61%	5,80%	0,00%	8,70%	2,90%
	7.3	Eu acredito que a comunidade está satisfeita com as melhorias realizadas pelo empreendedor do projeto eólico.	1,45%	20,29%	18,84%	59,42%	0,00%

Fonte: Elaborada pelos autores (2023).

Em relação às variáveis referentes à "justiça no processo" (6.1 – 6.4) na implantação dos parques eólicos na comunidade, cerca de 50% dos entrevistados concordaram ou concordaram totalmente que ocorreu desenvolvimento na comunidade após a instalação dos parques. Eles citam, como exemplo, a construção e pavimentação de estradas. Porém, mais de 70% informaram que o desenvolvedor do projeto não atuou de forma transparente, a comunidade não pôde influenciar o projeto e também não foram considerados os interesses dos moradores.

Quanto às variáveis relacionadas à "compensação financeira" (7.1 – 7.3), mais de 70% dos moradores entrevistados não receberam compensação financeira com a implantação do parque, porém, cerca de 60% acreditam que a comunidade está satisfeita com as melhorias realizadas pelo empreendimento.

Os resultados das variáveis relacionadas ao "incômodo com o ruído", "sensibilidade ao ruído" e "percepção do ruído de fundo" são apresentados na Tabela 4.

Tabela 4 | Respostas sobre incômodo com o ruído, sensibilidade ao ruído e percepção do ruído de fundo

Resposta	q	Variável	Nível de concordância*				
			1	2	3	4	5
Variável Incômodo com o ruído	9.1	Eu me incomodo com o barulho da turbina eólica em minha comunidade.	5,80%	10,14%	55,07%	14,49%	14,49%
Variável Sensibilidade ao ruído	10.1	No geral, eu sou sensível ao ruído.	1,45%	17,39%	43,48%	23,19%	14,49%
Variável Percepção do ruído de fundo	11.1	A área onde estou morando era originalmente tranquila.	0,00%	1,45%	0,00%	17,39%	81,16%

Fonte: Elaborada pelos autores (2023).

No tocante à variável relacionada ao "incômodo com o ruído" (9.1), mais da metade dos moradores entrevistados são indiferentes em relação ao incômodo com o ruído. Já em relação à variável "sensibilidade ao ruído" (10.1), cerca de 37% dos moradores entrevistados concordam ou concordam totalmente ser sensível ao ruído. E no que se refere à variável "percepção do ruído de fundo" (11.1), quase 100% dos moradores entrevistados informaram que a comunidade era tranquila antes da instalação dos parques eólicos. Esses resultados evidenciam que os parques eólicos podem gerar problemas ambientais, sendo o ruído incompatível com o estilo de vida local..

4.2 CORRELAÇÕES ENTRE VARIÁVEIS REFERENTES AO QUESTIONÁRIO APLICADO NA COMUNIDADE SERRA DOS PEREIROS

A partir da tabulação dos dados, identificaram-se os resultados nos quais existiam correlações moderadas ou fortes com significância estatística, a partir das 31 perguntas referentes às variáveis, como impacto na vida diária, mudança da paisagem, visibilidade, opinião sobre os parques eólicos, processo político de implantação dos parques eólicos, justiça do processo, compensação, incômodo com o ruído, sensibilidade ao ruído e percepção do ruído de fundo, coletadas na aplicação do questionário. Foi analisada a matriz de correlação entre as variáveis utilizando o *software* R, que também foi utilizado para conhecer o nível de confiabilidade do questionário com uma amostra de 69 pessoas residentes na Serra dos Pereiros. Do resultado obteve-se um coeficiente de *Cronbach* de 0.805, representando uma alta confiabilidade.

Nos casos em que a resposta possui uma única variável, como "visibilidade", realizou-se a correlação entre as variáveis "visibilidade" e "mudança na paisagem", que se identificam entre si. Também se correlacionaram, entre si, as variáveis "incômodo com o ruído", "sensibilidade ao ruído" e "percepção do ruído de fundo".

Das dez respostas analisadas nas Tabelas 1, 2, 3 e 4, apenas cinco apresentaram correlações moderadas e fortes com significância estatística. As respostas para a "mudança na paisagem" possuem uma correlação moderada positiva entre q2.2 e q2.3 ($r_s = 0,74$; $p < 0,001$). Esses dados indicam uma moderada tendência de que aqueles que consideram bonita a presença das turbinas eólicas na paisagem e gostam da paisagem de sua comunidade com parques eólicos tendem a apoiar mais os projetos eólicos. Esses resultados corroboram os resultados de Leite (2019).

Já as variáveis relacionadas à resposta para opinião sobre os parques eólicos, apresentam correlações moderada positiva, entre as variáveis q4.1 e q4.2 ($r_s = 0,76$; $p < 0,001$), q4.1 e q4.3 ($r_s = 0,74$; $p < 0,001$), q4.1 e q4.4 ($r_s = 0,73$; $p < 0,001$) e q4.2 e q4.4 ($r_s = 0,70$; $p < 0,001$). De acordo com os dados obtidos através das correlações moderadas em relação ao apoio do projeto do parque eólico existente na comunidade, há uma relação direta de apoio à instalação de mais turbinas na comunidade, e também em outras localidades do Piauí, com a finalidade de satisfazer as necessidades da energia eólica no Brasil. Já entre as variáveis q4.2 e q4.3 ($r_s = 0,86$; $p < 0,001$) e q4.3 e q4.4 ($r_s = 0,86$; $p < 0,001$), existe uma correlação forte positiva. Sobre essas variáveis, percebe-se uma mesma relação de apoio das anteriores, contudo, estas demostraram um maior apoio em relação à instalação de mais turbinas na comunidade e em outros locais do Piauí para atender às necessidades da energia eólica no Brasil.

As variáveis no tocante às respostas ao "processo político de implantação dos parques eólicos" possuem correlação moderada positiva, entre q5.3 e q5.6 ($r_s = 0,64$; $p < 0,001$) e q5.3 e q5.8 ($r_s = 0,56$; $p < 0,001$). Esses dados sugerem uma tendência direta nas respostas entre aqueles que não participaram das audiências públicas, afirmando que o governo municipal e o Ministério Público não esclareceram dúvidas e preocupações em relação às eólicas na comunidade. Já as variáveis q5.3 e q5.4 ($r_s = 0,94$; $p < 0,001$), possuem uma correlação forte positiva. Essa tendência é mais forte ainda nas respostas entre aqueles que não participaram das audiências públicas e a oportunidade de expressar preocupações e esclarecer dúvidas antes de o projeto ser aprovado.

Em relação às variáveis para a resposta "justiça no processo", existe uma correlação moderada positiva entre as variáveis q6.1 e q6.2 ($r_s = 0,57$; $p < 0,001$) e q6.3 e q6.4 ($r_s = 0,63$; $p < 0,001$). Esses dados mostram, através de correlações moderadas, que as respostas referentes à "justiça no processo" de desenvolvimento da comunidade após a instalação do parque e a forma que o desenvolvedor atuou durante esse processo estão diretamente relacionadas, como também as respostas da comunidade referentes à capacidade de influenciar o resultado do projeto eólico e o interesse dos moradores estão diretamente relacionadas.

Já as variáveis referentes à resposta sobre "compensação" possuem correlação moderada positiva entre q7.1 e q7.2 ($r_s = 0,64$; $p < 0,001$). Esse dado possui uma tendência nas respostas de forma direta entre a compensação recebida pelas pessoas e a compensação recebida referente ao arrendamento da terra.

5 CONCLUSÃO

As análises das respostas da comunidade Serra dos Pereiros em relação aos parques eólicos mostram que 50% dos entrevistados são favoráveis ao projeto de energia eólica, porém 37,0% foram impactados negativamente com a instalação do parque.

Esses impactos estão relacionados com a visibilidade das turbinas eólicas, considerando que quase 99,0% dos moradores entrevistados enxergam os aerogeradores de suas residências, e nem com a mudança na paisagem, tendo em vista que 78,27% concordam ou são indiferentes a essa afirmação.

Pouco mais de 60,0% dos entrevistados expressaram aceitação ao projeto do parque eólico na comunidade e, de forma semelhante, também houve apoio para projetos dessa geração de energia em nível estadual (64,8%) e nacional (71,0%).

Verificou-se que para 55% dos entrevistados houve uma consulta inicial sobre o projeto de energia eólica na comunidade, porém 82,6% informaram que não dispunham de conhecimento sobre o projeto e 97,1% não conseguiram expressar suas preocupações e esclarecer dúvidas antes de o projeto ser aprovado. Apenas 2,9% participaram de audiência pública, confirmando a pouca participação e capacidade de interferência da comunidade no projeto local. Esses dados mostram que, segundo Brannstrom e Gorayeb (2016), o desenvolvimento de políticas que não incluam a participação direta da sociedade gera conflitos entre os diferentes níveis institucionais e problemas de ordem ambiental e social graves, cuja proporção talvez tenhamos noção exata somente em algumas décadas.

Em relação à justiça processual, cerca de 50% dos entrevistados afirmaram que ocorreu desenvolvimento na comunidade após a instalação dos parques. Cita-se, como exemplo, a construção e pavimentação de estradas. Porém, mais de 70% informaram que o desenvolvedor do projeto não atuou de forma transparente, não considerando os interesses da comunidade, e nem dando oportunidade para que a comunidade influenciasse o desenvolvimento do projeto. Já em relação à justiça distributiva, 70% dos entrevistados não receberam compensação financeira com a implantação do parque, apesar disso, cerca de 60% acreditam que a comunidade está satisfeita com as melhorias realizadas pelo empreendimento. Com a concepção de que os parques eólicos podem gerar problemas ambientais, sendo o ruído o principal deles, isso fica claro quando quase 100% dos moradores entrevistados informaram que a comunidade era tranquila antes da instalação dos parques eólicos.

Por meio do Coeficiente de Correlação de *Spearman*, foi possível confirmar que as variáveis relacionadas às respostas referentes à "mudança na paisagem", à "opinião sobre os parques eólicos", ao "processo político de implantação dos parques eólicos", à "justiça do processo" e "compensação" possuem uma correlação moderada positiva, e também as variáveis relacionadas às respostas referentes à "opinião sobre os parques eólicos" e ao "processo político de implantação dos parques eólicos" possuem uma correlação forte positiva, o que mostra sempre uma relação diretamente proporcional entre essas variáveis.

Pesquisas de Baxter e Walker (2017a, 2017b) revelam que a aceitação de empreendimentos de energia eólica aumenta quando as pessoas têm um papel no processo decisório, o que seria justiça processual. A questão de justiça no planejamento e no licenciamento (justiça processual) e a distribuição dos benefícios e malefícios (justiça distributiva) são essenciais nesse processo.

Brannstrom e Gorayeb (2016) trazem propostas para a adequação da implementação dos parques de energia eólica no Nordeste, como: pagamento de valores mensais relativos à produtividade e aluguéis às associações comunitárias; abatimento das contas de energia dos moradores locais; criação de programas permanentes de educação e promoção de boas práticas voltadas à comunidade local; construção de dispositivos legais que normatizem a implementação da energia eólica em nível estadual e municipal, a partir da elaboração de leis e planos municipais; elaboração de estudos de impacto ambiental que tenham como premissa a conscientização pública, informação ampla e estratégias de comunicação acerca dos benefícios e possíveis danos ao ambiente natural, social e à saúde humana; e construção de um zoneamento estadual que identifique níveis de compatibilidade das regiões do estado com a implantação de parques eólicos, com ampla participação social.

A pesquisa possui limitações relacionadas ao tamanho da amostra, que, ao se apresentar em número reduzido, permite considerar os resultados encontrados apenas para a população em questão. Outra limitação foi a baixa escolaridade dos entrevistados que, muitas vezes, não compreendiam inteiramente as perguntas do questionário.

Assim, sugerem-se novas pesquisas, a fim de aprofundar essas discussões, que buscam entender os critérios utilizados para as instalações de novos parques eólicos, bem como possibilitar a distribuição de benefícios mais justa.

A partir dessas diretrizes, a pesquisa contribuiu para auxiliar na elaboração de instrumentos normativos mais detalhados que preservem o bem-estar das comunidades locais que residem dentro ou no entorno de parques eólicos, auxiliando nas políticas vinculadas à justiça social energética justa.

REFERÊNCIAS

ABEEÓLICA – Brazilian Wind Energy Association. **'No sertão do Nordeste, Casa dos Ventos inaugura um dos maiores complexos eólicos da América Latina**'. June 12, 2017. Available in: https://abeeolica.org.br/no-sertao-do-nordeste-casa-dos-ventos-inaugura-um-dos-maiores-complexos-eolicos-da-america-latina/. Access in: February 23, 2020.

ABEEÓLICA – Brazilian Wind Energy Association. **'Energia Eólica**: os bons ventos do Brasil'. October 22, 2020. Available in: http://abeeolica.org.br/wp-content/uploads/2020/10/Infovento-18.pdf. Access in: February 23, 2021.

ABEEÓLICA – Brazilian Wind Energy Association **'Boletim anual 2022'**. Available in: https://abeeolica.org.br/wp-content/uploads/2023/06/Boletim-de-Geracao-Eolica-2022.pdf. Access in: August 10, 2023.

ANCHUSTEGUI, I. H. **Distributive justice, community benefits and renewable energy**: the case of offshore wind projects. University of Bergen, Faculty of Law. October 29, 2020.

ANEEL. **'Sistema de Informações Geográficas do Setor Elétrico'.** SIGEL, 2022. Available in: https://sigel.aneel.gov.br/portal/home/. Access in: September 10, 2022.

BELL, D.; GRAY, T.; HAGGETT, C. The 'social gap' in wind farm siting decisions: explanations and policy responses. **Environ. Politics**, v. 14, n. 4, p. 460-477, 2005.

BELL, D. *et al.* Re-visiting the 'social gap': public opinion and relations of power in the local politics of wind energy. **Environ. Politics**, v. 22, n. 1, p.115-135, 2013.

BRANNSTROM, C. *et al.* What explains the community acceptance of wind energy? Exploring benefits, consultation, and livelihoods in coastal **Brazil. Energy Research & Social Science**, v. 83, p. 1-13, 2022.

BRANNSTROM, C. 'Distribuição com Justiça? Conceitos e Abordagens. **Descarbonização na América do Sul:** conexões entre o Brasil e a Argentina'. Editions EERN, Mossoró, RN. 2022.

BRASIL. National Council of the Environment. **'Resolução 462, de 24 de julho de 2014'**. Available in: https://www.ibama.gov.br/component/legislacao/?view= legislacao& legislacao=133565#:~:text=Estabelece%20procedimentos%20para%20o %20licenciameto,fonte%20e%C3%B3lica%20em%20superf%C3%ADcie%20terrestre.Access in: May 30, 2020.

DEVINE-WRIGHT, P. Beyond NIMBYism: toward an integrated framework for understanding public perceptions of wind energy. **Wind Energy**, v. 8, p.125–191, 2005. DOI: https://doi.org/10.1002/we.124.

DEVINE-WRIGHT, P. Public engagement with large-scale renewable energy technologies: breaking the cycle of NIMBYism. **WIREs, Clim. Change**, v. 2, n. 1, p. 19–26, 2011. DOI: https://doi.org/10.1002/wcc.v2.110.1002/wcc.89.

DEVORE, J. L. **'Probabilidade e Estatística para Engenharia e Ciências'**. Editor Cengage. 9º edit. 656 p. 2018.

FRATE, C. A. *et al.* Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil. **Energy Policy**, v. 132, p. 185–195, 2019.

GASPAR, I. DE. A.; SHIMOYA, A. **'Avaliação da Confiabilidade de uma Pesquisa utilizando o Coeficiente Alfa de Cronbach'.** Production Engineering Symposium. Universidade Federal de Goiás – Regional Catalão. Catalão, Goiás, Brasil. From 09 to 11, August, 2017.

GIANNETTI, B. F. Cleaner production for achieving the sustainable development goals. 2020. **J. Clean. Prod**., v. 271 DOI: https://doi.org/10.1016/j.jclepro.2020.122127, 122127.

GORAYEB, A.; BRANNSTROM, C. 'Licenciamento Ambiental e Oposição Social à Energia Eólica: estudo de caso com foco no social gap em comunidade litorânea do Ceará, Brasil'. **Magazine of Geography (Recife)**. v. 37, nº. 3, 2020.

GORAYEB, A.; BRANNSTROM, C. **'Impactos socioambientais da implantação dos parques de energia eólica no Brasil**. Diretrizes para o Planejamento Socialmente Justo com Vistas à Implantação de Parques Eólicos no Brasil'. Fortaleza: Editions UFC, 2019.

GORAYEB, A.; BRANNSTROM, C. 'Caminhos para uma Gestão Participativa dos Recursos Energéticos de Matriz Renovável (Parques Eólicos) no Nordeste do Brasil'. **Mercator**, Fortaleza, v.15, n.1, p. 101-115, jan./mar., 2016.

GROSS, C. Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. **Energy Policy,** v. 35, p. 2727–2736, 2007. DOI: https://doi.org/10.1016/j.enpol.2006.12.013.

HALL, N.; WRIGHT, P. D. Societal acceptance of wind farms: analysis of four common themes across. **Australian case studies**, v. 58, July 2013, p. 200-208. DOI: https://doi.org/10.1016/j.enpol.2013.03.009.

LEITE, N. S. **'Respostas de Comunidades ao Desenvolvimento da Energia Eólica no Litoral do Ceará, Brasil'**. 2019. 257 f. Thesis (Doctorate in Geography) – Universidade Federal do Ceará, Fortaleza, 2019.

MONTEFUSCO, C.; SANTOS, M. J.; SANTOS, J. R. C. 'Energia Eólica e ODS: uma análise dos níveis de evidenciação socioambiental no Rio Grande do Norte/Brasil'. **Socioeconomic Development in Debate Magazine – RSSD**. RDSD v. 6 n. 3 (2020), Special Number IV CRIARS 03-17p.

PASQUALETTI, M. J. Opposing wind energy landscapes: a search for common cause. **Ann. Assoc. Am. Geogr**., v. 101, n. 4, p. 907-917, 2011a.

PASQUALETTI, M. J. Social barriers to renewable energy landscapes. **Geogr. Rev**., v. 101, n. 2, p. 201-223, 2011b.

RAND, J.; HOEN, B. Thirty years of North American wind energy acceptance research: what have we learned? **Energy Res. Soc. Sci**, v. 29, p. 135-148, 2017.

SILVA JÚNIOR, S. D.; COSTA, F. J. Measurement and Verification Scales: a comparative analysis between the likert and phrase completion scales. **Revista Brasileira de Pesquisas de Marketing**, Opinião e Mídia, 2014.

SIMCOCK, N. Procedural justice and the implementation of community windenergy projects: a case study from South Yorkshire, UK. **Land Use Policy**, v. 59, p. 467–477, 2016.

WALKER, C. J. R. **Wind energy policy, development, and justice in Ontario and Nova Scotia, Canada**: a comparison of technocratic and community-based siting processes" (2017). Electronic Thesis and Dissertation Repository. 4696.

WALKER, C.; BAXTER, J. "It's easy to throw rocks at a corporation": wind energy development and distributive justice in Canada. **J. Environ. Policy Plan**., v. 19, n. 6, p. 754-768, 2017a.

WALKER, C.; BAXTER, J. Procedural justice in Canadian wind energy development: a comparison of community-based and technocratic siting processes. **Energy Res. Soc. Sci**., v. 29, p. 160-169, 2017b.

WOLSINK, M. Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support. **Renew. Energy**, v. 21, p. 49–64, 2000. DOI: https://doi.org/10.1016/S0960-1481(99)00130-5.

WOLSINK, M. Wind power implementation: the nature of public attitudes: equity and fairness instead of 'backyard motives'. **Renew. Sustain. Energy Rev**., v. 11, p. 1188–1207, 2007. DOI: https://doi.org/10.1016/j.rser.2005.10.005.

WÜSTENHAGEN, R.; WOLSINK, M.; BÜRER, M. J. Social acceptance of renewable energy innovation: an introduction to the concept. **Energy Policy**, v. 35, p. 2683–2691, 2007. DOI: https://doi.org/10.1016/j.enpol.2006.12.001.

YUN, S. J. *et al.* Local residents' attitudes about wind farms and associated noise annoyance in South Korea. **Energy Policy**, v. 163, p. 112847, 2022.

Institutional conditions for the development of energy communities in Chile and Brazil

Condições institucionais para o desenvolvimento das comunidades energéticas no Chile e no Brasil

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ABSTRACT

Energy is an essential factor that must not be overlooked in discussions concerning mitigating and confronting effects associated with human-induced climate change. This work delves into the Chilean and Brazilian energy transitions, scrutinizing just and sustainable aspects, primarily in the local context. The study highlights and compares the experiences of both nations' on-grid energy communities. The methodological pathway comprises three phases: examining regulatory frameworks, assessing on-grid energy communities' infrastructure in both countries and delving into emerging energy cooperatives. Our findings suggest that on-grid energy communities have the potential to foster a more widespread sustainable energy transition, especially when established as cooperative entities. However, there are no easy solutions to date, as justice and democracy are not guaranteed if stakeholders are not adequately engaged. Although there are fewer cooperative cases in Chile, all show a cross-cutting involvement of different members of society, while some Brazilian cases do not.

Keywords: Energy transition. Just transition. Energy communities. Chile. Brazil.

RESUMO

A energia é um fator essencial que não deve ser ignorado nas discussões sobre a mitigação e o enfrentamento dos efeitos associados às mudanças climáticas induzidas pelo homem. Este trabalho aprofunda o debate sobre as transições energéticas do Chile e do Brasil, examinando os aspectos justos e sustentáveis, principalmente em âmbito local. O estudo destaca e compara as experiências das comunidades energéticas on-grid de ambas as nações. O percurso metodológico compreende três fases: examinar as estruturas regulatórias, avaliar a infraestrutura das comunidades energéticas on-grid e investigar as cooperativas energéticas emergentes em ambos os países. Nossos resultados sugerem que as comunidades energéticas on-grid têm o potencial de promover uma transição energética sustentável mais ampla, especialmente quando estabelecidas como entidades cooperativas. Embora haja menos casos de cooperativas energéticas operando no Chile, todos eles mostram um envolvimento transversal de diferentes membros da sociedade, enquanto alguns casos brasileiros não o fazem. A justiça e a democracia não são garantidas se as partes interessadas não estiverem adequadamente envolvidas. Ainda que as experiências no Chile e no Brasil apontem direções exitosas, não há soluções únicas até o momento.

Palavras-chave: Transição energética. Transição justa. Comunidades energéticas. Chile. Brasil.

1 INTRODUCTION

Energy plays an essential role in facing and mitigating anthropic climate change through the sustainable energy transition. The International Renewable Energy Agency—Irena (2023)—points out that achieving the goal of limiting global warming to 1.5 °C in alignment with the Paris Agreement necessitates a reduction of approximately 37 gigatonnes (Gt) of carbon dioxide (CO_2) emissions from 2022 levels, along with achieving net-zero emissions in the energy sector by 2050. On the energy production side, low-carbon sources ought to replace fossil fuels. On the demand side, systems should increase efficiency, and electricity must raise its share of end-use energy[1]—the *electrification of the economy* (IPCC, 2022). Currently, all efforts seem insufficient to stop climate and socioecological crises (IEA, 2023; IPCC, 2023). 2023 could represent a pivotal moment in the progression of climate change, with potentially irreversible consequences for the Earth's natural boundaries. Notably, July 2023 set a new record for the warmest month in recent history (Copernicus, 2023; Rohde, 2023).

Sustainable energy transitions are much more than merely technological changes. They imply a complete transformation of how societies consume and produce energy, which takes on different patterns depending on cultural, economic and social factors (Irena, 2023; Sun *et al.*, 2023). The social and human nature of energy has become primordial, and concepts such as 'democracy' and 'justice' have become critical, as have calls for 'just transitions' (Abram; Winthereik; Yarrow, 2020; García Parra *et al.*, 2023; Lampis; Bermann, 2022; Leo Coleman, 2021). Transition-focused scholars highlight how it is crucial to consider social protection, dialogue, well-being, and equity while respecting vulnerable groups and their dignity in decision-making while also maintaining ecological awareness (Heffron *et al.*, 2023; Poque González *et al.*, 2023a).

Latin America and the Caribbean (LAC) is an interesting case since there are diverse, nonconventional perspectives and ideas about energy, the environment, and society (Alarcón, 2023; García Parra *et al.*, 2023). In recent decades, LAC electrical systems have diversified their energy matrices as some countries installed high levels of nonconventional renewable energy (NCRE) sources (Poque González; Silva; Macia, 2022). This study focuses on Chile and Brazil as two major power systems in LAC, with expanding installations of NCREs and emerging regulatory frameworks for distributed generation (DG). Additionally, they have historically relied on water and fossil fuels and are recognised globally as emerging economies. Likewise, both have had conflicts linked to renewables and unresolved social and

environmental challenges, raising new questions about the 'just' and 'sustainable' dimensions of the transition (Lampis *et al.*, 2022; Poque González *et al.*, 2023a).

This paper explores the 'just' and 'sustainable' aspects of energy transitions in Chile and Brazil. The analysis includes a review of the critical literature scrutinizing both energy transition paths, including works by Flores-Fernández (2020) and Lampis *et al.* (2022). As both countries struggle with unfinished tasks related to local energy transitions, this study concentrates on local energy schemes (Hernando-Arrese; Rasch, 2022; Lazaro *et al.*, 2022; Poque González *et al.*, 2023a). As Cunha *et al.* (2021a) emphasised, energy communities (ECs) offer potential as local catalysts for more 'just' and 'sustainable' energy transitions. Typically utilising renewable sources on a small scale, ECs also might empower citizens (Acosta *et al.*, 2018; Cunha *et al.*, 2021a; Lode *et al.*, 2022, 2023; Pérez-Pérez, 2023; Wyse; Hoicka, 2019).

In summary, this paper explores the potential role of ECs in facilitating 'just' and 'sustainable' energy transitions in Chile and Brazil. It investigates the present state of ECs in both countries and the institutional aspects that enable their execution. Furthermore, the study analyses energy cooperatives as a type of EC that advocates for more democratic and participatory social structures (Lode; Coosemans; Ramirez Camargo, 2022; Schneider *et al.*, 2019a).

In addition to this introduction, the paper contains five sections. Section 2 contextualises the 'just' and 'sustainable' energy transition as a worldwide agenda and describes what we know regarding ECs. In Section 3, we describe the methodological path constituting this work. Afterwards, the main content of our arguments on the status of Chilean and Brazilian ECs and energy cooperatives is developed in Section 4. Finally, in Sections 5 and 6, we discuss—in a dialogue with classical and emergent authors and interdisciplinary views—the main findings of our work, intersecting the issues of 'just' and 'sustainable' energy transitions with the Chilean and Brazilian EC cases.

2 CONTEXTUALIZATION

Linked to the contemporary energy transition, 'just' and 'sustainable' concepts have gained acknowledgement in worldwide plans and agendas but are often challenged in the literature. The contradiction between social welfare and environmental challenges is deeply rooted in a broader debate on sustainability within the frame of socioecological crisis—particularly in growth-dependent capitalist economies (Cleveland; Ruth, 1997; Latour, 2017; Leff, 2021; Max-Neef, 2010).

This contradiction triggers discussions on new eco-social policy paradigms, bringing together environmental limits and social rights. The energy sector and socially rooted, ecologically minded initiatives, such as ECs, could play a key role (Carrosio; De Vidovich, 2023; Cunha *et al.*, 2021a). Energy (practices, policies and infrastructures) involves collective life, power distributions and opportunities for participation in managing common goods at different levels (Leo Coleman, 2021). More specifically, a significant emphasis on electricity (production, consumption and transformation) is crucial in investigating contemporary human behaviour and its impact on society (Abram; Winthereik; Yarrow, 2020).

2.1 'JUST' AND 'SUSTAINABLE' ENERGY TRANSITIONS AND GLOBAL PATHS

Sun *et al.* (2023) argue that a 'sustainable' and 'just' energy transition is also political and social, in addition to its technological and ecological components. Ramírez-Tovar and Schneider (2023) point out that the inclusion of new actors suggests changes in the systems' structures and interactions, especially in the active participation of citizens. Likewise, Lampis *et al.* (2022) call for better and more effective mechanisms of local democracy. Cunha *et al.* (2021a) posit that to achieve favourable, 'just'

and 'sustainable' outcomes in the energy transition, there is a need for robust engagement from public institutions, citizens, and civil society.

Two global agendas pursue sustainable development paths: The Climate Paris Agreement (2015) and the United Nations Sustainable Development Goals (SDGs). Both initiatives share energy goals closely tied to social and environmental matters. Addressing these issues is pivotal in achieving a fair energy transition towards a low-carbon society (Cunha *et al.*, 2021a). While the United Nations Sustainable Development Goals "SDG7 calls for affordable, reliable, sustainable and modern energy for all by 2030" (Se For All, 2023), the Paris Agreement is strongly linked to decarbonization to restrict the rise in worldwide mean temperature levels, which implies that the GHG concentration will remain below 450 parts per million (ppm) CO_2-equivalent (IPCC, 2014); in May 2023, it was 424 ppm (CO2 Earth, 2023).

The 'just transition' term emerged into the global agenda after it was set in the Silesia Declaration on Solidarity and Just Transition adopted at the Conference of the Parties (COP) 24 in 2019 and the Just Transition Declaration of COP 26 in Glasgow in 2021 (Alarcón, 2023). In this context, it focuses on support workers, communities, and regions particularly vulnerable to the effects of moving away from carbon-intensive economies—for example, the coal industries—to greener ones (ILO, 2021). Promoting a 'just energy transition' and respecting populations and ecosystems is still on the COP 27 agenda (COP 27, 2022).

2.2 CRITICAL PERSPECTIVES ON THE 'JUST ENERGY TRANSITION'

Outside the COP context, the term 'just transition' extends beyond its focus on labour-oriented goals. Indeed, in the academic realm, it encompasses a broader range of topics (Alarcón, 2023), including the commons, harmonious human-nature relationships, race, colonialism, gender and governance (Dunlap; Tornel, 2023; Sovacool *et al.*, 2023; Svampa, 2023; Wang; Lo, 2021). Other perspectives shaping a just energy transition are derived from the framework of 'energy justice' (Jenkins *et al.*, 2016; Mccauley; Heffron, 2018).

Lander (2023), Bertinat and Chemes (2022) and Svampa and Bertinat (2022) pointed to energy transition as questioning current social relations and human-nature relations. Bertinat and Chemes (2022) have two distinct narratives regarding the contemporary energy transition. The first is a capitalist-technocratic narrative that considers energy as a commodity, known as the 'corporate energy transition.' The second narrative critiques the current socioeconomic global model for its responsibility for the ongoing socioecological crisis. There is a dedication to achieving a socioecological transition founded on solid or superstrong sustainability and pursuing an energy transition centred on socioenvironmental, participatory, and cooperative justice rooted in the anti-capitalist and socioecological transition manifesto. This perspective has given rise to the 'popular energy transition'.

This research highlights the significance of social involvement and governance within local ECs and cooperative schemes. Hence, the text does not examine labour perspectives on 'just transitions' and deems these dissenting opinions.

2.3 THE CHILEAN AND BRAZILIAN ENERGY TRANSITIONS

The starts of the energy transition processes in both countries have similar drivers. At the end of the 20th century and the beginning of the 21st century, both countries faced critical junctures triggered by droughts and weaknesses in the fossil fuel supply. This compelled them to diversify their electrical matrices to increase energy security. Concurrently, sustainable transitions and the decarbonization of economies gained global attention, and local socioecological conflicts sparked opposition to conventional large-scale projects (large hydropower and fossil fuels). Then, NCREs and DG emerged

as alternatives in the political sphere and materialised in public policies and regulations such as the Quotas Law and the Proinfa plan—in Chile and Brazil, respectively. At the beginning of the 2020s, both nations approached a production milestone of generating one-quarter of their annual electricity supply from NCREs, excluding hydro (Castillo *et al.*, 2022). In a second wave of reforms, from the 2010s onwards, both countries considered on-grid ECs (Poque González *et al.*, 2023b).

Table 1 depicts the indicators related to SDG 7 in Chile and Brazil. Compared to global levels, the two countries display commendable progress in achieving cleaner, more efficient energy systems and addressing social concerns (indicators 7.1.1; 7.2.1; 7.3.1; 7.b.1). Although assessments of progress on indicator 7.2.1 show satisfactory performance, a holistic examination of the energy systems in both countries reveals a significant dependence on fossil fuels (Castillo *et al.*, 2022). These circumstances pose some dilemmas. On the flip side, the burgeoning and pervasive presence of renewables in power grids bolsters the case for the electrification of economies to achieve low-carbon or net-zero economies. Nevertheless, large-size renewable energy facilities face conflicts and challenges (Poque González *et al.*, 2023a), which cannot be measured by the SDG 7 indicators (Galbiati *et al.*, 2022).

Thus, both national cases offer an opportunity to examine how local solutions can aid just energy transitions within their political and sociotechnical contexts (Lazaro *et al.*, 2022; Merino; Montero; Dastres, 2020). Nonetheless, caution is warranted, as while establishing DG structures is viewed as a possible enabler of more equitable and democratic energy systems, past research cautions against overvaluing DG proliferation as a panacea (Pavanelli *et al.*, 2022).

Table 1 | National SDG 7 profiles

SDG7	*Parameter*	*Chile*	*Brazil*	*Global*
7.1.1	2021 Share population with access to electricity (%)	~100	~99	91
7.2.1	2020 Share of renewable energy in total final energy consumption (%)	26.7	50.1	19.1
7.3.1	2020 Energy intensity level of primary energy(a)	3.6	4.0	4.6
7.a.1	2021 International financial flows (USD million, 2020 PPP)	36	414	10,775
7.b.1	2021 Renewable electricity generation capacity (Watts per capita)	764	746	268

Source: Data from ESMAP (2023).
(a) Megajoules per GDP, expressed in constant 2017 purchasing power parity (PPP).

2.4 ENERGY COMMUNITIES

An EC is "a group of citizens producing, managing, and using their energy in a defined local, geography, or place; customarily, in a distributed modality, and based on renewable sources (solar, wind, water, biomass, geothermal) and/or energy conservation/efficiency methods/technologies" (Poque González; Viglio; Ferreira, 2022, p.157). Among the elements motivating the development of ECs, the literature distinguishes at least four spheres: economic (Salm; Hille; Wüstenhagen, 2016), social (Curtin; Mcinerney; Johannsdottir, 2018; Mirzania *et al.*, 2019; Mundaca; Busch; Schwer, 2018), ecological (Holstenkamp; Kahla, 2016), and political (Mirzania *et al.*, 2019).

ECs have become attractive alternatives to large, centralised, and property-closed traditional energy systems—they are not exclusive and can coexist with conventional energy systems—since they are run by and for the welfare of the local population, triggering widespread social engagement (Poque González *et al.*, 2023b). ECs can assume two modalities: on-grid and off-grid. As generally used in power systems (Sergi *et al.*, 2018), on-grid ECs are grid-connected power projects implying bidirectional power fluxes, whereas off-grid ECs are not connected to the national grid and comprise isolated systems. In LAC, ECs are a long-standing practice seen as a respectful way to relate people to energy (Baigorrotegui; Chemes, 2023).

Since the main objective of studying ECs is to analyse their contributions to the 'just' and 'sustainable' energy transition, we will concentrate on on-grid ECs. This is because, in South American nations, off-grid[2] ECs typically stem from the need to provide electricity to individuals in isolated regions without access to electrical power. This goes beyond a sustainable sense and is often not a choice but the sole option. Note that South American EC projects (on-grid and off-grid) have assumed the format of cooperatives, small private companies, or they have remained managed by bodies at the state or municipal level (Poque González; Viglio; Ferreira, 2022).

2.4.1 ENERGY COOPERATIVES

A cooperative is a self-governing group of individuals who unite voluntarily to fulfil their daily economic, social, and cultural requirements and ambitions through a collectively owned and democratically run venture (Schneider *et al.*, 2019b). The philosophy of cooperativism advocates the transformation of communities to make them fairer and more equal. Additionally, cooperatives play a vital role in fostering local development, as they prioritise the well-being of members, employees, and the wider community. Since its emergence in the 19th century, cooperativist guiding principles centred on democratic participation, solidarity, independence, and autonomy (Lima, 2018).

A cooperative for energy production involves collaborating with individuals who have a shared desire to produce their energy but cannot do so independently or have chosen not to (Lima, 2018). Usually, such cooperatives are run by and for their members, with decisions following the principle of one-member-one-vote (Schneider, 2020). According to Lode, Coosemans and Ramirez Camargo (2022), energy cooperatives provide an innovative approach to transforming the centralised energy system towards a more decentralised one that serves environmental, economic, and social purposes.

3 METHODOLOGICAL PATHWAY

The work is divided into three steps, beginning with a qualitative analysis of the political definitions enabling on-grid ECs in both countries. We examine the regulatory frameworks governing Chilean and Brazilian ECs, as outlined in current energy laws and resolutions related to DG. These frameworks include Law No 21118 in Chile (Ministerio de Energía, 2018) and Brazil's Normative Resolution No 687 of 2015—REN 687/2015 (Aneel, 2015). This allows us to decipher the type of arrangements or schemes every regulation considers—by size and source. Then, similar to Sokolowsky and Heffron (2022), we can examine whether these initiatives align with local, national, and international energy and climate goals.

Second, in a mainly quantitative phase, using secondary data from public institutions, we want to know how the implementation of both regulations has evolved regarding the collective infrastructure added to the systems. This involves counting the number of on-grid ECs and the capacity added to the grid concerning each regulation. We then requested public information from Chile's Electricity and Fuels Superintendency (SEC, 2023a, 2023b) and collected it from the BI platform of the Brazilian National Electric Energy Agency (Aneel, 2023). This analysis takes a medium-term view, as both regulatory frameworks were implemented in the last decade, and the aim is not to forecast further scenarios but to analyse the present state of development. We explore what economic sectors are implementing on-grid ECs, how many projects are installed, and which energy sources are used.

In the third phase, a particular focus is given to energy cooperatives as we try to map the development of these projects and their main characteristics. As this is an emerging issue, data are becoming available through initiatives such as the Plataforma de Energia Cooperativa, which monitors the development of energy cooperatives in Chile, Brazil, Mexico and Colombia and provides information on this stage of this work (Energía Cooperativa, 2023). We flesh out this phase with the most recently published

literature in English, Spanish and Portuguese, including Chilean and Brazilian national publishers and authors, available on Google Scholar and grey literature.

Finally, Section 5 presents information from an additional phase where previous results are discussed and analysed within an interdisciplinary framework. This includes exploration at the national and local levels, emphasizing the 'just' and 'sustainable' dimensions of energy transitions. This article employs predominantly secondary sources, which are appropriately referenced. As such, there are no ethical infringements or transgressions.

4 RESULTS

This section develops the three steps of our methodology: recognizing the institutional frames for on-grid ECs, evaluating the linked infrastructure installed since the start of regulations, and mapping the emerging energy cooperatives.

4.1 POLITICAL DEFINITIONS

Chile and Brazil recently developed institutional bodies to govern collective on-grid projects. Thus, in Chile, on-grid ECs are defined as '*collective owners*', and in Brazil, they are defined as '*shared generation*'. Since 2018, Chilean residential power generation legislation has incorporated '*collective owners*' of NCREs or efficient cogeneration infrastructure—smaller than 300 kW. Since 2015, Brazil has used the term '*shared generation*', which refers to the confluence of consumers into the same concession area through a cooperative or consortium with micro—equal to or smaller than 75 kW—or mini—above 75 kW and equal to or smaller than 5 MW—DG infrastructure (Aneel, 2015; Ministerio de Energía, 2018). An update of these standards recently limited the upper limit for mini-generation to 3 MW for intermittent sources and for assessing payments for the power fed into the grid (BRASIL, 2022). Chile and Brazil had previously established DG regulations (Aneel, 2012; Ministerio de Economía, 2006); however, collective systems only surfaced after the frameworks were enhanced (Poque González *et al.*, 2023b).

Figure 1 presents the institutional frames and the allowed size for on-grid ECs in Chile and Brazil. Note that, institutionally, Brazil has only one frame for DG, whereas Chile has two frames for DG; the first is focused on the industrial sector—small means of DG—while the second is focused on the residential sector—net billing. Chilean on-grid ECs are inside the residential frame (Poque González *et al.*, 2023b). In the Brazilian case, on-grid ECs—*shared generation*—can assume the format of consortiums or cooperatives. A consortium gathers enterprises that make a business agreement to benefit from the sharing system. Additionally, individuals who wish to gather voluntarily can constitute cooperatives (Schneider *et al.*, 2019a).

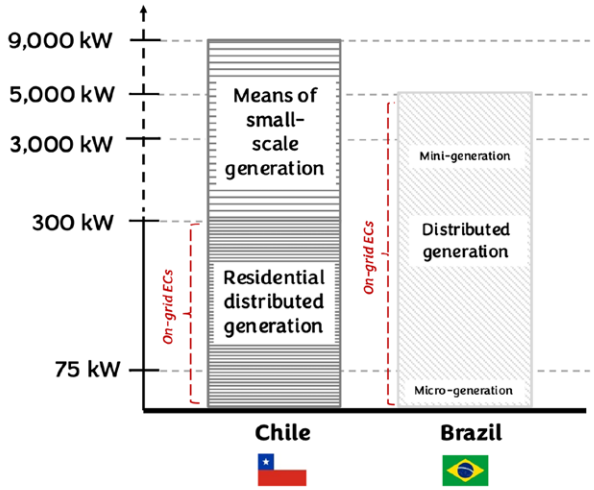

Figure 1 | Chilean and Brazilian political institutional frames for on-grid ECs.

4.2 ON-GRID ENERGY COMMUNITIES IN CHILE AND BRAZIL

It is pertinent to examine the current state of DG in Chile and Brazil, focusing specifically on the installations associated with on-grid CEs, '*collective owners*' and '*shared generation*', respectively. Due to the primary focus of this research on social engagement in specific projects, we emphasise the economic sectors implementing them.

Until September 2023, the residential-DG installed capacity in Chile was 202.7 MW (SEC, 2023a). According to information provided by the SEC, five projects have been registered since 2021 as '*collective owners*', totalling 119.7 kW, all being solar photovoltaic (SEC, 2023b).

Brazil has had 24 GW installed in 2023 across all DG sectors in over 2 million projects nationwide. Of these, 6,752 projects are '*shared generation*' (on-grid ECs), totalling 667 MW, i.e., 2.8% of all Brazilian DG capacity is *shared generation*. The year 2022 represents a milestone in terms of the installation of new *shared generation* units in Brazil, from 809 new units in 2021 to 2986 units in 2022 (Aneel, 2023).

Regarding the sources of all Brazilian *shared generation* projects, 18 projects are hydropower (adding 16 MW), one project is wind (adding 5 MW), 6,714 projects are solar photovoltaic (adding 632 MW), and 19 projects use biomass (adding 14 MW). Note that economic sectors having on-grid ECs are commercial (1,508 projects), public lighting (one project), industrial (151 projects), public (11 projects), and rural (1,172). The housing sector has 3,909 projects. Another format, which could eventually be a type of on-grid EC, is defined in the Brazilian regulation as a '*multi-consumer enterprise*', but this format has only 326 projects with 9 MW (Aneel, 2023).

4.3 ENERGY COOPERATIVES—AN EC SCHEME AS A CHANNEL FOR POPULAR PARTICIPATION?

In both countries, energy cooperatives are a form of EC that assumes institutional cooperation in self-governance. The Energia Cooperativa (2023) platform currently recognises four on-grid energy cooperatives in Chile, totalling 163 kW of capacity and involving 480 individuals (Table 2). Presently, Petorca Sustentable and Coopeumo are operational. The Petorca Sustentable project involves the Municipality of Petorca and 18 other beneficiaries whose health depends on electricity. The Coopeumo initiative comprises nine injection recipients and 328 affiliated individuals and entities.

Its energy-sharing mechanism benefits the agricultural Coopeumo Cooperative establishments and public institutions such as schools and health centres within Pichidegua Municipality (Energía Cooperativa, 2023).

Note that energy cooperatives are incipient in Chile and concentrated in the central region. From the Energia Cooperativa (2023) platform, we identify that all projects have a wide range of institutional engagement, from private to public actors, but municipalities are always involved, demonstrating the importance of local governments. Likewise, all projects possess societal purposes.

Table 2 | Chilean energy cooperatives

Name	*Date*	*Size (kW)*	*Source*	*Location*
Petorca Sustentable	2021	66.3	Solar PV	Petorca, Valparaiso Region
Planta Solar Comunitaria de Tiltil	2023	50	Solar PV	Santiago Metropolitan Region
Energía Solar Comunitaria Nueva Zelandia	2022	12	Solar PV	Santiago Metropolitan Region
Cooperativa Coopeumo	2021	32	Solar PV	Pichidegua, Region of the Libertador General Bernardo O'Higgins

Source: Data from Energía Cooperativa (2023).

In Brazil, Schneider (2020) identified 19 cooperatives totalling approximately 26 MW (16 using photovoltaic infrastructure) in 2020. As of 2023, the Energia Cooperativa platform includes 24 on-grid energy cooperatives (Table 3). In contrast to Chile, some Brazilian energy cooperatives—at least COOGD, Cooerma, Coopsolar, Photon, Ciclos, Enercred, Renovaeco, Sun Mobi, Hadar do Sol, Sinergi, Paraná Energía, Cogecom and Alka—focus on reducing electricity bill payments by involving cooperatives that supply energy and generate credits, mainly in urban areas. These initiatives were mainly the work of civilian organizations without government support (Energía Cooperativa, 2023)

On the other hand, another example of community involvement is the Percília e Lúcio cooperative. It is the first solar energy cooperative in Brazil's favelas. More than 30 families have benefited from the power plant in the Morro da Babilônia shanty town in Rio de Janeiro. The creation of the cooperative was initiated by Revolusolar, a nonprofit association promoting the sustainable development of low-income communities through solar energy (Oliveira, 2022). Similarly, the Bem Viver Cooperative aims to practice rural-urban solar solidarity by involving family farming groups and communities (Bem Viver Cooperativa, 2023).

Table 3 | Brazilian energy cooperatives

Name	*Date*	*Size (kW)*	*Source*	*Location*
Cooperon			Solar PV	Porto Velho-RO
COOGD	2016		Hydro	Vilhena-RO
Coober	2016	75	Solar PV	Paragominas-PA
Cooerma	2019	75	Solar PV	Açailândia-MA
Coopetro Energia				Natal-RN
Coopsolar	2020	75	Solar PV	João Pessoa-PB
Cooperativa Bem Viver	2021	63	Solar PV	Matureia-PB
Photon			Solar PV	Itabaiana-SE
Cooperativa de Energías Renováveis do Nordeste	2021		Solar PV	Feira de Santana-BA
Coesgo	2021		Solar PV	Goiânia-GO

Name	Date	Size (kW)	Source	Location
Ciclos	2018	240 (a)	Solar PV	Vitória-ES
Percília e Lúcio	2021	26	Solar PV	Rio de Janeiro-RJ
Enercred	2017	6885 (a)	Solar PV	Pedralva-MG
Renovaeco	2020		Solar PV	Santa Rita do Sapucaí-MG
Sun Mobi			Solar PV	Mogi das Cruzes-SP
Hadar so Sol			Solar PV	Vinhedo-SP
Sinergi	2019	855 (a)	Solar PV	Maringá-PR
Ambicoop	2021	2300 (a)	Solar PV-Biomass	Toledo-PR
Paraná Energía			Solar PV	Cascavel-PR
Cogecom	2018	6200 (a)	Biomass	Carambeí-PR
Cobragedi			Solar PV	Curitiba-PR
Alka			Solar PV	Florianópolis-SC
Coopervales			Solar PV	Arroio do Meio-RS
Coopsolar	2020	30	Solar PV	Campinas-SP

Source: Data from Energía Cooperativa (2023).
(a) These projects comprise more than one power plant.

5 DISCUSSION

In both countries, emerging on-grid ECs, incorporating NCREs and small-sized DG formats, appears to be a paradigm shift towards open, participatory, democratic, and decentralised electrical systems that are also sustainable. However, specific nuances have been observed regarding both emergent cases, which have sparked further discussion.

5.1 REGARDING ENERGY COMMUNITIES- ROLE IN THE 'JUST' AND 'SUSTAINABLE' ENERGY TRANSITION

One pivotal issue in our criticism is the conception of 'just' and 'sustainable' energy transition. Thus far, Chile and Brazil have implemented energy transitions that seem institutionally and technically proficient, given the steady increase in NCRE levels over recent decades, searching for decarbonization. Nonetheless, socioecological conflicts linked to renewables—in addition to the large conventional energy sources—and the lack of broad civic involvement challenge the justness and sustainability assumptions underpinning these transitions. Both transition cases could be associated with the concept of 'corporate transition'—following Bertinat and Chemes's (2022) terms. Furthermore, as Carrosio and De Vidovic (2023) defined, integral eco-social policies strive to align social welfare with environmental sustainability; thus, whether this alignment has been fully achieved in these cases could be questioned.

In this sense, on-grid EC regulations are remarkable and innovative as they create a new structure beyond atomised energy systems. However, the just and democratic sense of these initiatives is contingent on the stakeholders' chosen mechanism. Assuming the Bertinat and Chemes (2022) terms, and based on what is exposed in Section 4, ECs, particularly energy cooperatives, might open a chance for a 'popular energy transition', even starting within current paths dominated by corporative trends. Similarly, building on the work of Carrosio and De Vidovic (2023), energy cooperatives in Chile and examples such as the Percília e Lúcio cooperative in Brazil serve as a means of wealth redistribution, as each member from vulnerable populations directly reaps the benefits of generated wealth. Thus, ECs are devices that promote social welfare and environmental care.

When adopting the 'energy justice' perspective (Jenkins *et al.*, 2016), energy cooperatives may at least enhance social recognition. As Schneider *et al.* (2019) pointed out, cooperatives are flexible and inclusive organizations that should follow the one-member-one-vote principle, opening societal engagement opportunities and more democratic energy systems.

5.2 POTENTIALITIES AND BARRIERS

ECs are not new institutions in South America. Despite old experiences in the region—being mainly isolated off-grid systems (Poque González; Viglio; Ferreira, 2022)—with the on-grid Chilean and some Brazilian energy cooperative cases, we understand that widespread societal engagement potential exists. ECs are more than a simple energy structure; they go beyond a technological solution since they involve sociopopular articulation. However, some hindrances to advancing this approach have been noted in Brazil. These include a dearth of technical and institutional expertise, a lack of proper guidance and prior experience, and financial insecurity (Cunha *et al.*, 2021a, 2021b; Schneider, 2020; Schneider *et al.*, 2019b). Moreover, new complexities have emerged since the reform to the Brazilian DG frame—in 2019—which reduced the value of the credits obtained by injecting power into the grid (Netto; Júnior, 2022).

We note that on-grid ECs in Chile and Brazil rely heavily on solar power, which has great potential due to the region's abundant sunlight. However, it may be necessary to explore other energy sources depending on the community's specific needs, local resources and geographies—biomass is an example in the agro environment.

We have more findings as we deepen on some examples regarding on-grid energy cooperatives. When common spaces and infrastructure are used for energy projects—namely, public buildings—benefiting all cooperators, land disputes, such as those emerging in large projects (Comissão Pastoral da Terra, 2021), are avoided. It also demonstrates a potential for greater environmental protection.

Energy cooperatives in Chile are closely associated with municipalities and public institutions, which is a positive aspect of local governance. Nonetheless, it is crucial to scrutinise why citizens hesitate to initiate these projects independently, especially if the motivation is driven by avoiding reliance on certain institutions. It is necessary to investigate this issue further.

On the other hand, Brazilian energy cooperatives are occasionally perceived solely as a means to decrease electricity bills without promoting cooperator social engagement. As Netto and Júnior (2022) pointed out, third parties take on the role of investors in promoting projects where the primary users do not have the appropriate budgets or the means to initiate them. Regarding this phenomenon, Ramírez-Tovar and Schneider (2023) warned that people's engagement may be threatened, as third parties may take a leading role to the detriment of communities. They called this format 'energy by subscription'. It looks like a social, economic and environmental opportunity to reduce energy payments and emissions, but it is not necessarily a driver of social engagement.

6 FINAL CONSIDERATIONS

While the Chilean and Brazilian energy transitions have been touted as successful examples, they reveal that sustainable energy transitions require more than just an increase in NCREs. Currently, the production, management, and demand for energy by citizens and societies at varying levels are crucial aspects of this topic. Therefore, reflecting on the 'just' and 'sustainable' dimensions of energy transitions is essential. When exploring social engagement, the local level is critical. Thus, it is by this point that we see on-grid ECs as a pivotal milestone in Chilean and Brazilian energy regulations.

Sociopopular (re)engagement in energy issues is probably one of the better milestones ECs can bring to these critical times. However, it is essential to concentrate and explore particular cases to avoid wishful thinking. This study investigated the prevailing political definitions of on-grid ECs and the current installations in both countries. Moreover, we revisited documented cases of energy cooperatives to gain insights into their operational practices and challenges. Consequently, we argue that ECs can potentially drive more sustainable energy transitions in Chile and Brazil, even within the parameters determined by the current energy models.

Nevertheless, current regulations are insufficient to guarantee more just and democratic systems with social engagement. From cases such as the Percília and Lúcio cooperatives in Brazil and the four Chilean cooperative cases, we appreciate the emergence of cooperatives as an incipient format that might reinforce community involvement and social articulation within EC development. However, as Ramírez-Tovar and Schneider (2023) highlighted, there are certain Brazilian cases where cooperatives are presented merely as a means for consumers to reduce electricity bills while maintaining their consumer status. Thus, the paradigm shift from consumer citizens to engaged prosumers and to more democratic and just energy systems is not guaranteed.

As a further challenge, there is a necessity for studying Chilean and Brazilian on-grid ECs in situ to understand why and how people engage in those projects, as well as the appropriation of technology, the administration of systems and the limitations and lessons of those experiences. Some literature has started to analyse technical issues; nevertheless, there is a lack of research on societal experience regarding ECs.

NOTES

1| "Electricity would become the main energy carrier, accounting for over 50% of total final energy consumption by 2050 in the 1.5°C scenario" (IRENA, 2023).

2| According to Levy *et al.* (2023), Brazil is a well-known example of an off-grid isolated EC.

DECLARATION OF CONFLICTING INTERESTS

The author declares no potential conflicts of interest concerning this study's research, authorship, and publication.

REFERENCES

ABRAM, S.; WINTHEREIK, B. R.; YARROW, T. Current thinking – an introduction. *In*: SARKAR, A. (Ed.). **Electrifying anthropology**: exploring electrical practices and infrastructures. London; New York: Routledge, Taylor & Francis Group, 2020. p. 3–24.

ACOSTA, C. *et al.* Facilitating Energy Transition through Energy Commons: an application of socio-ecological systems framework for integrated community energy systems. **Sustainability**, v. 10, n. 2, p. 366, 31 jan. 2018.

ALARCÓN, P. Old and new challenges of the energy transition: insights from South America. **South African Journal of International Affairs**, p. 1–16, 15 jun. 2023.

ANEEL. **Resolução 482**. 2012. Available at: https://www2.aneel.gov.br/cedoc/ren2012482.pdf. Accessed on: 16 oct. 2023.

ANEEL. **Resolução 687**. 24 nov. 2015. Available at: http://www2.aneel.gov.br/cedoc/ren2015687.pdf. Accessed on: 8 dec. 2019.

ANEEL. **Microsoft Power BI**. Available at: https://app.powerbi.com/view?r=eyJrIjoiY2VmMmUwN2QtYWFiOS00ZDE3LWI3NDMtZDk0NGI4MGU2NTkxIiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Accessed on: 12 oct. 2023.

BAIGORROTEGUI, G.; CHEMES, J. Comunidades energéticas latinoamericanas. Sostenedoras de transiciones que mantienen y reparan la vida. **Energía y Equidad**, n. 6, p. 14–25, jul. 2023.

BEM VIVER COOPERATIVA. **Bem Viver**. 2023. Available at: https://bemviver.coop.br/social/. Accessed on: 17 oct. 2023.

BERTINAT, P.; CHEMES, J. Transición energética y disputa de sentidos. *In*: **Informe Ambiental 2022**. Abordar una transición socioecológica integral: el desafío de nuestro tiempo. 1. ed. Argentina: [s.n.].

BRASIL. **L14300.** 2022. Available at: https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/lei/l14300.htm. Accessed on: 12 oct. 2023.

CARROSIO, G.; DE VIDOVICH, L. Towards eco-social policies to tackle the socio-ecological crisis: energy poverty as an interface between welfare and environment. **Environmental Sociology**, v. 9, n. 3, p. 243–256, 3 jul. 2023.

CASTILLO, T. *et al.* **Panorama Energético de América Latina y el Caribe 2022**. 1. ed. Quito, Ecuador: Olade, 2022.

CLEVELAND, C. J.; RUTH, M. When, where, and by how much do biophysical limits constrain the economic process? A survey of Nicholas Georgescu-Roegen's contribution to ecological economics. **Ecological Economics**, v. 22, n. 3, p. 203–223, sept. 1997.

CO_2 EARTH. **Earth's CO2 Home Page**. Available at: https://www.co2.earth/. Accessed on: 30 jun. 2023.

COMISSÃO PASTORAL DA TERRA. **Conflitos no campo Brasil 2020**. Goiana: Comissão Pastoral da Terra, maio 2021. Available at: https://www.cptnacional.org.br/downlods?task=download.send&id=14242&catid=41&m=0. Accessed on: 15 aug. 2023.

COP 27. **Sharm el-Sheikh Implementation Plan**. 20 nov. 2022. Available at: https://unfccc.int/sites/default/files/resource/cp2022_L19_adv.pdf. Accessed on: 20 jul. 2023.

COPERNICUS. **July 2023, the warmest month in Earth's recent history**. Copernicus. European Union's Earth observation programme. Available at: https://climate.copernicus.eu/july-2023-warmest-month-earths-recent-history?utm_source=socialmedia&utm_medium=tw&utm_campaign=news-CBjulyteaser. Accessed on: 11 aug. 2023.

CUNHA, F. B. F. *et al.* Transitioning to a low carbon society through energy communities: lessons learned from Brazil and Italy. **Energy Research & Social Science**, v. 75, p. 101994, maio 2021a.

CUNHA, F. B. F. *et al.* Renewable energy planning policy for the reduction of poverty in Brazil: lessons from Juazeiro. **Environment, Development and Sustainability**, v. 23, n. 7, p. 9792–9810, jul. 2021b.

CURTIN, J.; MCINERNEY, C.; JOHANNSDOTTIR, L. How can financial incentives promote local ownership of onshore wind and solar projects? Case study evidence from Germany, Denmark, the UK and Ontario. **Local Economy: The Journal of the Local Economy Policy Unit**, v. 33, n. 1, p. 40–62, feb. 2018.

DUNLAP, A.; TORNEL, C. Pluralizing energy justice? Towards cultivating an unruly, autonomous and insurrectionary research agenda. **Energy Research & Social Science**, v. 103, 2023.

ENERGÍA COOPERATIVA. **Energía Cooperativa. Plataforma de Energía Cooperativa**. energia.coop. Available at: https://www2.energia.coop/. Accessed on: 15 aug. 2023.

ESMAP. **Trends. Tracking SDG 7**. Available at: https://trackingsdg7.esmap.org/time?country=Brazil. Accessed on: 10 oct. 2023.

FLORES-FERNÁNDEZ, C. The Chilean energy "transition": between successful policy and the assimilation of a post-political energy condition. **Innovation: The European Journal of Social Science Research**, v. 33, n. 2, p. 173–193, 2 apr. 2020.

GALBIATI, L. A. *et al.* Ruptures from the cattle policy: an analysis according to the sustainable development goals. **Ambiente & Sociedade**, v. 25, p. e0021, 2022.

GARCÍA PARRA, G. *et al.* **Transiciones justas**. Una agenda de cambios para América Latina y el Caribe. 1. ed. Buenos Aires, Argentina: Clacso; Oxfam, 2023.

HEFFRON, R. J. *et al.* Pathways of scholarship for energy justice and the social contract. **Journal of Energy & Natural Resources Law**, v. 41, n. 2, p. 211–232, 3 apr. 2023.

HERNANDO-ARRESE, M.; RASCH, E. D. The micropolitical life of energy projects: a collaborative exploration of injustice and resistance to small hydropower projects in the Wallmapu, Southern Chile. **Energy Research & Social Science**, v. 83, p. 102332, jan. 2022.

HOLSTENKAMP, L.; KAHLA, F. What are community energy companies trying to accomplish? An empirical investigation of investment motives in the German case. **Energy Policy**, v. 97, p. 112–122, oct. 2016.

IEA. **Credible pathways to 1.5°C**. Four pillars for action in the 2020s. France: International Energy Agency, abr. 2023. Available at: https://iea.blob.core.windows.net/assets/ea6587a0-ea87-4a85-8385-6fa668447f02/CrediblepathwaysTo1.5C-FourpillarsforactioninthE2020s.pdf. Accessed on: 10 aug. 2023.

ILO. **ILO welcomes COP 26 Just Transition Declaration**. News. Available at: http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_826717/lang--en/index.htm. Accessed on: 19 jul. 2023.

IPCC. Summary for Policymakers. *In*: **Climate Change 2014**: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [EDENHOFER, O.; R. PICHS-MADRUGA; Y. SOKONA; E. FARAHANI; S. KADNER; K. SEYBOTH; A. ADLER; I. BAUM; S. BRUNNER; P. EICKEMEIER; B. KRIEMANN; J. SAVOLAINEN; S. SCHLÖMER; C. VON STECHOW; T. ZWICKEL and J. C. MINX (eds.)]. Cambridge, United Kingdom: Cambridge University Press, 2014.

IPCC. **Climate Change 2022**. Mitigation of Climate Change. Intergovernmental Panel on Climate Change, 2022. Available at: https://www.ipcc.ch/report/ar6/wg3/. Accessed on: 14 apr. 2022.

IPCC. Climate Change 2023. Synthesis Report. Summary for Policymakers. *In*: **Climate Change 2023**: synthesis report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC, 2023. p. 36.

IRENA. **World Energy Transitions Outlook 2023**: 1.5°C Pathway. 1. ed. Abu Dhabi: International Renewable Energy Agency, 2023. v. 1.

JENKINS, K. *et al.* Energy justice: a conceptual review. **Energy Research & Social Science**, v. 11, p. 174–182, jan. 2016.

LAMPIS, A. *et al.* Energy transition or energy diversification? Critical thoughts from Argentina and Brazil. **Energy Policy**, v. 171, p. 113246, dec. 2022.

LAMPIS, A.; BERMANN, C. Public Policy and Governance Narratives of Distributed Energy Resources in Brazil. **Ambiente & Sociedade**, v. 25, 2022.

LATOUR, B. **Où atterrir?** Paris: La Découverte, 2017.

LAZARO, L. L. B. *et al.* Energy transition in Brazil: Is there a role for multilevel governance in a centralized energy regime? **Energy Research & Social Science**, v. 85, p. 102404, mar. 2022.

LEFF, E. **Ecologia política**: da desconstrução do capital à territorialização da vida. Tradução: Jorge Calvimontes. Brasil: Editora da Unicamp, 2021.

LEO COLEMAN. Afterword: People Thinking Energetically. *In*: LOLOUM, T.; ABRAM, S.; ORTAR, N. (Eds.). **Ethnographies of power**: a political anthropology of energy. 1. ed. New York: Berghahn Books, 2021. v. 42, p. 180–194.

LEVY, A. *et al.* Pathways to sustainable planning for a just energy transition in Latin America and the Caribbean: an analysis of best practices in selected countries. **Natural Resources and Development**, 2023.

LIMA, D. DE B. **Cooperativas de energia. Guia de constituição de cooperativas de geração distribuída fotovoltaica**. 1. ed. Brasília: Sistema OCB, Cooperação Alemã, Giz, DGRV, 2018.

LODE, M. L. *et al.* A transition perspective on Energy Communities: a systematic literature review and research agenda. **Renewable and Sustainable Energy Reviews**, v. 163, p. 112479, jul. 2022.

LODE, M. L. *et al.* Energy communities in rural areas: the participatory case study of Vega de Valcarce, Spain. **Renewable Energy**, p. 119030, jul. 2023.

LODE, M. L.; COOSEMANS, T.; RAMIREZ CAMARGO, L. Is social cohesion decisive for energy cooperatives existence? A quantitative analysis. **Environmental Innovation and Societal Transitions**, v. 43, p. 173–199, jun. 2022.

MAX-NEEF, M. The World on a Collision Course and the Need for a New Economy: contribution to the 2009 Royal Colloquium. **AMBIO**, v. 39, n. 3, p. 200–210, may 2010.

MCCAULEY, D.; HEFFRON, R. Just transition: integrating climate, energy and environmental justice. **Energy Policy**, v. 119, p. 1–7, aug. 2018.

MERINO, F.; MONTERO, A. M.; DASTRES, C. An inclusive and participative model for energy transition in Latin America: the case of Chilean Generación Comunitaria. *In*: **The Regulation and Policy of Latin American Energy Transitions**. [s.l.] Elsevier, 2020. p. 331–345.

MINISTERIO DE ECONOMÍA. **Decreto 244. 246461**, 17 jan. 2006. Available at: http://www.leychile.cl/N?i=246461&f=2015-09-30&p=. Accessed on: 29 nov. 2019.

MINISTERIO DE ENERGÍA. **Ley 21118. Modifica la Ley General de Servicios Eléctricos, con el fin de incentivar el desarrollo de las generadoras residenciales**. 17 nov. 2018. Available at: https://www.bcn.cl/leychile. Accessed on: 21 jul. 2021.

MIRZANIA, P. *et al.* The impact of policy changes: the opportunities of community renewable energy projects in the UK and the barriers they face. **Energy Policy**, v. 129, p. 1282–1296, jun. 2019.

MUNDACA, L.; BUSCH, H.; SCHWER, S. 'Successful' low-carbon energy transitions at the community level? An energy justice perspective. **Applied Energy**, v. 218, p. 292–303, may 2018.

NETTO, A. DE M.; JÚNIOR, J. U. Análise da geração compartilhada de energia elétrica no Brasil. Anais CBENS 2022. **Anais [...]** *In*: IX CONGRESSO BRASILEIRO DE ENERGIA SOLAR. Florianópolis: may 2022. Available at: https://anais-cbens.emnuvens.com.br/cbens/article/view/1203.

OLIVEIRA, B. **EasyCoop – Cooperativismo em Revistas**. Available at: https://www.easycoop.com.br/. Accessed on: 12 oct. 2023.

PAVANELLI, J. M. M. *et al.* O contexto da geração distribuída e sua evolução na Macrometrópole Paulista. *In*: JACOBI, P. R. *et al.* (Eds.). **Governança Ambiental na Macrometrópole Paulista face à Variabilidade Climática**. Brasil: Rima Editora, 2022. p. 379–394.

PÉREZ-PÉREZ, B. **Comunidades energéticas en barrios patrimoniales**: comunidad energética (CE) Barrios de La Alhambra (Granada). n. 46, 2023.

POQUE GONZÁLEZ, A. B. *et al.* Socio-Ecological Controversies from Chilean and Brazilian Sustainable Energy Transitions. **Sustainability**, v. 15, n. 3, p. 1861, 18 jan. 2023a.

POQUE GONZÁLEZ, A. B. *et al.* Redistributing power? Comparing the electrical system experiences in Chile and Brazil from a historical institutional perspective. **Energy Research & Social Science**, v. 101, may 2023b.

POQUE GONZÁLEZ, A. B.; SILVA, B. D. J.; MACIA, Y. M. Transición energética en América Latina y el Caribe: diálogos inter y transdisciplinarios en tiempos de pandemia por Covid-19. **Lider**, v. 39, p. 33–61, 15 mar. 2022.

POQUE GONZÁLEZ, A. B.; VIGLIO, J. E.; FERREIRA, L. DA C. Energy communities in sustainable transitions. The South American Case. **Sustainability in Debate**, v. 13, n. 2, p. 19, 30 aug. 2022.

RAMÍREZ-TOVAR, A. M.; SCHNEIDER, K. Por más, y no menos, comunidades energéticas en la generación ciudadana: diálogo entre las regulaciones brasileña y colombiana. **Energía y Equidad**, n. 6, p. 14–25, jul. 2023.

ROHDE, R. **June 2023 Temperature Update**. Berkeley Earth, 11 jul. 2023. Available at: https://berkeleyearth.org/june-2023-temperature-update/. Accessed on: 19 jul. 2023.

SALM, S.; HILLE, S. L.; WÜSTENHAGEN, R. What are retail investors' risk-return preferences towards renewable energy projects? A choice experiment in Germany. **Energy Policy**, v. 97, p. 310–320, oct. 2016.

SCHNEIDER, K. *et al.* Community Solar in Brazil: the cooperative model context and the existing shared solar cooperatives up to date. Proceedings of the ISES Solar World Congress 2019. *In*: ISES SOLAR WORLD CONGRESS 2019/IEA SHC INTERNATIONAL CONFERENCE ON SOLAR HEATING AND COOLING FOR BUILDINGS AND INDUSTRY 2019. **Anais [...]** Santiago, Chile: International Solar Energy Society, 2019a. Available at: http://proceedings.ises.org/citation?doi=swc.2019.31.04. Accessed on: 27 aug. 2021.

SCHNEIDER, K. *et al.* Shared solar cooperatives in Brazil: context, overcoming barriers and lessons to be drawn from previous European countries experiences. *In*: 36TH EUROPEAN PHOTOVOLTAIC SOLAR ENERGY CONFERENCE AND EXHIBITION. **Anais [...]**. 2019b.

SCHNEIDER, K. Geração comunitária e descentralizada de energia renovável no Brasil: cooperativas de geração distribuída compartilhada. **Diálogos Socioambientais**, v. 3, n. 9, p. 39–42, dec. 2020.

SE FOR ALL. **Sustainable Development Goal 7 (SDG7)**. Available at: https://www.seforall.org/sustainable-development-goal-7-sdg7. Accessed on: 19 jul. 2023.

SEC. **Solicitud de acceso a la información**. Ref.: Solicitud NoAU004T0036504, 25 oct. 2023a.

SEC. **Solicitud de acceso a la información**. Ref.: Solicitud NoAU004T0036430, 3 nov. 2023b.

SERGI, B. *et al.* Institutional influence on power sector investments: a case study of on- and off-grid energy in Kenya and Tanzania. **Energy Research & Social Science**, v. 41, p. 59–70, jul. 2018.

SOKOŁOWSKI, M. M.; HEFFRON, R. J. Defining and conceptualising energy policy failure: the when, where, why, and how. **Energy Policy**, v. 161, p. 112745, feb. 2022.

SOVACOOL, B. K. *et al.* Pluralizing energy justice: incorporating feminist, anti-racist, indigenous, and postcolonial perspectives. **Energy Research & Social Science**, v. 97, p. 102996, mar. 2023.

SUN, Z. *et al.* Literature review and analysis of the social impact of a just energy transition. **Frontiers in Sustainable Food Systems**, v. 7, p. 1119877, 29 jun. 2023.

SVAMPA, M. Dilemas de la transición ecosocial desde América Latina. *In*: **Transiciones Justas**. Una agenda de cambios para América Latina y el Caribe. 1. ed. Buenos Aires: Clacso; Oxfam, 2023. p. 35–88.

SVAMPA, M.; BERTINAT, P. **La transición energética en la Argentina**: una hoja de ruta para entender los proyectos en pugna y las falsas soluciones. 1. ed. Argentina: Siglo XXI Editores, 2022.

WANG, X.; LO, K. Just transition: a conceptual review. **Energy Research & Social Science**, v. 82, p. 102291, dec. 2021.

WYSE, S. M.; HOICKA, C. E. "By and for local people": assessing the connection between local energy plans and community energy. **Local Environment**, v. 24, n. 9, p. 883–900, 2 sept. 2019.

Condições institucionais para o desenvolvimento das comunidades energéticas no Chile e no Brasil

Institutional conditions for the development of energy communities in Chile and Brazil

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RESUMO

A energia é um fator essencial que não deve ser ignorado nas discussões sobre a mitigação e o enfrentamento dos efeitos associados às mudanças climáticas induzidas pelo homem. Este trabalho aprofunda o debate sobre as transições energéticas do Chile e do Brasil, examinando os aspectos justos e sustentáveis, principalmente em âmbito local. O estudo destaca e compara as experiências das comunidades energéticas *on-grid* de ambas as nações. O percurso metodológico compreende três fases: examinar as estruturas regulatórias, avaliar a infraestrutura das comunidades energéticas *on-grid* e investigar as cooperativas energéticas emergentes em ambos os países. Nossos resultados sugerem que as comunidades energéticas *on-grid* têm o potencial de promover uma transição energética sustentável mais ampla, especialmente quando estabelecidas como entidades cooperativas. Embora haja menos casos de cooperativas energéticas operando no Chile, todos eles mostram um envolvimento

transversal de diferentes membros da sociedade, enquanto alguns casos brasileiros não o fazem. A justiça e a democracia não são garantidas se as partes interessadas não estiverem adequadamente envolvidas. Ainda que as experiências no Chile e no Brasil apontem direções exitosas, não há soluções únicas até o momento.

Palavras-chave: Transição energética. Transição justa. Comunidades energéticas. Chile. Brasil.

ABSTRACT

Energy is an essential factor that must not be overlooked in discussions concerning mitigating and confronting effects associated with human-induced climate change. This work delves into the Chilean and Brazilian energy transitions, scrutinizing just and sustainable aspects, primarily in the local context. The study highlights and compares the experiences of both nations' on-grid energy communities. The methodological pathway comprises three phases: examining regulatory frameworks, assessing on-grid energy communities' infrastructure in both countries and delving into emerging energy cooperatives. Our findings suggest that on-grid energy communities have the potential to foster a more widespread sustainable energy transition, especially when established as cooperative entities. However, there are no easy solutions to date, as justice and democracy are not guaranteed if stakeholders are not adequately engaged. Although there are fewer cooperative cases in Chile, all of them show a cross-cutting involvement of different members of society, while some Brazilian cases do not.

Keywords: Energy transition. Just transition. Energy communities. Chile. Brazil.

1 INTRODUÇÃO

O setor de energia desempenha um papel essencial no enfrentamento e na mitigação das mudanças climáticas antrópicas, desenvolvido por meio da transição energética para a sustentabilidade. A Agência Internacional de Energia Renovável — Irena (2023) — aponta que, para atingir a meta de limitar o aquecimento global para 1,5°C, em conformidade com o Acordo de Paris, é necessário reduzir aproximadamente 37 gigatoneladas (Gt) de emissões de dióxido de carbono (CO_2) em relação aos níveis de 2022, além de atingir emissões net zero no setor energético até 2050. No lado da produção, as fontes de baixas emissões devem substituir os combustíveis fósseis. No lado da demanda, os sistemas devem aumentar a eficiência, e a eletricidade deve aumentar a sua participação relativa dentro dos energéticos de uso final1— num processo nomeado *eletrificação da economia* (IPCC, 2022). Atualmente, todos os esforços parecem insuficientes para deter as crises climática e socioecológica (IEA, 2023; IPCC, 2023). O ano de 2023 pode representar um momento crucial na progressão das mudanças climáticas, com consequências potencialmente irreversíveis para os limites naturais da Terra. Notavelmente, julho de 2023 estabeleceu um recorde para o mês mais quente da história recente (Copernicus, 2023; Rohde, 2023).

A transição energética para a sustentabilidade é muito mais do que meras mudanças tecnológicas. Ela implica uma transformação em como as sociedades consomem e produzem energia, o que assume diferentes nuances, dependendo de fatores culturais, econômicos e sociais (Irena, 2023; Sun *et al.*, 2023). A natureza social e humana da energia se tornou primordial, e conceitos como "democracia" e "justiça" se tornaram críticos, assim como os apelos por "transições justas" (Abram; Winthereik; Yarrow, 2020; García Parra *et al.*, 2023; Lampis; Bermann, 2022; Leo Coleman, 2021). Estudos focados na transição destacam como é crucial considerar a proteção social, o diálogo, o bem-estar e a equidade, respeitando os grupos vulneráveis e sua dignidade na tomada de decisões e, ao mesmo tempo, mantendo a consciência ecológica (Heffron *et al.*, 2023; Poque González *et al.*, 2023a).

A América Latina e o Caribe (ALC) é um caso interessante, pois há perspectivas e ideias diversas e não convencionais sobre energia, meio ambiente e sociedade (Alarcón, 2023; García Parra *et al.*,

2023). Nas últimas décadas, os sistemas elétricos da ALC diversificaram as suas matrizes quando alguns países passaram a instalar cada vez mais fontes de energia renovável não convencional – ERNC (Poque González; Silva; Macia, 2022). Este estudo se concentra no Chile e no Brasil como dois dos principais sistemas de energia da ALC, com instalações em expansão de ERNCs e estruturas regulatórias emergentes para geração distribuída (GD). Ademais, historicamente, ambos os países dependeram do recurso hídrico e dos combustíveis fósseis, além de serem economias reconhecidas globalmente como emergentes. Da mesma forma, ambos tiveram conflitos ligados às energias renováveis, desafios sociais e ambientais não resolvidos, levantando novas questões sobre as dimensões "justa" e "sustentável" da transição (Lampis *et al.*, 2022; Poque González *et al.*, 2023a).

Este artigo explora os aspectos em que as transições energéticas no Chile e no Brasil são "justas" e "sustentáveis". A análise inclui uma revisão da literatura crítica que examina as nuances da transição energética, incluindo os trabalhos de Flores-Fernández (2020) e Lampis *et al.* (2022). O estudo se concentra nos esquemas energéticos locais, pois ambos os países enfrentam desafios locais inacabados (Hernando-Arrese; Rasch, 2022; Lazaro *et al.*, 2022; Poque González *et al.*, 2023a). Como Cunha *et al.* (2021a) enfatizaram, as comunidades energéticas (CEs) são potencialmente catalisadores locais para transições mais "justas" e "sustentáveis". Normalmente, utilizando fontes renováveis em pequena escala, as CEs também podem empoderar seus cidadãos (Acosta *et al.*, 2018; Cunha *et al.*, 2021a; Lode *et al.*, 2022, 2023; Pérez-Pérez, 2023; Wyse; Hoicka, 2019).

Em resumo, este artigo explora o papel potencial das CEs na facilitação de transições energéticas investigando o estado atual dessas comunidades no Brasil e no Chile, bem como os aspectos institucionais que permitem sua execução. Além disso, o estudo analisa as cooperativas energéticas enquanto um tipo particular de CE que poderia sustentar estruturas sociais mais democráticas e participativas (Lode; Coosemans; Ramirez Camargo, 2022; Schneider *et al.*, 2019a).

Este documento contém cinco seções. Além da Introdução como primeira seção, a seção 2 contextualiza a transição energética "justa" e "sustentável" como uma agenda mundial, e ademais descreve o que sabemos sobre as CEs. Na seção 3, descrevemos o percurso metodológico que dirigiu este trabalho. Em seguida, na seção 4, o conteúdo principal de nossos argumentos sobre a situação das CEs e cooperativas energéticas chilenas e brasileiras. Por fim, nas seções 5 e 6, discutimos — em um diálogo com autores clássicos e emergentes, e visões interdisciplinares — as principais conclusões do trabalho, cruzando as questões das transições energéticas "justas" e "sustentáveis" com os casos das CEs chilenas e brasileiras.

2 CONTEXTUALIZAÇÃO

Vinculados à transição energética contemporânea, os conceitos "justo" e "sustentável" ganharam reconhecimento em planos e agendas globais, mas são frequentemente questionados na literatura. A contradição entre o bem-estar social e os desafios ambientais está profundamente enraizada em um debate mais amplo sobre sustentabilidade no contexto da crise socioecológica — especialmente em economias capitalistas dependentes do crescimento (Cleveland; Ruth, 1997; Latour, 2017; Leff, 2021; Max-Neef, 2010).

Essa contradição desencadeia discussões sobre novos paradigmas de política ecossocial, associando limites ambientais e direitos sociais. O setor de energia e as iniciativas socialmente enraizadas e com senso ecológico, como as CEs, poderiam desempenhar um papel fundamental nessa matéria (Carrosio; De Vidovich, 2023; Cunha *et al.*, 2021a). A energia (práticas, políticas e infraestruturas) envolve a vida coletiva, as distribuições de poder e as oportunidades de participação na gestão de bens comuns em diferentes níveis (Leo Coleman, 2021). Mais especificamente, uma ênfase significativa na eletricidade (produção, consumo e transformação) é crucial na investigação do comportamento humano contemporâneo e seu impacto na sociedade (Abram; Winthereik; Yarrow, 2020).

2.1 TRANSIÇÕES ENERGÉTICAS "JUSTAS" E "SUSTENTÁVEIS" E PERCURSOS GLOBAIS

Sun *et al.* (2023) argumentam que uma transição energética "sustentável" e "justa" também é política e social, além das suas componentes tecnológicas e ecológicas. Ramírez-Tovar e Schneider (2023) destacam que a inclusão de novos atores sugere mudanças nas estruturas e interações dos sistemas, especialmente na participação ativa dos cidadãos. Da mesma forma, Lampis *et al.* (2022) pedem mecanismos melhores e mais eficazes de democracia local. Cunha *et al.* (2021a) postulam que, para obter resultados favoráveis, "justos" e "sustentáveis" na transição energética, é necessário um engajamento sólido das instituições públicas, dos cidadãos e da sociedade civil.

Duas agendas globais buscam vias de desenvolvimento sustentável: o Acordo Climático de Paris (2015) e os Objetivos de Desenvolvimento Sustentável (ODS) das Nações Unidas. Ambos os compromissos compartilham metas energéticas intimamente ligadas a questões sociais e ambientais. Abordar essas questões é fundamental para alcançar uma transição energética justa rumo a uma sociedade de baixo carbono (Cunha *et al.*, 2021a). Enquanto os Objetivos de Desenvolvimento Sustentável das Nações Unidas (SDG7) apontam a necessidade de energia acessível, confiável, sustentável e moderna para todos até 2030 (Se For All, 2023), o Acordo de Paris está fortemente vinculado à descarbonização para restringir o aumento dos níveis de temperatura média mundial, o que implica que a concentração de GEE permanecerá abaixo de 450 partes por milhão (ppm) de CO_2-equivalente (IPCC, 2014); veja que, em maio 2023, foi de 424 ppm (CO_2 Earth, 2023).

O termo "transição justa" surgiu na agenda global depois de ter sido definido na Declaração da Silésia sobre Solidariedade e Transição Justa adotada na Conferência das Partes — COP 24, em 2019, e na Declaração de Transição Justa da COP 26, em Glasgow, em 2021 (Alarcón, 2023). Nesse contexto, ele se concentra no apoio a trabalhadores, comunidades e regiões particularmente vulneráveis aos efeitos da mudança de economias com uso intensivo de carbono — por exemplo, os setores de carvão — para economias mais verdes (ILO, 2021). A promoção de uma "transição energética justa" e o respeito às populações e aos ecossistemas ainda estão na agenda da COP 27 (COP 27, 2022).

2.2 PERSPECTIVAS CRÍTICAS SOBRE A "TRANSIÇÃO ENERGÉTICA JUSTA"

Fora do contexto da COP, o termo "transição justa" vai além do seu foco em metas voltadas para o âmbito do trabalho. Aliás, no ambiente acadêmico, ele abrange uma gama mais ampla de tópicos (Alarcón, 2023), incluindo os bens comuns, relações harmoniosas entre seres humanos e natureza, raça, colonialismo, gênero e governança (Dunlap; Tornel, 2023; Sovacool *et al.*, 2023; Svampa, 2023; Wang; Lo, 2021). Outras perspectivas que moldam uma transição energética justa são derivadas da teoria associada à "justiça energética" (Jenkins *et al.*, 2016; Mccauley; Heffron, 2018).

Lander (2023) assim como Bertinat e Chemes (2022) e Svampa e Bertinat (2022) apontaram a transição energética como um questionamento das relações sociais atuais e das relações homem-natureza. Bertinat e Chemes (2022) têm duas narrativas distintas sobre a transição energética contemporânea. A primeira é uma narrativa capitalista-tecnocrática que considera a energia como uma mercadoria, conhecida como a "transição energética corporativa". A segunda narrativa critica o atual modelo socioeconômico global pela sua responsabilidade na crise socioecológica em curso. Há uma dedicação à realização de uma transição socioecológica baseada em uma sustentabilidade sólida ou superforte, juntamente com a busca de uma transição energética centrada na justiça socioambiental, participativa e cooperativa, conforme enraizada no manifesto anticapitalista e de transição socioecológica. Essa perspectiva deu origem à "transição energética popular".

Esta pesquisa destaca a importância do envolvimento social e da governança nas CEs locais e nos esquemas cooperativos. Por isso, este texto não examina as perspectivas trabalhistas sobre as "transições justas" e considera as opiniões divergentes apresentadas nos parágrafos anteriores.

2.3 AS TRANSIÇÕES ENERGÉTICAS CHILENA E BRASILEIRA

O início dos processos de transição energética em ambos os países tem motivações semelhantes. No final do século XX e no início do século XXI, ambos os países enfrentaram conjunturas críticas provocadas por secas e deficiências no fornecimento de combustíveis fósseis. Isso os obrigou a diversificar suas matrizes elétricas para aumentar a segurança energética. Ao mesmo tempo, as transições sustentáveis e a descarbonização das economias ganharam atenção global, e, ademais, os conflitos socioecológicos locais provocaram oposição aos projetos convencionais de grande porte (grandes hidrelétricas e usinas dependentes dos combustíveis fósseis). Assim, as ERNCs e a GD surgiram como alternativas na esfera política e logo se materializaram em políticas públicas e regulamentações, como a Lei de Cotas e o plano Proinfa — no Chile e no Brasil, respectivamente. No início da década de 2020, ambos os países praticamente atingiram um quarto do seu fornecimento anual de eletricidade a partir de ERNCs, excluindo a hidreletricidade (Castillo *et al.*, 2022). Em uma segunda onda de reformas, a partir da década de 2010, ambos os países consideraram CEs *on-grid* (Poque González *et al.*, 2023b).

A Tabela 1 mostra os indicadores relacionados ao ODS 7 no Chile e no Brasil. Em comparação com os níveis globais, os dois países apresentam um progresso louvável na obtenção de sistemas de energia mais limpos e eficientes e na abordagem de questões sociais (indicadores 7.1.1; 7.2.1; 7.3.1; 7.b.1). Embora as avaliações do progresso no indicador 7.2.1 mostrem um desempenho satisfatório, um exame holístico dos sistemas energéticos em ambos os países revela uma dependência significativa dos combustíveis fósseis (Castillo *et al.*, 2022). Essas circunstâncias criam alguns dilemas. Por outro lado, a presença crescente e generalizada de energias renováveis nas redes elétricas reforça o intuito da eletrificação das economias para alcançar economias de baixo carbono ou com emissões net zero. No entanto, as instalações de energia renovável de grande porte ainda enfrentam conflitos e desafios (Poque González *et al.*, 2023a), os quais ainda não podem ser medidos pelos indicadores do ODS 7 (Galbiati *et al.*, 2022).

Assim, ambos os casos nacionais oferecem uma oportunidade de examinar como as soluções locais podem ajudar em transições energéticas justas dentro dos seus contextos políticos e sociotécnicos (Lazaro *et al.*, 2022; Merino; Montero; Dastres, 2020). No entanto, é preciso ter cautela, pois embora o estabelecimento de estruturas de GD seja visto como um possível facilitador de sistemas energéticos mais equitativos e democráticos, pesquisas anteriores advertem contra a supervalorização da proliferação de GD como uma panaceia (Pavanelli *et al.*, 2022).

Tabela 1 | Perfis nacionais do ODS 7.

ODS 7	*Parâmetro*	*Chile*	*Brasil*	*Mundial*
7.1.1	2021 Percentual da população com acesso à eletricidade (%)	~100	~99	91
7.2.1	2020 Participação da energia renovável no consumo final total de energia (%)	26,7	50,1	19,1
7.3.1	2020 Nível de intensidade energética da energia primária (a)	3,6	4,0	4,6
7.a.1	2021 Fluxos financeiros internacionais (milhões de dólares, PPP de 2020)	36	414	10.775
7.b.1	2021 Capacidade de geração de eletricidade renovável (Watts per capita)	764	746	268

Fonte: Dados de Esmap (2023).
(a) Megajoules por PIB, expressos em paridade de poder de compra (PPP) constante de 2017.

2.4 COMUNIDADES ENERGÉTICAS

Uma CE é "um grupo de cidadãos que produz, gerencia e utiliza sua energia em um local, geografia ou lugar definido; costumeiramente, em uma modalidade distribuída e com base em fontes renováveis (solar, eólica, hídrica, biomassa, geotérmica) e/ou métodos/tecnologias de conservação/eficiência

energética" (Poque González; Viglio; Ferreira, 2022, p.157). Entre os elementos que motivam o desenvolvimento das CEs, a literatura distingue pelo menos quatro esferas: econômica (Salm; Hille; Wüstenhagen, 2016), social (Curtin; Mcinerney; Johannsdottir, 2018; Mirzania *et al.*, 2019; Mundaca; Busch; Schwer, 2018), ecológica (Holstenkamp; Kahla, 2016) e política (Mirzania *et al.*, 2019).

As CEs se tornaram alternativas atraentes para os sistemas energéticos tradicionais de grande porte, centralizados e fechados em termos de propriedade — elas não são exclusivas e podem coexistir com os sistemas energéticos convencionais — uma vez que são administradas por e para o bem-estar da população local, desencadeando um amplo engajamento social (Poque González *et al.*, 2023b). As CEs podem assumir duas modalidades: *on-grid* e *off-grid*. Como geralmente usado em sistemas energéticos (Sergi *et al.*, 2018), as CEs *on-grid* são projetos de energia conectados à rede que implicam fluxos de energia bidirecionais, enquanto as CEs *off-grid* não estão conectadas à rede nacional e compreendem sistemas isolados. Na ALC, as CEs são uma prática antiga vista como uma forma respeitosa de relacionar as pessoas à energia (Baigorrotegui; Chemes, 2023).

Como o principal objetivo do estudo das CEs é analisar as suas contribuições para a transição energética "justa" e "sustentável", vamos nos concentrar nas CEs *on-grid*. Isso se deve ao fato de que, nos países da América do Sul, as CEs *off-grid*[2] geralmente resultam da necessidade de fornecer eletricidade a indivíduos em regiões isoladas sem acesso à energia elétrica. Isso vai além de um sentido sustentável e, muitas vezes, não é uma escolha, mas é a única opção. Observe que os projetos de CEs sul-americanos (*on-grid* e *off-grid*) já documentados na literatura assumiram o formato de cooperativas, pequenas empresas privadas ou permaneceram gerenciados por órgãos públicos no nível estadual ou municipal (Poque González; Viglio; Ferreira, 2022).

2.4.1 COOPERATIVAS ENERGÉTICAS

Uma cooperativa é um grupo autônomo de indivíduos que se unem voluntariamente para atender às suas necessidades e ambições econômicas, sociais e culturais por meio de um empreendimento de propriedade coletiva e democraticamente administrado (Schneider *et al.*, 2019b). A filosofia do cooperativismo defende a transformação das comunidades para torná-las mais justas e igualitárias. Além disso, as cooperativas desempenham um papel fundamental na promoção do desenvolvimento local, pois priorizam o bem-estar dos membros, dos funcionários e da comunidade em geral. Desde seu surgimento no século XIX, os princípios orientadores do cooperativismo se concentram na participação democrática, solidariedade, independência e autonomia (Lima, 2018).

Uma cooperativa energética envolve a colaboração de indivíduos que têm um desejo comum de produzir sua energia, mas não podem fazê-lo de forma independente ou optaram por não fazê-lo (Lima, 2018). Normalmente, essas cooperativas são administradas por e para os seus membros, com decisões que seguem o princípio de um membro, um voto (Schneider, 2020). De acordo com Lode, Coosemans e Ramirez Camargo (2022), as cooperativas energéticas oferecem uma abordagem inovadora para transformar os sistemas energéticos centralizados em sistemas mais descentralizados e que atendam a propósitos ambientais, econômicos e sociais.

3 PERCURSO METODOLÓGICO

A obtenção de dados do trabalho está dividida em três etapas, e começa com uma análise qualitativa das definições políticas que possibilitam as CEs *on-grid* em ambos os países. Examinamos as estruturas regulatórias que regem as CEs chilenas e brasileiras, conforme descrito nas leis e resoluções energéticas atuais relacionadas à GD. Essas estruturas incluem a Lei nº 21118 no Chile (Ministerio de Energía, 2018) e a Resolução Normativa nº 687 de 2015 — REN 687/2015 — no Brasil (Aneel, 2015). Isso nos permite decifrar os tipos de arranjos ou esquemas que estão sendo considerados por

cada regulamento — tamanho e fonte. Em seguida, de forma semelhante a Sokolowsky e Heffron (2022), podemos examinar se essas iniciativas estão alinhadas com as metas locais, nacionais e internacionais de energia e clima.

Em segundo lugar, em uma fase principalmente quantitativa, usando dados secundários de instituições públicas, queremos saber como a implementação de ambos os regulamentos evoluiu em relação à infraestrutura coletiva adicionada aos sistemas. Isso envolve contar o número de CEs *on-grid* e a capacidade adicionada à rede com relação a cada regulamento. Em seguida, solicitamos informações públicas da Superintendência de Eletricidade e Combustíveis do Chile — SEC (SEC, 2023a, 2023b) — e as coletamos da Plataforma BI da Agência Nacional de Energia Elétrica do Brasil — Aneel (Aneel, 2023). Essa análise tem uma visão de médio prazo, já que ambas as estruturas regulatórias foram implementadas na última década, e o objetivo não é prever cenários futuros, mas analisar o estado atual de desenvolvimento. Exploramos quais setores econômicos estão implementando CEs na rede, quantos projetos estão instalados e quais fontes de energia são usadas.

Na terceira fase, um foco especial é dado às cooperativas energéticas, pois tentamos mapear o desenvolvimento desses projetos e as suas principais características. Como se trata de uma questão emergente, os dados estão se tornando disponíveis por meio de iniciativas como a Plataforma de Energia Cooperativa, que monitora o desenvolvimento de cooperativas energéticas no Chile, Brasil, México e Colômbia, e fornece informações para essa parte deste trabalho (Energía Cooperativa, 2023). Complementamos essa fase com a literatura publicada mais recentemente em inglês, espanhol e português, incluindo autores nacionais chilenos e brasileiros, disponíveis no Google Scholar, bem como literatura cinza.

Por fim, a seção 5 apresenta uma fase adicional, na qual os resultados anteriores são discutidos e analisados dentro de um enquadramento interdisciplinar. Isso inclui a análise em nível nacional e local, enfatizando as dimensões "justa" e "sustentável" das transições energéticas. Este artigo emprega predominantemente fontes de dados secundárias, que são devidamente referenciadas. Dessa forma, não há infrações ou transgressões éticas.

4 RESULTADOS

Esta seção desenvolve as três etapas da nossa metodologia: reconhecimento das estruturas institucionais para CEs *on-grid*, avaliação da infraestrutura vinculada instalada desde o início das regulamentações e o mapeamento das cooperativas energéticas emergentes.

4.1 DEFINIÇÕES POLÍTICO-INSTITUCIONAIS

O Chile e o Brasil desenvolveram recentemente órgãos institucionais para governar projetos coletivos *on-grid*. Assim, no Chile, as CEs *on-grid* são definidas como empreendimentos de "propriedade conjunta", enquanto, no Brasil, são definidas como "geração compartilhada". Desde 2018, a legislação chilena de geração de energia residencial incorporou a "propriedade conjunta" de ERNCs ou infraestrutura de cogeração eficiente — menores que 300 kW. Desde 2015, o Brasil tem usado o termo "geração compartilhada", que se refere à confluência de consumidores na mesma área de concessão por meio de uma cooperativa ou consórcio com infraestrutura de microgeração igual ou inferior a 75 kW ou minigeração acima de 75 kW e igual ou inferior a 5 MW (Aneel, 2015; Ministerio de Energía, 2018). Recentemente, uma atualização dessas normas limitou a capacidade máxima de minigeração para 3 MW para fontes intermitentes e reavaliou os pagamentos pela energia injetada na rede (Brasil, 2022). O Chile e o Brasil já haviam estabelecido regulamentações de GD (Aneel, 2012; Ministerio de Economía, 2006), entretanto, os sistemas coletivos só surgiram depois que as estruturas foram aprimoradas (Poque González *et al.*, 2023b).

A Figura 1 apresenta as estruturas institucionais e o tamanho permitido para CEs *on-grid* no Chile e no Brasil. Observe que, institucionalmente, o Brasil tem apenas um quadro para GD, enquanto o Chile tem dois quadros para GD; o primeiro é voltado para o setor industrial — pequenos meios de GD — enquanto o segundo é voltado para o setor residencial — ou *Netbilling*. As CEs chilenas *on-grid* estão dentro do quadro residencial (Poque González *et al.*, 2023b). No caso brasileiro, as CEs *on-grid* — geração compartilhada — podem assumir o formato de consórcios ou cooperativas. Um consórcio reúne empresas que fazem um acordo comercial para se beneficiar do sistema de compartilhamento. Além disso, indivíduos que desejam se reunir voluntariamente podem constituir cooperativas (Schneider *et al.*, 2019a).

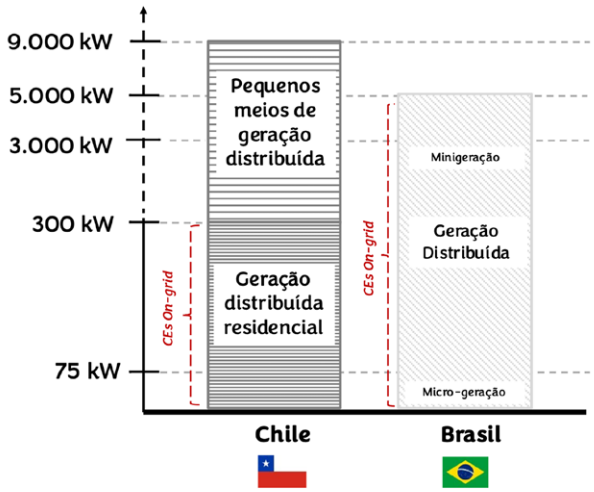

Figura 1 | Estruturas político-institucionais chilenas e brasileiras para as CEs *on-grid.*

4.2 COMUNIDADES ENERGÉTICAS *ON-GRID* NO CHILE E NO BRASIL

É pertinente examinar o estado atual da GD no Chile e no Brasil, concentrando-se especificamente nas instalações associadas a CEs *on-grid*, empreendimentos de "propriedade conjunta" e "geração compartilhada", respectivamente. Devido ao foco principal desta pesquisa no envolvimento social em projetos específicos, também enfatizamos os setores econômicos que os implementam.

Até setembro de 2023, a capacidade instalada de GD residencial no Chile era de 202,7 MW (SEC, 2023a). De acordo com as informações fornecidas pela SEC, cinco projetos foram registrados desde 2021 como de "propriedade conjunta", totalizando 119,7 kW, sendo todos solares fotovoltaicos (SEC, 2023b).

O Brasil teve 24 GW instalados em setembro de 2023 em todos os setores de GD em mais de 2 milhões de projetos em todo o país. Desses, 6.752 projetos são de "geração compartilhada" (CEs *on-grid*), totalizando 667 MW, ou seja, 2,8% de toda a capacidade de GD brasileira é de geração compartilhada. O ano de 2022 representa um marco em termos de instalação de novas unidades de geração compartilhada no Brasil, passando de 809 novas unidades em 2021 para 2.986 unidades em 2022 (Aneel, 2023).

Com relação às fontes empregadas nos projetos brasileiros de geração compartilhada, 18 projetos são hidrelétricos (adicionando 16 MW), um projeto é eólico (adicionando 5 MW), 6.714 projetos são solares fotovoltaicos (adicionando 632 MW) e 19 projetos usam biomassa (adicionando 14 MW). Observe que os setores econômicos com CEs *on-grid* são o comercial (1.508 projetos), iluminação pública (um projeto), industrial (151 projetos), público (11 projetos) e rural (1.172). O setor habitacional tem 3.909 projetos. Outro formato, que poderia eventualmente ser um tipo de CE *on-grid*, é definido na

regulamentação brasileira como "empreendimento multiconsumidor", mas esse formato tem apenas 326 projetos com 9 MW (Aneel, 2023).

4.3 COOPERATIVAS ENERGÉTICAS — UMA FORMA DE CE COMO CANAL DE PARTICIPAÇÃO POPULAR?

Em ambos os países, as cooperativas energéticas são uma forma de CE que pressupõe a cooperação institucional na autogovernança. A plataforma Energia Cooperativa (2023) reconhece atualmente quatro cooperativas energéticas *on-grid* no Chile, totalizando 163 kW de capacidade e envolvendo 480 indivíduos (Tabela 2). Atualmente, a P*etorca Sustentable* e a Coopeumo estão em operação. O projeto *Petorca Sustentable* envolve o município de Petorca e outros 18 beneficiários, cuja saúde depende da eletricidade — pacientes eletrodependentes. A iniciativa da Coopeumo inclui nove beneficiários da injeção de excedentes na rede e 328 indivíduos e entidades afiliados. Seu mecanismo de compartilhamento de energia beneficia os estabelecimentos agrícolas da Cooperativa Coopeumo e instituições públicas, como escolas e centros de saúde no município de Pichidegua (Energía Cooperativa, 2023).

Observe que as cooperativas energéticas são incipientes no Chile e estão concentradas na região central. A partir da plataforma Energia Cooperativa (2023), identificamos que todos os projetos têm uma ampla gama de atores privados e públicos envolvidos, mas os municípios estão sempre presentes, demonstrando a importância dos governos locais. Da mesma forma, todos os projetos têm propósitos sociais.

Tabela 2 | Cooperativas energéticas chilenas

Nome	*Data*	*Tamanho (kW)*	*Fonte*	*Localização*
Petorca Sustentable	2021	66,3	Solar fotovoltaica	Petorca, Região de Valparaíso
Planta Solar Comunitaria de Tiltil	2023	50	Solar fotovoltaica	Região Metropolitana de Santiago
Energía Solar Comunitaria Nueva Zelandia	2022	12	Solar fotovoltaica	Região Metropolitana de Santiago
Cooperativa Coopeumo	2021	32	Solar fotovoltaica	Pichidegua, Região do Libertador General Bernardo O'Higgins

Fonte: Dados de Energía Cooperativa (2023).

No Brasil, Schneider (2020) identificou 19 cooperativas energéticas, totalizando aproximadamente 26 MW (16 usando infraestrutura fotovoltaica) em 2020. Em 2023, a plataforma Energia Cooperativa considera 24 cooperativas energéticas *on-grid* (Tabela 3). Ao contrário do Chile, algumas cooperativas energéticas brasileiras — pelo menos COOGD, Cooerma, Coopsolar, Photon, Ciclos, Enercred, Renovaeco, Sun Mobi, Hadar do Sol, Sinergi, Paraná Energia, Cogecom e Alka — concentram-se em reduzir o pagamento das contas de eletricidade dos cooperados, envolvendo empreendimentos que fornecem energia e geram créditos, principalmente em áreas urbanas. Essas iniciativas foram realizadas principalmente por organizações civis sem engajamento do governo (Energía Cooperativa, 2023).

Tabela 3 | Cooperativas energéticas brasileiras

Nome	*Data*	*Tamanho (kW)*	*Fonte*	*Localização*
Cooperon			Solar fotovoltaica	Porto Velho-RO
COOGD	2016		Hidrelétrica	Vilhena-RO

Nome	Data	Tamanho (kW)	Fonte	Localização
Coober	2016	75	Solar fotovoltaica	Paragominas-PA
Cooerma	2019	75	Solar fotovoltaica	Açailândia-MA
Coopetro Energia				Natal-RN
Coopsolar	2020	75	Solar fotovoltaica	João Pessoa-PB
Cooperativa Bem Viver	2021	63	Solar fotovoltaica	Matureia-PB
Photon			Solar fotovoltaica	Itabaiana-SE
Cooperativa de Energias Renováveis do Nordeste	2021		Solar fotovoltaica	Feira de Santana-BA
Coesgo	2021		Solar fotovoltaica	Goiânia-GO
Ciclos	2018	240 (a)	Solar fotovoltaica	Vitória-ES
Percília e Lúcio	2021	26	Solar fotovoltaica	Rio de Janeiro-RJ
Enercred	2017	6885 (a)	Solar fotovoltaica	Pedralva-MG
Renovaeco	2020		Solar fotovoltaica	Santa Rita do Sapucaí-MG
Sun Mobi			Solar fotovoltaica	Mogi das Cruzes-SP
Hadar so Sol			Solar PV	Vinhedo-SP
		Solar fotovoltaica	Vinhedo-SP	Maringá-PR
Sinergi	2019	855 (a)	Solar fotovoltaica	Maringá-PR
Ambicoop	2021	2300 (a)	Solar fotovoltaica -Biomassa	Toledo-PR
Paraná Energia			Solar fotovoltaica	Cascavel-PR
Cogecom	2018	6200 (a)	Biomassa	Carambeí-PR
Cobragedi			Solar fotovoltaica	Curitiba-PR
Alka			Solar fotovoltaica	Florianópolis-SC
Coopervales			Solar fotovoltaica	Arroio do Meio-RS
Coopsolar	2020	30	Solar fotovoltaica	Campinas-SP

Fonte: Dados de Energía Cooperativa (2023).
(a) Esses projetos compreendem mais de uma usina de energia.

Por outro lado, um outro exemplo de envolvimento da comunidade é a cooperativa Percília e Lúcio. Ela é a primeira cooperativa de energia solar nas favelas do Brasil. Mais de 30 famílias foram beneficiadas com a usina solar na favela Morro da Babilônia, no Rio de Janeiro. A criação da cooperativa foi iniciada pela Revolusolar, uma associação sem fins lucrativos que promove o desenvolvimento sustentável de comunidades de baixa renda por meio da energia solar (Oliveira, 2022). Na mesma linha, a Cooperativa Bem Viver tem como objetivo praticar a solidariedade solar rural-urbana envolvendo grupos e comunidades de agricultores familiares (Bem Viver Cooperativa, 2023).

5 DISCUSSÃO

Em ambos os países, as CEs *on-grid*, incorporando ERNCs e formatos de GD de pequeno porte, parecem ser uma mudança de paradigma em direção para sistemas elétricos mais abertos, participativos, democráticos e descentralizados, os quais também são sustentáveis. No entanto, foram observadas nuances específicas em relação a ambos os casos emergentes, o que provocou uma discussão mais aprofundada.

5.1 PAPEL DAS COMUNIDADES ENERGÉTICAS NA TRANSIÇÃO ENERGÉTICA "JUSTA" E "SUSTENTÁVEL"

Uma questão fundamental em nossa crítica é a concepção de transição energética "justa" e "sustentável". Até o momento, o Chile e o Brasil implementaram transições energéticas que parecem institucional e tecnicamente proficientes, dado o aumento constante dos níveis de ERNCs nas últimas décadas, buscando a descarbonização. No entanto, os conflitos socioecológicos ligados às energias renováveis — além das usinas de grande porte convencionais — e a falta de um amplo envolvimento cívico desafiam as premissas de justiça e sustentabilidade que sustentam essas transições. Ambos os casos de transição podem ser associados ao conceito de "transição corporativa", seguindo os termos de Bertinat e Chemes (2022). Além disso, como definiram Carrosio e De Vidovic (2023), as políticas ecossociais integrais se esforçam para alinhar o bem-estar social com a sustentabilidade ambiental, portanto, pode-se questionar se esse alinhamento foi totalmente alcançado nesses casos.

Nesse sentido, a existência de regulamentações de CE *on-grid* é notável e inovadora, pois cria uma estrutura além dos sistemas de energia atomizados. Entretanto, o sentido justo e democrático dessas iniciativas depende do mecanismo escolhido pelas partes interessadas. Assumindo os termos de Bertinat e Chemes (2022), e com base no que foi exposto na seção 4, as CEs, especialmente as cooperativas, podem abrir uma chance para uma "transição energética popular", mesmo começando dentro dos percursos atuais, dominados por tendências corporativas. Da mesma forma, com base no trabalho de Carrosio e De Vidovic (2023), as cooperativas energéticas no Chile e exemplos como a cooperativa Percília e Lúcio, no Brasil, servem como um meio de redistribuição da riqueza, pois cada membro de populações vulneráveis colhe diretamente os benefícios da riqueza gerada. Assim, as CEs são um dispositivo que promove o bem-estar social e o cuidado com o meio ambiente.

Ao adotar a perspectiva da "justiça energética" (Jenkins *et al.*, 2016), as cooperativas energéticas podem, no mínimo, aumentar o reconhecimento social. Como Schneider *et al.* (2019) apontaram, as cooperativas são organizações flexíveis e inclusivas que devem seguir o princípio de um membro-um voto, abrindo oportunidades de engajamento social e o fomento de sistemas energéticos mais democráticos.

5.2 POTENCIALIDADES E BARREIRAS

As CEs não são uma instituição nova na América do Sul. Apesar de experiências antigas na região — principalmente sistemas isolados *off-grid* (Poque González; Viglio; Ferreira, 2022) —, com os casos chilenos de cooperativas energéticas *on-grid* e alguns casos brasileiros de cooperativas energéticas, entendemos que existe um amplo potencial de engajamento social. As CEs são mais do que uma simples infraestrutura energética, elas vão além de uma solução tecnológica, pois envolvem a articulação sociopopular. No entanto, alguns obstáculos para o avanço dessa abordagem foram observados no Brasil. Entre eles estão a escassez de conhecimento técnico e institucional, a falta de orientação adequada e de experiência prévia e a insegurança financeira (Cunha *et al.*, 2021a, 2021b; Schneider, 2020; Schneider *et al.*, 2019b). Além disso, novas complexidades surgiram desde a reforma da estrutura de GD brasileira em 2019, que reduziu o valor dos créditos obtidos pela injeção de energia na rede (Netto; Júnior, 2022).

Observamos que as CEs *on-grid* no Chile e no Brasil dependem muito da energia solar, que tem grande potencial devido à abundância de luz solar na região. Entretanto, pode ser necessário explorar outras fontes de energia, dependendo das necessidades específicas da comunidade assim como também dos recursos locais e da geografia — a biomassa é um exemplo no setor agrícola.

Ao nos aprofundarmos em alguns exemplos relacionados a cooperativas de energia *on-grid*, temos mais descobertas. Quando espaços e infraestruturas comuns são usados para projetos de energia — ou seja, prédios públicos que beneficiam todos os cooperados — evitam-se disputas de terras, como

as que surgem em grandes projetos (Comissão Pastoral da Terra, 2021). Isso também demonstra um potencial para uma maior proteção ambiental.

As cooperativas energéticas no Chile estão intimamente associadas a municípios e instituições públicas, o que é um aspecto positivo da governança local. No entanto, é fundamental examinar por quê os cidadãos hesitam em iniciar esses projetos por conta própria, especialmente se a motivação for evitar a dependência de determinadas instituições. É necessário investigar essa questão mais a fundo.

Por outro lado, as cooperativas energéticas brasileiras são ocasionalmente vistas apenas como um meio para reduzir as contas de eletricidade sem promover o engajamento social dos cooperados. Como Netto e Júnior (2022) apontaram, terceiros assumem o papel de investidores na promoção de projetos em que os usuários primários não têm os orçamentos adequados ou os meios para iniciá-los. Em relação a esse fenômeno, Ramírez-Tovar e Schneider (2023) alertaram para o fato de que o engajamento das pessoas pode ser ameaçado, pois terceiros podem assumir um papel de liderança em detrimento das comunidades. Elas chamaram esse formato de "energia por assinatura". Aliás, parece ser uma oportunidade social, econômica e ambiental para reduzir os pagamentos de energia e as emissões, mas não é necessariamente um impulsionador do engajamento social.

6 CONSIDERAÇÕES FINAIS

Embora as experiências das transições energéticas do Chile e do Brasil tenham sido apresentadas como exemplos bem-sucedidos, elas revelam que as transições energéticas sustentáveis exigem mais do que apenas um aumento nos níveis de ERNCs. Atualmente, a produção, o gerenciamento e a demanda de energia por parte dos cidadãos e das sociedades em vários níveis são um aspecto crucial desse tópico. É essencial refletir sobre as dimensões "justa" e "sustentável" das transições. Ao explorar o engajamento social, o nível local é fundamental. Portanto, é nesse ponto que vemos as CEs *on-grid* como um marco importante nas regulamentações energéticas do Chile e do Brasil.

O (re)engajamento sociopopular nas questões energéticas é provavelmente um dos melhores marcos que as CEs podem trazer para esses tempos críticos. No entanto, é essencial concentrar-se e explorar casos específicos para evitar a ilusão. Este estudo investigou as definições políticas predominantes de CEs *on-grid* e as instalações atuais em ambos os países. Além disso, revisitamos casos documentados de cooperativas energéticas para obter *insights* sobre suas práticas operacionais e desafios. Consequentemente, argumentamos que as CEs podem potencialmente impulsionar transições mais sustentáveis no Chile e no Brasil, mesmo dentro dos parâmetros determinados pelos modelos energéticos atuais.

No entanto, as regulamentações atuais são insuficientes para garantir sistemas mais justos e democráticos com engajamento social. A partir de casos como as cooperativas Percília e Lúcio no Brasil e os quatro casos de cooperativas chilenas, percebemos o surgimento de cooperativas como um formato incipiente que pode reforçar o envolvimento da comunidade e a articulação social no desenvolvimento da CE. Entretanto, como Ramírez-Tovar e Schneider (2023) destacaram, há certos casos brasileiros em que as cooperativas são apresentadas meramente como um meio para os consumidores reduzirem as contas de eletricidade enquanto mantêm seu *status* de mero consumidor. Assim, a mudança de paradigma de cidadãos consumidores para *prosumidores* engajados e para sistemas de energia mais democráticos e justos não está garantida.

Como desafio adicional, é necessário estudar *in loco* as CEs *on-grid* chilenas e brasileiras para entender por que e como as pessoas se envolvem nesses projetos, bem como a apropriação da tecnologia, a administração dos sistemas e as limitações e lições dessas experiências. Alguma literatura começou a analisar questões técnicas, no entanto, faltam pesquisas sobre a experiência da sociedade em relação às CEs.

NOTAS

1| A eletricidade se tornaria a principal fonte de energia, respondendo por mais de 50% do consumo total de energia final até 2050 no cenário de 1,5°C" (IRENA, 2023).

2| De acordo com Levy *et al.* (2023), o Brasil é um exemplo bem conhecido de CEs isoladas *off-grid*.

DECLARAÇÃO DE INTERESSES CONFLITANTES

Os autores declaram não haver conflitos de interesse em potencial com relação à pesquisa, autoria e publicação deste estudo.

REFERÊNCIAS

ABRAM, S.; WINTHEREIK, B. R.; YARROW, T. Current thinking – an introduction. *In*: SARKAR, A. (Ed.). **Electrifying anthropology**: exploring electrical practices and infrastructures. London; New York: Routledge, Taylor & Francis Group, 2020. p. 3–24.

ACOSTA, C. *et al.* Facilitating Energy Transition through Energy Commons: an application of socio-ecological systems framework for integrated community energy systems. **Sustainability**, v. 10, n. 2, p. 366, 31 jan. 2018.

ALARCÓN, P. Old and new challenges of the energy transition: insights from South America. **South African Journal of International Affairs**, p. 1–16, 15 jun. 2023.

ANEEL. **Resolução 482**. 2012. Available at: https://www2.aneel.gov.br/cedoc/ren2012482.pdf. Accessed on: 16 oct. 2023.

ANEEL. **Resolução 687**. 24 nov. 2015. Available at: http://www2.aneel.gov.br/cedoc/ren2015687.pdf. Accessed on: 8 dec. 2019.

ANEEL. **Microsoft Power BI**. Available at: https://app.powerbi.com/view?r=eyJrIjoiY2VmMmUwN2QtYWFiOS00ZDE3LWI3NDMtZDk0NGI4MGU2NTkxIiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Accessed on: 12 oct. 2023.

BAIGORROTEGUI, G.; CHEMES, J. Comunidades energéticas latinoamericanas. Sostenedoras de transiciones que mantienen y reparan la vida. **Energía y Equidad**, n. 6, p. 14–25, jul. 2023.

BEM VIVER COOPERATIVA. **Bem Viver**. 2023. Available at: https://bemviver.coop.br/social/. Accessed on: 17 oct. 2023.

BERTINAT, P.; CHEMES, J. Transición energética y disputa de sentidos. *In*: **Informe Ambiental 2022**. Abordar una transición socioecológica integral: el desafío de nuestro tiempo. 1. ed. Argentina: [s.n.].

BRASIL. **L14300.** 2022. Available at: https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/lei/l14300.htm. Accessed on: 12 oct. 2023.

CARROSIO, G.; DE VIDOVICH, L. Towards eco-social policies to tackle the socio-ecological crisis: energy poverty as an interface between welfare and environment. **Environmental Sociology**, v. 9, n. 3, p. 243–256, 3 jul. 2023.

CASTILLO, T. *et al.* **Panorama Energético de América Latina y el Caribe 2022**. 1. ed. Quito, Ecuador: Olade, 2022.

CLEVELAND, C. J.; RUTH, M. When, where, and by how much do biophysical limits constrain the economic process? A survey of Nicholas Georgescu-Roegen's contribution to ecological economics. **Ecological Economics**, v. 22, n. 3, p. 203–223, sept. 1997.

CO_2 EARTH. **Earth's CO_2 Home Page**. Available at: https://www.co2.earth/. Accessed on: 30 jun. 2023.

COMISSÃO PASTORAL DA TERRA. **Conflitos no campo Brasil 2020**. Goiana: Comissão Pastoral da Terra, maio 2021. Available at: https://www.cptnacional.org.br/downlods?task=download.send&id=14242&catid=41&m=0. Accessed on: 15 aug. 2023.

COP 27. **Sharm el-Sheikh Implementation Plan**. 20 nov. 2022. Available at: https://unfccc.int/sites/default/files/resource/cp2022_L19_adv.pdf. Accessed on: 20 jul. 2023.

COPERNICUS. **July 2023, the warmest month in Earth's recent history**. Copernicus. European Union's Earth observation programme. Available at: https://climate.copernicus.eu/july-2023-warmest-month-earths-recent-history?utm_source=socialmedia&utm_medium=tw&utm_campaign=news-CBjulyteaser. Accessed on: 11 aug. 2023.

CUNHA, F. B. F. *et al.* Transitioning to a low carbon society through energy communities: lessons learned from Brazil and Italy. **Energy Research & Social Science**, v. 75, p. 101994, maio 2021a.

CUNHA, F. B. F. *et al.* Renewable energy planning policy for the reduction of poverty in Brazil: lessons from Juazeiro. **Environment, Development and Sustainability**, v. 23, n. 7, p. 9792–9810, jul. 2021b.

CURTIN, J.; MCINERNEY, C.; JOHANNSDOTTIR, L. How can financial incentives promote local ownership of onshore wind and solar projects? Case study evidence from Germany, Denmark, the UK and Ontario. **Local Economy: The Journal of the Local Economy Policy Unit**, v. 33, n. 1, p. 40–62, feb. 2018.

DUNLAP, A.; TORNEL, C. Pluralizing energy justice? Towards cultivating an unruly, autonomous and insurrectionary research agenda. **Energy Research & Social Science**, v. 103, 2023.

ENERGÍA COOPERATIVA. **Energía Cooperativa. Plataforma de Energía Cooperativa**. energia.coop. Available at: https://www2.energia.coop/. Accessed on: 15 aug. 2023.

ESMAP. **Trends. Tracking SDG 7**. Available at: https://trackingsdg7.esmap.org/time?country=Brazil. Accessed on: 10 oct. 2023.

FLORES-FERNÁNDEZ, C. The Chilean energy "transition": between successful policy and the assimilation of a post-political energy condition. **Innovation: The European Journal of Social Science Research**, v. 33, n. 2, p. 173–193, 2 apr. 2020.

GALBIATI, L. A. *et al.* Ruptures from the cattle policy: an analysis according to the sustainable development goals. **Ambiente & Sociedade**, v. 25, p. e0021, 2022.

GARCÍA PARRA, G. *et al.* **Transiciones justas**. Una agenda de cambios para América Latina y el Caribe. 1. ed. Buenos Aires, Argentina: Clacso; Oxfam, 2023.

HEFFRON, R. J. *et al.* Pathways of scholarship for energy justice and the social contract. **Journal of Energy & Natural Resources Law**, v. 41, n. 2, p. 211–232, 3 apr. 2023.

HERNANDO-ARRESE, M.; RASCH, E. D. The micropolitical life of energy projects: a collaborative exploration of injustice and resistance to small hydropower projects in the Wallmapu, Southern Chile. **Energy Research & Social Science**, v. 83, p. 102332, jan. 2022.

HOLSTENKAMP, L.; KAHLA, F. What are community energy companies trying to accomplish? An empirical investigation of investment motives in the German case. **Energy Policy**, v. 97, p. 112–122, oct. 2016.

IEA. **Credible pathways to 1.5°C**. Four pillars for action in the 2020s. France: International Energy Agency, abr. 2023. Available at: https://iea.blob.core.windows.net/assets/ea6587a0-ea87-4a85-8385-6fa668447f02/CrediblepathwaysTo1.5C-FourpillarsforactioninthE2020s.pdf. Accessed on: 10 aug. 2023.

ILO. **ILO welcomes COP 26 Just Transition Declaration**. News. Available at: http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_826717/lang--en/index.htm. Accessed on: 19 jul. 2023.

IPCC. Summary for Policymakers. In: **Climate Change 2014**: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [EDENHOFER, O.; R. PICHS-MADRUGA; Y. SOKONA; E. FARAHANI; S. KADNER; K. SEYBOTH; A. ADLER; I. BAUM; S. BRUNNER; P. EICKEMEIER; B. KRIEMANN; J. SAVOLAINEN; S. SCHLÖMER; C. VON STECHOW; T. ZWICKEL and J. C. MINX (eds.)]. Cambridge, United Kingdom: Cambridge University Press, 2014.

IPCC. Climate Change 2022. Mitigation of Climate Change. Intergovernmental Panel on Climate Change, 2022. Available at: https://www.ipcc.ch/report/ar6/wg3/. Accessed on: 14 apr. 2022.

IPCC. Climate Change 2023. Synthesis Report. Summary for Policymakers. *In*: **Climate Change 2023**: synthesis report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC, 2023. p. 36.

IRENA. **World Energy Transitions Outlook 2023**: 1.5°C Pathway. 1. ed. Abu Dhabi: International Renewable Energy Agency, 2023. v. 1.

JENKINS, K. *et al.* Energy justice: a conceptual review. **Energy Research & Social Science**, v. 11, p. 174–182, jan. 2016.

LAMPIS, A. *et al.* Energy transition or energy diversification? Critical thoughts from Argentina and Brazil. **Energy Policy**, v. 171, p. 113246, dec. 2022.

LAMPIS, A.; BERMANN, C. Public Policy and Governance Narratives of Distributed Energy Resources in Brazil. **Ambiente & Sociedade**, v. 25, 2022.

LATOUR, B. **Où atterrir?** Paris: La Découverte, 2017.

LAZARO, L. L. B. *et al.* Energy transition in Brazil: Is there a role for multilevel governance in a centralized energy regime? **Energy Research & Social Science**, v. 85, p. 102404, mar. 2022.

LEFF, E. **Ecologia política**: da desconstrução do capital à territorialização da vida. Tradução: Jorge Calvimontes. Brasil: Editora da Unicamp, 2021.

LEO COLEMAN. Afterword: People Thinking Energetically. In: LOLOUM, T.; ABRAM, S.; ORTAR, N. (Eds.). **Ethnographies of power**: a political anthropology of energy. 1. ed. New York: Berghahn Books, 2021. v. 42, p. 180–194.

LEVY, A. *et al.* Pathways to sustainable planning for a just energy transition in Latin America and the Caribbean: an analysis of best practices in selected countries. **Natural Resources and Development**, 2023.

LIMA, D. DE B. **Cooperativas de energia. Guia de constituição de cooperativas de geração distribuída fotovoltaica**. 1. ed. Brasília: Sistema OCB, Cooperação Alemã, Giz, DGRV, 2018.

LODE, M. L. *et al.* A transition perspective on Energy Communities: a systematic literature review and research agenda. **Renewable and Sustainable Energy Reviews**, v. 163, p. 112479, jul. 2022.

LODE, M. L. *et al.* Energy communities in rural areas: the participatory case study of Vega de Valcarce, Spain. **Renewable Energy**, p. 119030, jul. 2023.

LODE, M. L.; COOSEMANS, T.; RAMIREZ CAMARGO, L. Is social cohesion decisive for energy cooperatives existence? A quantitative analysis. **Environmental Innovation and Societal Transitions**, v. 43, p. 173–199, jun. 2022.

MAX-NEEF, M. The World on a Collision Course and the Need for a New Economy: contribution to the 2009 Royal Colloquium. **AMBIO**, v. 39, n. 3, p. 200–210, may 2010.

MCCAULEY, D.; HEFFRON, R. Just transition: integrating climate, energy and environmental justice. **Energy Policy**, v. 119, p. 1–7, aug. 2018.

MERINO, F.; MONTERO, A. M.; DASTRES, C. An inclusive and participative model for energy transition in Latin America: the case of Chilean Generación Comunitaria. In: **The Regulation and Policy of Latin American Energy Transitions**. [s.l.] Elsevier, 2020. p. 331–345.

MINISTERIO DE ECONOMÍA. **Decreto 244. 246461**, 17 jan. 2006. Available at: http://www.leychile.cl/N?i=246461&f=2015-09-30&p=. Accessed on: 29 nov. 2019.

MINISTERIO DE ENERGÍA. **Ley 21118. Modifica la Ley General de Servicios Eléctricos, con el fin de incentivar el desarrollo de las generadoras residenciales**. 17 nov. 2018. Available at: https://www.bcn.cl/leychile. Accessed on: 21 jul. 2021.

MIRZANIA, P. *et al.* The impact of policy changes: the opportunities of community renewable energy projects in the UK and the barriers they face. **Energy Policy**, v. 129, p. 1282–1296, jun. 2019.

MUNDACA, L.; BUSCH, H.; SCHWER, S. 'Successful' low-carbon energy transitions at the community level? An energy justice perspective. **Applied Energy**, v. 218, p. 292–303, may 2018.

NETTO, A. DE M.; JÚNIOR, J. U. Análise da geração compartilhada de energia elétrica no Brasil. Anais CBENS 2022. **Anais [...]** In: IX CONGRESSO BRASILEIRO DE ENERGIA SOLAR. Florianópolis: may 2022. Available at: https://anais-cbens.emnuvens.com.br/cbens/article/view/1203.

OLIVEIRA, B. **EasyCoop – Cooperativismo em Revistas**. Available at: https://www.easycoop.com.br/. Accessed on: 12 oct. 2023.

PAVANELLI, J. M. M. *et al.* O contexto da geração distribuída e sua evolução na Macrometrópole Paulista. In: JACOBI, P. R. *et al.* (Eds.). **Governança Ambiental na Macrometrópole Paulista face à Variabilidade Climática**. Brasil: Rima Editora, 2022. p. 379–394.

PÉREZ-PÉREZ, B. **Comunidades energéticas en barrios patrimoniales**: comunidad energética (CE) Barrios de La Alhambra (Granada). n. 46, 2023.

POQUE GONZÁLEZ, A. B. *et al.* Socio-Ecological Controversies from Chilean and Brazilian Sustainable Energy Transitions. **Sustainability**, v. 15, n. 3, p. 1861, 18 jan. 2023a.

POQUE GONZÁLEZ, A. B. *et al.* Redistributing power? Comparing the electrical system experiences in Chile and Brazil from a historical institutional perspective. **Energy Research & Social Science**, v. 101, may 2023b.

POQUE GONZÁLEZ, A. B.; SILVA, B. D. J.; MACIA, Y. M. Transición energética en América Latina y el Caribe: diálogos inter y transdisciplinarios en tiempos de pandemia por Covid-19. **Lider**, v. 39, p. 33–61, 15 mar. 2022.

POQUE GONZÁLEZ, A. B.; VIGLIO, J. E.; FERREIRA, L. DA C. Energy communities in sustainable transitions. The South American Case. **Sustainability in Debate**, v. 13, n. 2, p. 19, 30 aug. 2022.

RAMÍREZ-TOVAR, A. M.; SCHNEIDER, K. Por más, y no menos, comunidades energéticas en la generación ciudadana: diálogo entre las regulaciones brasileña y colombiana. **Energía y Equidad**, n. 6, p. 14–25, jul. 2023.

ROHDE, R. **June 2023 Temperature Update**. Berkeley Earth, 11 jul. 2023. Available at: https://berkeleyearth.org/june-2023-temperature-update/. Accessed on: 19 jul. 2023.

SALM, S.; HILLE, S. L.; WÜSTENHAGEN, R. What are retail investors' risk-return preferences towards renewable energy projects? A choice experiment in Germany. **Energy Policy**, v. 97, p. 310–320, oct. 2016.

SCHNEIDER, K. *et al.* Community Solar in Brazil: the cooperative model context and the existing shared solar cooperatives up to date. Proceedings of the ISES Solar World Congress 2019. In: ISES SOLAR WORLD CONGRESS 2019/IEA SHC INTERNATIONAL CONFERENCE ON SOLAR HEATING AND COOLING FOR BUILDINGS AND INDUSTRY 2019. **Anais [...]** Santiago, Chile: International Solar Energy Society, 2019a. Available at: http://proceedings.ises.org/citation?doi=swc.2019.31.04. Accessed on: 27 aug. 2021.

SCHNEIDER, K. *et al.* Shared solar cooperatives in Brazil: context, overcoming barriers and lessons to be drawn from previous European countries experiences. In: 36TH EUROPEAN PHOTOVOLTAIC SOLAR ENERGY CONFERENCE AND EXHIBITION. **Anais [...]**. 2019b.

SCHNEIDER, K. Geração comunitária e descentralizada de energia renovável no Brasil: cooperativas de geração distribuída compartilhada. **Diálogos Socioambientais**, v. 3, n. 9, p. 39–42, dec. 2020.

SE FOR ALL. **Sustainable Development Goal 7 (SDG7)**. Available at: https://www.seforall.org/sustainable-development-goal-7-sdg7. Accessed on: 19 jul. 2023.

SEC. **Solicitud de acceso a la información**. Ref.: Solicitud NoAU004T0036504, 25 oct. 2023a.

SEC. **Solicitud de acceso a la información**. Ref.: Solicitud NoAU004T0036430, 3 nov. 2023b.

SERGI, B. *et al.* Institutional influence on power sector investments: a case study of on- and off-grid energy in Kenya and Tanzania. **Energy Research & Social Science**, v. 41, p. 59–70, jul. 2018.

SOKOŁOWSKI, M. M.; HEFFRON, R. J. Defining and conceptualising energy policy failure: the when, where, why, and how. **Energy Policy**, v. 161, p. 112745, feb. 2022.

SOVACOOL, B. K. *et al.* Pluralizing energy justice: incorporating feminist, anti-racist, indigenous, and postcolonial perspectives. **Energy Research & Social Science**, v. 97, p. 102996, mar. 2023.

SUN, Z. *et al.* Literature review and analysis of the social impact of a just energy transition. **Frontiers in Sustainable Food Systems**, v. 7, p. 1119877, 29 jun. 2023.

SVAMPA, M. Dilemas de la transición ecosocial desde América Latina. In: **Transiciones Justas**. Una agenda de cambios para América Latina y el Caribe. 1. ed. Buenos Aires: Clacso; Oxfam, 2023. p. 35–88.

SVAMPA, M.; BERTINAT, P. **La transición energética en la Argentina**: una hoja de ruta para entender los proyectos en pugna y las falsas soluciones. 1. ed. Argentina: Siglo XXI Editores, 2022.

WANG, X.; LO, K. Just transition: a conceptual review. **Energy Research & Social Science**, v. 82, p. 102291, dec. 2021.

WYSE, S. M.; HOICKA, C. E. "By and for local people": assessing the connection between local energy plans and community energy. **Local Environment**, v. 24, n. 9, p. 883–900, 2 sept. 2019.

Energy communities of repair in remote infrastructures: a study of Puerto Edén in the Chilean Patagonia

Comunidades Energéticas de Reparação em Infraestruturas Remotas: um estudo de Puerto Edén na Patagônia chilena

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ABSTRACT

Energy communities contribute to the justice of energy transition efforts to enhance the democratisation of contemporary energy policies. We ask what kind of circumstances and practices facilitate the continuity of energy access in remote communities with lagging infrastructures. To answer this question, we propose an approach to researching energy communities of repair based on a study of Puerto Edén, a remote island in the Chilean Patagonia. Since 2020, research has been carried out in this locality using an ethnographic and interactive methodology from a Science and Technology Studies (STS) perspective through systematic fieldwork. The results demonstrate the challenges these communities face as they address deficiencies in governance, providing provisional and definitive solutions. Abandonment of renewable infrastructure could be avoided if historic energy repair communities in remote locations are identified and involved in just energy transition programs.

Keywords: Energy Communities. Maintenance and Repair Studies. Remote Infrastructures. Science and Technology Studies. Puerto Edén.

RESUMO

As comunidades energéticas contribuem para a justiça dos esforços de transição energética que visam reforçar a democratização das políticas energéticas contemporâneas. Perguntamos que tipo de circunstâncias e práticas facilitam a continuidade do acesso à energia em comunidades remotas com infraestruturas atrasadas. Para responder a essa questão, propomos uma abordagem para a investigação de comunidades energéticas de reparação baseada num estudo de Puerto Edén, uma ilha remota na Patagônia chilena. Desde 2020, são realizadas pesquisas nessa localidade utilizando uma metodologia etnográfica e interativa, na perspectiva dos Estudos de Ciência e Tecnologia (CTS), por meio de trabalho de campo sistemático. Os resultados demonstram os desafios enfrentados por essas comunidades ao enfrentarem as deficiências de governança, fornecendo soluções que são ao mesmo tempo provisórias e definitivas. O abandono de infraestruturas renováveis poderia ser evitado se comunidades históricas de reparação energética em locais remotos fossem identificadas e envolvidas em programas de transição energética justa.

Palavras-chave: Comunidades energéticas. Estudos de manutenção e reparação. Infraestruturas remotas. Estudos de Ciência e Tecnologia. Puerto Edén.

1 INTRODUCTION

Policies on energy communities in Latin America have been driven by discussions about people in the energy transition in the Global North (Bielig *et al.*, 2022; Felice *et al.*, 2022; Lowitzsch, 2019), mainly grassroots initiatives contributing to the spread of renewables (Doci *et al.*, 2015). They have also been inspired by lessons from Latin American civil society, strengthened by development cooperation projects, and are currently focused on economic decarbonisation models under the Sustainable Development Goals (Baigorrotegui, 2018b).

Promoting such policies has favoured just energy transition policies intended to reduce energy poverty and open the energy market to self-production and distributed generation (Hoicka *et al.* 2021). However, in general, citizenship—articulated in a collective, horizontal, supportive, and self-managing manner—is marginal and often managed under centralised and privatised systems that do not take pre-existing communities (Meyerson *et al.*, 2019; Verdezoto *et al.*, 2021) or local actors and their knowledge into account (Parker, 2020). Women play an important role in maintaining renewable energy technologies (Cecelski, 2000) and the communal viability of towns. Indeed, there is no doubt about the importance of cultural, collective economies in material place and time, especially where private initiatives are less lucrative and the State is almost non-existent (Svampa; Bertinat, 2022) and sometimes counterproductive for the community. So, why is it important to pay attention to these particularities? The temporal and material dimensions of repair and maintenance practices in energy communities are currently underrepresented in the literature (Lode *et al.*, 2022).

While the study of Energy Communities has often been context-specific, generic aspects centred on techno-economic dimensions overemphasise the need to generate a typology of energy communities that encourages their promotion (Baigorrotegui; Lowitzsch, 2019; Dudka; Moratal; Bauwens, 2023) in public policy. In the same way, STS contributions concerning infrastructures (Leigh Star, 1999; Star; Griesemer, 1989) and repair-maintenance studies (Cejka; Reihs; Fina; Stefan; Hauer; Zeilinger, 2022; Jackson, 2004) highlight the challenges of conceiving them as units or products replicated all over the world. In short, it seems that other types of notions are needed to think about their singularity.

Understanding energy as something beyond electricity, which is quite evident in rural territories, opens the door to possibilities of exchange and differentiated promotion and valorisation. The state's challenges in facing these issues bring to the fore what is understood by community and collective actions in the Global South, where negotiations, contracts, and consumption are important but insufficient in recognising the localised promotion of energy communities. In this regard, Colombian

grassroots organisations seek to influence national energy plans by coining the term Community Energies, understood as:

> […] the body of knowledge, practices and processes of socio-environmental transformation in the production and consumption of energy and food, that promote [...] dignified living conditions [...], respect all forms of life on the planet and contribute to mitigating the climate crisis, in the construction of peace and rebuilding social cohesion (VVAA, 2023 [personal translation]).

This definition diverges from the concept of energy community, understood as a successful business model (Vernay *et al.*, 2023) since it is situated in a daily life where collective actions and implicated people transcend prices, tariffs, and operating standards. The risks of malfunction, breakage, and forgetfulness remain high and discouragingly predictable in Latin America (Coss-Corzo, 2020). Nevertheless, remote energy infrastructures' risks of critical breaks, improvisations, acute inefficiencies, and abandonments (Velho; Ureta, 2019) are disregarded.

Some studies of energy poverty depict energy communities within informal economies (Kumar; Aiken, 2020) and vulnerable communities (Lai, 2021), where the colonial, white, and Eurocentric prism marginalises inhabitants even more (Lohman, 2023). Much research must be done to recognise the historical and powerful communities facing weak, broken, and quasi-abandoned energy infrastructures.

In this understanding of energy communities, justice is constituted with care, which is an irreducible task (Puig de la Bellacasa, 2017). Through this lens, we can observe the diverse and complex dimensions of energy communities in Latin American societies, described as —*abigarrada*— meaning jumbled or disjointed (Baigorrotegui, 2018b). This term highlights the difficulty of standardising energy communities and the impossibility of reducing them to promotional protocols based on universal conventions and canons.

Considering their fragile circumstances, inconsistent accessibility, failure to adhere to operational standards, deficit of replacement parts, and lack of a documented history of prior operation, we ask, what circumstances may or may not enable the continuity of specific energy communities on remote islands?

2 METHODOLOGY

The methodology used to advance the understanding of this remote energy community has been primarily qualitative (Creswell; Poth, 2018; Vasilachis, 2007). Our methodology stands out for its creative, participatory, and engaged approach with ethical implications (Cerrillo, 2009), which incorporates diverse disciplinary perspectives and asks for informed individual and group consent. It is grounded in iterative processes of induction and critical theoretical reflection, combining conventional methods and techniques of qualitative research with innovative approaches to speculative design. In the context of social sciences focused on the environment and sustainability, our approach is very close to "sustainable science and co-creative research praxis" (Franklin, 2022).

We have prioritised the ethnographic and phenomenological observation of the locality to conduct a "thick description" (Geertz, 1994). Throughout this process, we have observed and interacted with residents, social groups, and their ways of life, as well as energy infrastructures and the socio-technical, socio-ecological, and geographic contexts surrounding them.

In this project, two community delegates were brought into the fold due to the enthusiastic engagement of the Mapuche-Huilliche Lafken Mawida[1] and the Artisan Fishers Union in Puerto Edén. In collaboration with these delegates, two research projects were awarded public funding for research in social sciences and engineering for local energy systems. Furthermore, since March 2020, an interdisciplinary team has communicated with key informants in the locality of Puerto Edén, including leaders, residents, and

professionals responsible for implementing public policy in the Magallanes region of western Chilean Patagonia. An active and proactive dialogue with residents has allowed us to understand their ways of existence. This approach has been applied in various field research projects as part of a dynamic methodology that involves continuous and proactive interaction with the local community.

Fieldwork planning was meticulously carried out after data and background information about the locality of Puerto Edén were systematically collected. We conducted four visits to the town of Puerto Edén over four consecutive periods between 2020 and 2023. Each visit lasted an average of 10 days or more.

During these visits, we conducted systematic ethnographic and phenomenological observations, complemented by active participation in local activities and a series of interviews with a qualitative sample that included key informants, community leaders, and ordinary residents from various subgroups of the Puerto Edén community. Among those selected were key individuals involved in the maintenance and repair of the small-scale hydroelectric turbine and the current generators.

Since March 2020, our interdisciplinary team has been in touch with key informants from Puerto Edén and the Magallanes region government employees. Monthly meetings, lasting about an hour each, were conducted with our informants and the teacher from the town's public school using remote platforms on mobile phones. This engagement with the community allowed us to understand the importance of repair and maintenance rather than implementing a completely new local energy system.

Additionally, training was provided to two local operators at the sponsoring university (the University of Santiago de Chile), and communication regarding residents' concerns about complying with their development plan continues to be facilitated.

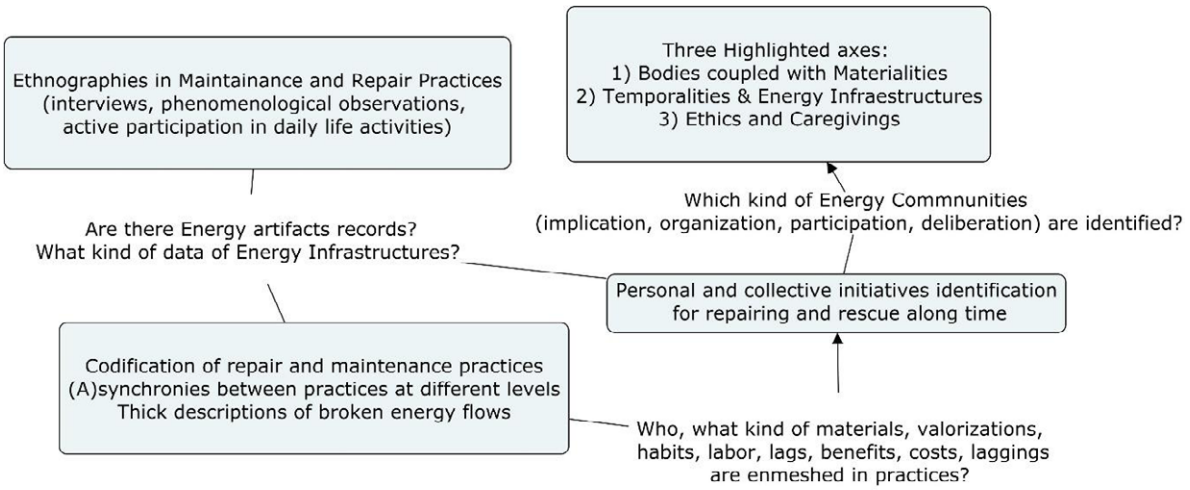

Figure 1 | Methodology of maintenance, repair practices, and energy Communities in Puerto Edén

The outcomes of this methodology (Figure 1) reveal three interpretive themes: 1) Bodies coupled with materialities, 2) temporalities and infrastructures, and 3) ethics and caregiving to overcome a common energy breakdown. Through these lenses, it is possible to recognise the abysses in these types of infrastructures and adopt certain practices where stability is established through provisional-definitive solutions.

In this way, those seeking to create more just, equitable, and energetically robust energy policies may find clues about the way of life and experiences of maintenance and repair of energy infrastructure in these remote energy communities.

3 THEORETICAL DISCUSSION

One of the premises of infrastructural studies is that when energy infrastructures work well, they are almost imperceptible. Thus, infrastructural breaks are key to studying their relational semiotic power (Leigh Star, 1999). In this way, the work of bringing infrastructures and their vitality to the forefront becomes evident when something goes wrong and even more so when the common is at stake (Star; Griesemer, 1989) and the effects of global warming become more acute.

When cracks, breaks, and crises produce long waiting times and anxiety in a town, especially where heat sources and shelter from inclement weather are all-important, people start to get restless. In these situations, the actions of communities of practice in general, and experts in particular, are not always available (Cross; Murray, 2018). When inspections of energy infrastructures are weak and are carried out remotely, compliance with contracts is at risk, price and interest changes and inspections of contractual agreements are not effectuated. Dropouts, as a prelude to dismissed, postponed, or forgotten negotiations, show that what is at stake is of little or almost no value to those responsible for making decisions concerning remote locations with few voters.

On the other hand, those who live near these infrastructures are affected in many ways since their proximity demands the involvement of their bodies, time, and creativity to find a way out of the emergency. This coexistence includes using and misusing things, parts, systems, bodies, limbs, and species (Ahmed, 2020).

3.1 PRACTICES OF REPAIR IN REMOTE LOCATIONS

The emergencies presented by climate change are inevitably intertwined with the energy that flows and crisscrosses specific territories and maritories. Clearly, the challenge of providing uncommodified energy sources closer to home, in accordance with socio-ecologies, is crucial. Remote locations depend on foreign science and technology, particularly in the Global South's economies. The corporal and rhythmic practices of repair and maintenance of artefacts and equipment (Danis; Pontille, 2015) designed in other places are demanding and exceed the canons, standards, and conventions expected as normal operating ranges (Zunino; Gruschetsky; Piglia, 2021).

Establishing energy infrastructures conceived from afar implies repairs rather than maintenance. For example, in the case of sanitary infrastructure in Mexico City, Coss-Corzo (2020) argues that patches make it possible to drastically differentiate repair practices embedded in decaying infrastructures, where austerity is common and pollution caused by infrastructural breaks is evident. Given the recurring presence of patches, maintenance is not carried out frequently and is often postponed until the possibility of repair becomes impossible, leading to abandonment. Thus, for those who directly benefit from such infrastructure, the possibility of salvaging the here and now, using anything at hand, is the rule and not the exception.

We propose that in a remote territory like Puerto Edén, any energy repair proposal that may or may not consider electricity and heat to some degree would imply the need for 1) Bodies coupled with materialities, 2) Times and synchronised infrastructures, and 3) Ethics and caregiving to overcome a common energy break.

- Bodies coupled with materialities.

If a break or failure occurs, channels must diverge to access the iron, steel, and gear structure, which requires people or groups to coordinate actions and identify anomalies. For example, they may be sensitive to auditory strangeness coming from engines and turbines.

The paralysis of flow and the type of noise signal the degree of severity and what actions and materials are needed. Appropriate tools and implements are used to determine whether the repair may be carried out locally. Depending on the failure, it may be necessary to contact other insiders who can identify and address specific equipment issues or reach out to the community so they can begin plans to prevent potential failures right away to avoid the worst.

- Time management and scheduling repairs

Records of objects' operation are part of their memory. They can help users make the most of failures by teaching them how things and objects may be designed or adapted in place of others. This is extremely important for a timely response. Identifying the possible causes of a malfunction requires experience and intuition. Those who remember and record how something previously worked correctly can provide valuable information for diagnosing and fixing current problems (Denis; Pontille, 2015). The most critical repairs require planning what is necessary to accomplish them, especially for complex machines. This implies scheduling repair stages, timelines, and wait times, identifying ways of implementing repairs, identifying stages of the repair process, and managing demands and consumption that inhabitants cannot exceed. Communicating these timelines to users is crucial. However, in places where nomadic life forms persist, plans constantly need to be updated due to contingent changes in weather conditions and wind patterns.

- Local community training

Users connected to an energy system need to be aware of different situations and the complexity of repairs to recognise how and when the failures of these infrastructures are linked to their daily lives. Those implementing energy systems must initiate dialogue with inhabitants and conduct training regarding the relevance of these tasks. Indeed, the rhythms and intensities in which daily activities are carried out, especially in winter in cold places, influence the demand for the equipment in use.

Malfunctioning of remote devices and systems may last longer than expected. Operating conditions can worsen if this occurs, causing the machines and objects to work in critical conditions. In these events, repairs in remote places require collective efforts to repair the system before it collapses. This generally implies the call for people willing to collaborate to promote open discussions concerning the most plausible solutions and available materials. For example, people chose to collaborate off the grid to give PV panels a second life and reduce the effects of contamination (Cross; Murray, 2018).

The maintenance plans and manuals for the design and operating conditions of machines and systems are references for consultation and recording that experience imbalances and changed conditions when normal usage is neglected. In these situations, other means are adopted to maintain the supply until another solution is found. This is why machines and equipment in remote ecosystems have more unexpected behaviours, and their solutions are very specific.

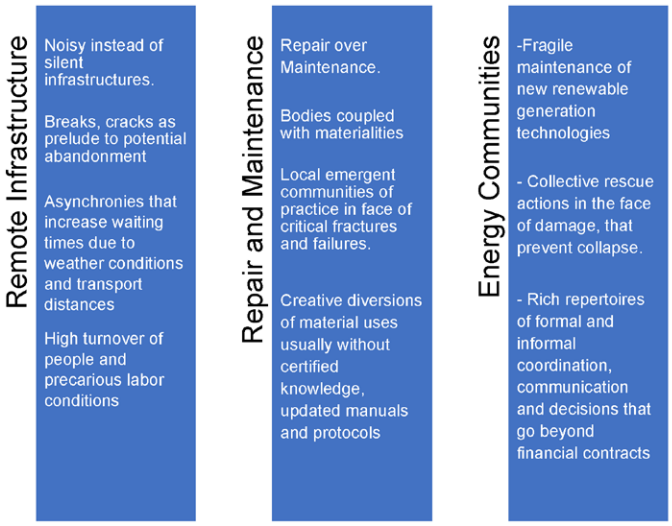

Figure 2 | Intertwining of energy communities with infrastructure and repairs conceived from remote locations

4 RESULTS

Puerto Edén is in one of the remote populated areas amidst the channels of the Magallanes Region and the Chilean Antarctic (49°07'34"S 74°24'48"O/-49.126196, -74.41326). From the perspective of Chilean public policy of regional integration, it is highly isolated due to its location within the Patagonian Archipelago on the eastern coast of Wellington Island, in the province of Last Hope.

Puerto Eden's location on the eastern coast of Wellington Island has the particularity of being located inside the Patagonian archipelago of Magallanes, with a geographical condition described as "territorial vulnerability" (Ferrada, 2013). This is due to the climatic characteristics of the archipelago and its distance from its administrative centre, the city of Puerto Natales—the largest commune in Chile—which is located about 27 hours away via barge (approximately 500 kilometres to the southeast). The usual modes of transport to the communal urban area are ferries and barges that arrive twice a week or helicopters in cases of emergency. This impacts residents' access to products and services; establishing a dwelling is considered "extreme" under such circumstances (Matus, 2008).

Figure 3 | Location of Puerto Edén in southern Chilean Patagonia

Source: Fondecyt Project. Prepared by the authors.

Puerto Edén is geostrategically relevant for the Chilean State, which colonised the area after the installation of an Air Force base in 1936 for the supply of fuel for hydroplanes. In 1969, it was refounded and annexed to the national population system after the navy established the settlement of the Kawèsqar indigenous population and after the arrival of Mapuche-Huilliche fishing families and other artisanal fishermen (Martinic, 2004).

In 2020, Puerto Edén was declared a lagging area according to the Provincial Development Plan of Última Esperanza (Subdere, 2021). Technological gaps, fragility in energy infrastructures, and high mobility costs persist due to Puerto Edén's remote condition. Electricity is essential for communication with the municipal administration in Puerto Natales.

Likewise, since there is no sustained electric power distribution, the most relevant common-use infrastructures, such as a wooden walkway, houses, and the local school, have prompted the involvement of inhabitants—mainly due to the extension and geographical characteristics of the area—in care and repair work when this infrastructure fails. As a result, energy-community management is visible in real instances of breakage and breakage prevention (Baigorrotegui, 2018). However, these efforts are not maintained over time, nor do they aspire to a decentralised territorial administration in energy matters (Baigorrotegui; Valenzuela; González, 2023).

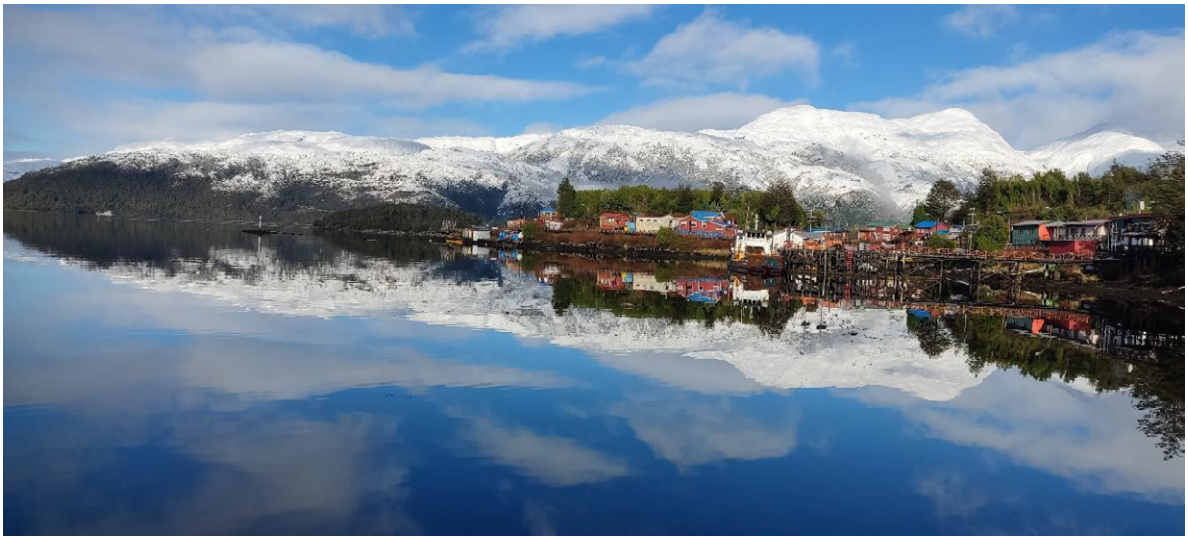

Figure 4 | Landscape of Puerto Edén. Fondecyt MaReCe, august 2022.

The state of Minas Gerais also has a strong silviculture sector. Having its origins in the steel and iron industries' stimulation in the 1970s by the military dictatorship (1964-1985), the lack of coal to fire the sector was presented as an impediment. An incentive project was created, giving a 50% tax reduction to private owners and companies willing to invest in silviculture (CALIXTO *et al.*, 2009). This marked the beginning of the development of the eucalyptus sector in the country. By 2016, more than 2 million tonnes of wood were produced yearly in Minas Gerais (SIDRA; IBGE, 2015b). In the more productive areas, the estimation of the potential energy production from silviculture residues (Figure 5) could reach up to 8 MW with the annual yearly harvest per municipality.

Puerto Edén is considered to have a high degree of territorial isolation, with its population (mainly artisan fishermen) fluctuating seasonally between 155 and 70 people over the last 2 years (Estroz, 2022).

The electrical supply of Puerto Edén is discontinuous, powered by a diesel combustion electro-generator 14 hours a day in two separate time slots. Monthly electricity demand is around 40.300kWh, considering a 100 kWh household consumption average (Estroz, 2022).

In the past, the town of Edén had a micro-hydroelectric plant, which shut down in 2008. Inhabitants remember this plant as an energy solution that granted 24-hour access to the town. The abandonment of the micro-hydro plant is still a controversial story. Lack of information, follow-up, and monitoring of its operations place its failures, maintenance, and repairs in a discursive ambiguity amidst decision-makers, technical reports, and user experiences. Today, the MHP is still awaiting its restoration or replacement.

In 2022, the Regional Government released the Development Plan of Lagging Zones concerning social issues in Puerto Edén, which includes the "Replacement of Micro Hydro Electric Plant" planned for 2024, among 36 other projects.

As of August 2022, Puerto Edén depends on a Cummins Diesel generator (61.149 kWh/august) (Estroz, 2022). Due to the state's interest in maintaining sovereignty in remote places, water and electricity services are made available free of charge to users, as in the case of Puerto Edén. We have evidence of a reverse energy transition that returns Puerto Eden's energy source to fossil fuels with diesel oil tanks regularly delivered to the island.

To reach the engine room of the abandoned MHP, one must take a twenty-minute boat trip from Puerto Edén and trek through the peat for about two hours. Additionally, to maintain the machine's intake, one must hike another four more hours on a trail with steeper slopes. While the construction of this entire generation system was a monumental enterprise, its daily maintenance without supervision threatened its proper functioning. Furthermore, according to some interviewees, some residents boycotted the MHP to establish an oil-dependent supply, which was beneficial for some and easier to operate but more expensive for the municipal budget. Thus, replacing this MHP project is an important part of the lagging area plan and would signify a historic repair of energy paralysis to move towards sustainability.

Although the carelessness of authorities becomes evident in daily experiences in relation to local energy projects, repair also emerges as a local emergency practice that is neither continuous nor seeks to be understood in relation to ready-to-use technological innovations available on the market. Rather, repair practices intersect with temporalities loaded with pauses, interruptions, and waiting periods that adopt the ecological rhythm of specific places.

Puerto Eden and its Repair Communities

Times and Synchronised Infrastructures: Understanding breakage from a historical and temporal perspective allows us to identify Puerto Edén as a territory that is waiting. This pause within which a breakdown or failure occurs leads users to experience the inconsistency between the service expected from the infrastructure and its perceived behaviour. Users' dependence on regional authorities to achieve modern living standards dates back to the first years of the settlement of Edén (Martinic, 2004). For many years, different governments have implemented specific development plans in which the infrastructural pillar was understood as a technopolitical challenge.

As stated by Baigorrotegui, Valenzuela and González (2023, p. 31),

> It is in the waiting times, those moments in which collective actions begin to be energised, which carry reminiscences of abandonment for several years, triggers that braid anger and action in the search for transformation through alternative paths (Ahmed, 2022). These actions constitute the repertoire of energy communities entwined in repairing and knowing how to deal with breakages. However, the practices of repair and maintenance of the infrastructures installed in each technopolitical regime fall into municipal management of backwardness, in which some of its inhabitants, positions as official managers of the services, seek to solve with what is at hand, including a public complaint in the regional media. Therefore, there is a correlation between lag, wait, complaint and reparation.

Thus, Puerto Edén is forming a tangled network of negotiations that become entangled and unravelled through links that require cooperation and collaboration. This leads to conflicts, frictions and associations that reduce the interest in calculated exchanges, provoking an observation regarding who/what is affected by what is intended to be repaired in specific moments and contexts.

Figure 5 | Abandoned mini-hydro power plant in Puerto Edén. Fondecyt MaReCe archives, November 2021.

Localities supplied with energy by the state, where users do not pay for the electric bill, are plagued by formal and informal actions, both their own and those of others. These actions reflect users' habits; they are unpredictable, leading to power imbalances that users subvert every time the inadequately maintained infrastructure batters their daily lives with its adversities.

Bodies coupled with Materialities: In Puerto Edén, the turnover of qualified technical personnel that maintain energy infrastructure is very high. Low salaries and adverse conditions due to isolation, especially in the winter season, have meant that technicians only remain in this job position for one or two years in exceptional cases. Although critical failures pressure companies and contractors to travel to the island to deal with crises—often hiring some inhabitants to do maintenance work due to their technical knowledge, despite not being specialists—a present solution is for inhabitants to carry out maintenance on equipment and resolve failures in the face of inaction on the part of public officials.

The training of maintenance specialists, based on the skills of navigation, has facilitated the knowledge of local technical support and mobilised the bodies of inhabitants, organised in lobbying groups or groups of cooperation to restore electricity, heating, etc. Certainly, the lack of timely provision of spare parts causes those concerned and involved in the operation of the energy infrastructure to arrange for provisionary repairs, which, due to the delay of the authorities, become definitive.

Figure 6 | Provisional patch that has become definitive for the wood-burning heater at the school. Fondecyt MaReCe, November 2021.

In this way, those in charge of repairs experience the slowness, routine, and rigour that a remedial action demands in these conditions. At the same time, this makes visible the ethical commitment that maintenance specialists take on, which, for the most part, coincides with the literature concerning their technical creativity in using available materials (Denis; Pontille, 2015) to meet local demands when subject to state abandonment. The community of repairmen from the Eighties evokes those times when Puerto Eden was not as depopulated as it is today. The importance of this collective ethic is still present in the memory of Eden's oldest inhabitants. By taking the initiative on behalf of the people, maintenance specialists seek to revert to repairing methods based on waiting and submitting complaints, understanding that geographical distance and the slowness of government project plans affect forms of resistance to crises. However, users are not alien to contemporary individualism and are thus subject to negotiations in the face of the need for certified expertise in technical repair support.

Ethics and Caregiving to overcome a common energy breakdown: The community rescues the Mini-Hydro Power (MHP) plant.

In 2010, the organised residents of Puerto Edén exposed the management problems of the Municipality of Puerto Natales, as well as the local authorities' lack of technical information regarding the failure of the Mini-Hydro Power (MHP) plant in the local media:

> They have not told us what really failed; there is no control, there is no monitoring, there is no follow-up, there is nothing, there are opinions, but there is no real information about what went wrong. (Interview RPA, 05 of August 2019 [personal translation]).

We estimate that the 90-kW capacity MHP was completely inactive in 2008 due to a lack of adequate maintenance, inappropriate material for its operational conditions, abandonment by the external-municipal custodian, and systematic postponement of part replacements (Coyuntura Política, 2010). Five years later, the Municipality proposed to build a new MCH, given the obsolescence of the previous one and due to various failures and damaged, broken, and collapsed facilities. The need for intervention was announced in the local press since the disruption of this infrastructure left the population dependent on the supply of Diesel, with electric supply available between 8:00hrs-15:00hrs and 17:00hrs-00:00hrs.

This news contrasts with the cost that the construction of the MCH in that place signified at the time. Due to the site's inaccessibility, a helicopter was required to transport the turbines and the main facilities. The Center for the Study of Energy Resources at the University of Magallanes noted that the Puerto Edén MHP was the most important in terms of off-grid energy supply in the region. Unfortunately, the replacement of the MCH did not materialise, affecting the energy vulnerability of the area.

Ten years later, the local neighbourhood organisation claims that the infrastructural problem of Puerto Edén is historical and is related to a crisis of the Chilean Subsidiary State, whose actions lag in the territory. However, in our conversations with some of its maintainers, we learned that the challenges and ignorance about the many failures leave no clear diagnosis concerning the most critical role in paralysing the MCH forever. Of course, a community rescue event that occurred when the decline of the river flow endangered the MCH's operation stands out in the memory of one repairman:

> I don't know how I convinced people there. I told them look, the same problem happens here because we don't all go (laughs) and a large part of the people there is *chilota* [2], and they assume it as a minga [...] Everything had to be done on foot and on the shoulder, and they had to carry a lot of wood and zinc sheets and build a small dam (Maintainer MCH_a, personal interview 01/28/19).

Figure 7 | Mini-hydro intake in Puerto Edén. Fondecyt MaReCe, November 2021.

After walking for more than three hours over difficult terrain, where gusts of wind can be surprisingly strong and walking itself very difficult. There were parts where the only possible way to continue was to climb over the pipe, which can be seen on the right side of Figure 7. Without a doubt, as a research team, we were surprised to see the remains of this collective work carried out by Puerto Edén's inhabitants.

Figure 8 | Mini-hydro intake in Puerto Edén. Fondecyt MaReCe, November 2021.

As can be seen in Figure 8, pieces of corrugated tin, tree trunks arranged as pillars, and rocks as foundations are visible. This dam of simple and intuitive construction is surprisingly perceived amid an immense uninhabited southern landscape. While walking, abysses emerge, since in any moment of carelessness, it is possible to miss one's step and fall into endless muddy, rocky areas.

Figure 9 | Broken MCH pipe. Photographed by Gloria Baigorrotegui, February 2019.

When we retrace our steps through that marvellous and hidden place, we notice the different types of patching on the entire section of the pipe that now, after rupturing, appears before our eyes as residual pale pieces laying on the peat, threatening to disappear.

This collective work characterises the oldest inhabitants of Puerto Edén. In general, examples of these rescues continue to demonstrate people's strength and ability to accomplish what they consider important. Although outsiders associate the people of Puerto Edén with their constant complaints and public grievances, the truth is that the waiting and complaints are active parts of their stories, interspersed with concerted efforts and determined collective work.

ANALYSIS OF RESULTS

Usually, those who live in remote areas live closely and sensitively with and through their energy infrastructures. In places where systems operate under normal ranges, the operation of motors, generators, and boilers may be imperceptible, but this is not the case in other geographic locations. For an outsider, the experience of living in (with) remote infrastructures usually draws attention since waiting, sporadic access to an internet connection, and unstable electricity are common. *Bodies are coupled with breakdowns*: All of these breaks and failures combined can give rise to communities that are affected in different ways when involved in one or more series of breaks.

Remote infrastructures are covered in patches, rust, and wear. They are noisy. Overlooked parts are mended to avoid collapse. Breaks warp *the notion of time* since a break can be linked to isolation, rendering equipment outdated and wearing out both materials and the bodies of those in charge. Undoubtedly, people and families who live in remote places mobilise their creativity in the face of a lack of conventions and standards. With this understanding, new conceptions of innovative, reparative action and reparation arise from such crises and wear and tear, demonstrating the abysmal relationship of these remote infrastructures with urban areas.

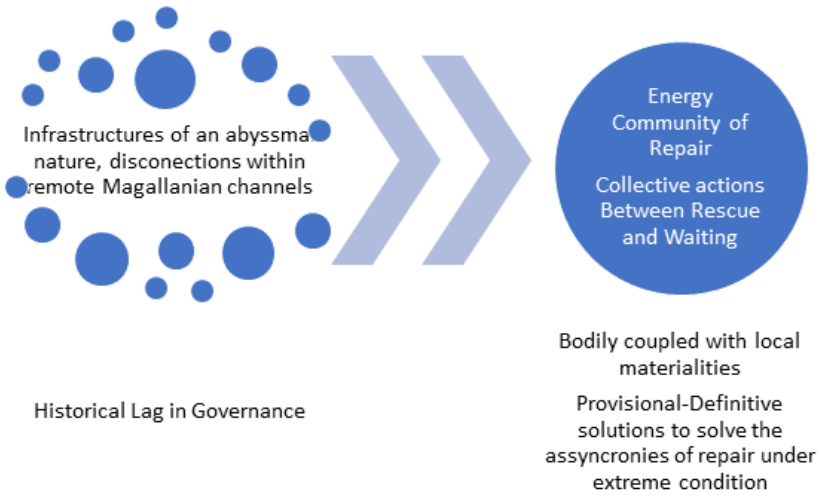

Figure 10 | Energy Community of Repair as conceived by the remote Edenino.

Figure 10 shows the intertwining of energy repair communities where maintenance is improper.

The materials are there to be arranged and to create other creative patches because the existing ones are inadequate. Informal methods widen the scope of possible manipulation in emergencies since memories and records are difficult to compare due to contradictory or non-existent accounts.

Situating ourselves from the remote implies an act of constant repair of records, data, and narratives, as well as once provisional repairs, but through abandonment, have become definitive.

5 CONCLUSIONS

This paper posits that energy communities are not solely associated with renewable electricity generation but also with the long-term maintenance of energy systems in general, particularly in remote locations. To address this, we propose to track situated repair and maintenance practices to investigate particular breakages and the emergence of energy communities of some kind. Thanks to this approach, we expand the concept of energy communities by introducing interpretive axes for energy repair communities, which can partially address the unique challenges of remote island environments. Confronted with various forms of energy vulnerability and the uncertainty of impending collapse, energy repair communities step in to provide support, even when temporary solutions become permanent due to delays in public policy.

This is where the significance of documenting the diverse manifestations of energy repair communities in remote areas becomes part of the process of resisting the oblivion of their existence. These communities distinguish themselves by caring for their physical resources, adapting to challenging circumstances, maintaining essential infrastructures, and adhering to a pragmatic ethical approach to safeguard what is essential for their survival and the common good.

Remote energy repair communities offer valuable insights into learning and adaptation processes and the trials and errors inherent in their continuous efforts to secure energy resources. Their actions require spontaneous and physically demanding responses, often transcending formal memberships or contractual relationships, setting them apart from well-established, lucrative, and systematically maintained energy communities.

Finally, assuming that the principles of justice are entangled in the memories of repair practices, we may conclude that energy communities of repair are a constitutive part of any just energy transition,

especially in remote places. This assumption enriches energy communities' contributions in general and promotes justice for such communities in particular.

NOTES

1| Puerto Eden is a small coastal town with fewer than 80 inhabitants. This town has Chilean residents of both indigenous and non-indigenous origins. Among the latter, there are two indigenous groups: the Kawèsqar, the ancestral and original inhabitants of southwestern Patagonia, and the Mapuche-Huilliche indigenous people, migrants native to Chiloé Island, approximately 725 kilometres to the north of Puerto Eden. The Mapuche-Huilliche Lafken Mawida is the formal organisation representing this last ethnic group.

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REFERENCES

AHMED, S. **¿Para qué sirve? Sobre los usos del uso**. Barcelona: Edicions Bellaterra, 2020.

AHMED, S. **¡Denuncia! El activismo de la queja frente a la violencia institucional.** Argentina: Editora Caja Negra, 2022.

BAIGORROTEGUI, G.; VALENZUELA, C.; GONZÁLEZ, D. Comunidades energéticas a partir de la reparación en infraestructuras remotas. Algunas enseñanzas desde la localidad chilena de Puerto Edén. **Revista Energía y Equidad**, n. 6, June 2023, ISSN 1853-5089, p. 26-36. Available from: https://co.boell.org/sites/default/files/2023-08/e_y_e_2023-n6_comunidades_energeticas_energias_comunitarias.pdf Accessed on: 30 aug. 2023.

BAIGORROTEGUI, G.; LOWITZSCH, J. Institutional aspects of consumer (co-) ownership in RE energy communities. In: LOWITZSCH, J. (ed.) **Energy Transition**: financing consumer ownership in renewables. ISBN: 9783319935171, Cham, Suiza, Palgrave. McMillan, 2019, p. 663-702.

BAIGORROTEGUI, G. Comunidades energéticas en la Patagonia: tan lejos y tan cerca del extractivismo. **Revista Estudios Avanzados**, n. 29, julio 2018a, p. 56-74. ISSN 0718-5014.

BAIGORROTEGUI, G. Comunidades Energéticas en Latinoamérica. Notas para situar lo abigarrado de prácticas energocomunitarias. In: BAIGORROTEGUI, G.; PARKER, C. (Coord.) **¿Conectar o Desconectar? Comunidades Energéticas y transiciones hacia la sustentabilidad**. ISBN: 9789563033588, Colección IDEA: Santiago of Chile, 2018b, p. 197-222.

, M. *et al.* Evidence behind the narrative: critically reviewing the social impact of energy communities in Europe. **Energy Research & Social Science**, v. 94, 2022. 102859. DOI: 10.1016/j.erss.2022.102859.

CECELSKI, E. **The Role of Women in Sustainable Energy.** Energy, Environment & Development Germany. NREL/SR-550-26889. June 2000. Available from: https://www.nrel.gov/docs/fy00osti/26889.pdf Accessed on: 18 October 2023.

CEJKA, S. *et al.* **Typical future energy communities - an analysis on operational areas, member structure and used infrastructure**. CIRED Porto Workshop 2022: E-mobility and power distribution systems, Hybrid Conference, Porto, Portugal, 2022, p. 498-502. DOI: 10.1049/icp.2022.0757.

CERRILLO VIDAL, J. A. El intermediario imposible. Algunas reflexiones en torno a epistemología y ética en la investigación cualitativa. **Nómadas. Critical Journal of Social and Juridical Sciences**, n. 24, v. 4, 2009.

COSS-CORZO, A. Patchwork: repair labor and the logic of infrastructure adaptation in México City. **Society and Space D**, 2020, p. 1-17.

COYUNTURA POLÍTICA. **¿Por qué Puerto Edén no tiene Energía Eléctrica?** (5/05/2010) Available from: https://coyunturapolitica.wordpress.com/2010/05/05/%C2%BFporque-puerto-eden-no-tiene-energia-electrica. Accessed on: 30 aug. 2023.

CRESWELL, J. W.; POTH, C. N. **Qualitative Inquiry and Research Design**: choosing among five approaches. Los Angeles: Sage. 2018.

CROSS, J.; MURRAY, D. The afterlives of solar power: waste and repair off the grid in Kenya. **Energy Research & Social Science**, v. 44, p. 100-109, 2018.

DENIS, J.; PONTILLE, D. Material Ordering and the Care of Things. **Science, Technology, & Human Values**, v. 40, n. 3, 2015, p. 338–367. DOI: 10.1177/0162243914553129

DOCI, G.; VASILEIADOU, E.; PETERSEN, A. Exploring the transition potential of renewable energy communities. **Futures**, n. 66, p. 85–95, 2015.

DUDKA, A.; MORATAL, N.; BAUWENS, T. A typology of community-based energy citizenship: an analysis of the ownership structure and institutional logics of energy communities in France. **Energy Policy**, v. 178, July 2023, 113588. DOI: 10.1016/j.enpol.2023.11358.

ESTROZ, M. **Diseño de ingeniería básica para la microcentral hidroeléctrica de pasada en Puerto Edén**. Tesis de Pregrado para optar al título de Ingeniero Civil Eléctrico. Departamento de Ingeniería Eléctrica. Universidad de Santiago de Chile. 2022.

FELICE, A. *et al.* Renewable energy communities: Do they have a business case in Flanders? **Applied Energy**, n. 322, 119419. 2022. DOI: https://doi.org/10.1016/j.apenergy.2022.119419

FERRADA, C. **Puerto Edén**: paso obligado de un territorio incierto. Estudios de caso sobre la vulnerabilidad territorial. 136 p. Dissertation (Masters in Geographical Sciences). Pontificia Universidad Católica de Valparaíso, Valparaíso, 2013. Available from: https://www.camposdehielo.cl/wp-content/uploads/2015/09/TESIS-FERRADA-SILVA-CAMILA_PUERTO-EDEN-ESTUDIO-DE-CASO-DE-LA-VULNERABILIDAD-TERRITORIAL.pdf. Accessed on: 30 aug. 2023.

FOSTER, J. B. Marx's theory of metabolic rift: classical foundations for environmental sociology. **American Journal of Sociology**, n. 105, 1999, p. 366-405. DOI: 10.1086/210315

FRANKLIN, A. Introduction: sustainability science as co-creative research praxis. In: FRANKLIN, A. (Ed). **Co-Creativity and Engaged Scholarship**. Transformative Methods in Social Sustainability Research, Cham: Palgrave. p. 1-42. 2022.

GEERTZ, C. **Ensayos sobre la interpretación de las culturas**. Barcelona: Piados Básica. 1994.

GONZÁLEZ, D. **Prácticas de cuidado y reparación en las infraestructuras escolares de Coyhaique y Puerto Edén, contribuciones hacia el surgimiento de comunidades energéticas en Chile**. 146 p. Dissertation (Masters in Social Science). Universidad de Santiago de Chile, Santiago of Chile, 2022.

HOICKA, C. *et al.* Implementing a Just Renewable Energy Transition: policy advice for transposing the new European rules for renewable energy communities. **Energy Policy**, n. 156. 112435. 2021. DOI: http://dx.doi.org/10.2139/ssrn.3729512

JACKSON, S. "Rethinking Repair". In: GILLESPIE, T.; BOCZKOWSKI, P. J.; FOOT, K. A. (eds). **Media Technologies**: essays on communication, materiality, and society (Cambridge, MA, 2014; online edn, MIT Press Scholarship Online, 18 Sept. 2014). DOI: https://doi.org/10.7551/mitpress/9780262525374.003.0011. Accessed on: 18 oct. 2023.

KUMAR, A.; TAYLOR AIKEN, G. A Postcolonial Critique of Community Energy: searching for community as solidarity in India and Scotland. **Antipode**, v. 53, n. 1, p. 200-221, 2021. DOI: 10.1111/anti.12683

LAI, H.-L. Foregrounding the community: geo-historical entanglements of community energy, environmental justice, and place in Taihsi Village, Taiwan. **Environment and Planning E: Nature and Space**, v. 5, n. 2, p. 666–693, 2022. DOI: 10.1177/25148486211000745

LODE, M. L. *et al.* A transition perspective on Energy Communities: a systematic literature review and research agenda. **Renewable and Sustainable Energy Reviews**, n. 163, 112479. 2022. DOI: 10.1016/j.rser.2022.112479

LOHMAN, L. **The Colonialism inside Energy (and Energy Transitions)**. Available from: Insurrection in Energy Research: Pluriversal Encounters with Energy Transition & Renewability - YouTube Exhalt Helsinki, 2023. Accessed on: 30 aug. 2023.

LOWITZSCH, J. (ed.) **Energy Transition**: financing consumer ownership in renewables. ISBN: 9783319935171, Cham, Suiza. Palgrave. McMillan, 2019.

MARTINIC, M. **Archipiélago Patagónico. La última frontera**. Punta Arenas: Ediciones de la Universidad de Magallanes, 2004.

MATUS, M. **Puerto Edén. El desaliento inesperado del desarrollo:** los impactos del Programa Gubernamental de Superación de la Pobreza 1994-2004, evaluado por sus propios habitantes. 261 p. Dissertation (Grade of Anthropology). Facultad de Ciencias Sociales. Departamento de Antropología. Universidad de Chile, Santiago of Chile, 2008.

MEYERSON, J. *et al.* Maintenance Community Framework (MCF). 2019. Paper of The Maintainers.org. Available from: MCF_Complete_Oct4-2.pdf (wpengine.com). Accessed on: 22 oct. 2023.

PARKER, C. Local Energy Transition and Technical Knowledge in the Southern Cone: a sociological approach. **Revista de Estudios Sociales**, n. 2, p. 2-17. 2020. DOI: https://doi.org/10.7440/res72.2020.01

PUIG DE LA BELLACASA, M. **Matters of Care Speculative Ethics in More than Human Worlds**. Minnesota: University of Minnessota Press, 2017.

STAR, S. L. The Ethnography of Infrastructure. **American Behavioral Scientist**, v. 43, n. 3, 1999, p. 377–391. DOI: 10.1177/00027649921955326

STAR, S. L.; GRIESEMER, J. R. Institutional Ecology, 'Translations,' and Boundary Objects: amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907 – 1939. **Social Studies of Science**, n. 19, 1989, p. 387-420.

SUBDERE Subsecretaría de Desarrollo Regional y Administrativo, Región de Magallanes y de la Antártica Chilena. **Plan de Trabajo Política de Zonas Rezagadas – Puerto Edén**. Ministerio del Interior, Gobierno de Chile. Abril, 2021.

SVAMPA, M.; BERTINAT, P. **La Transición Energética Justa**. Una ruta para entender los proyectos en pugna y las falsas soluciones. Buenos Aires: Siglo XXI, 2022.

VASILACHIS DE GIALDINO, I. (coord.). **Estrategias de investigación cualitativa**, Barcelona: Editorial GEDISA. 2007.

VELHO, R.; URETA, S. Frail Modernities: Latin American infrastructures between repair and ruination. **Tapuya: Latin American Science, Technology and Society**, n. 2, v. 1, p. 428-441, 2019. DOI: 10.1080/25729861.2019.1678920

VERDEZOTO, N. *et al.* **The Invisible Work of Maintenance in Community Health:** challenges and opportunities for digital health to support frontline health workers in Karnataka, South India. Association for Computing Machinery, n. 5, CSCW1, 2021. DOI: 10.1145/3449165.

VERNAY, A-L.; CARINE SEBI, C.; ARROYO, F. Energy community business models and their impact on the energy transition: lessons learnt from France. **Energy Policy**, v. 175, 113473. 2023. DOI: 10.1016/j.enpol.2023.113473.

VVAA. Promoción y fortalecimiento de las Energías Comunitarias en Colombia. Propuesta para el Plan Nacional de Desarrollo 2023-2026, 2023. **Ruta de la Transición Energética Justa, Planes Departamentales y Municipales de Desarrollo**. Available from: https://censat.org/energiascomunitarias-pnd/. Accessed on: 10 apr. 2023.

ZUNINO, D.; GRUSCHETSKY, V.; PIGLIA, M. (coord.). **Pensar las infraestructuras en Latinoamérica**. Ciudad Autónoma de Buenos Aires: Dhan Sebastián Zunino Singh, 2021. ISBN 978-987-88-0392-0

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Predictive model of the outage of transmission lines exposed to wildfires

Modelo previsor de desligamentos de linhas de transmissão expostas a incêndios florestais

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ABSTRACT

Transmission lines are essential for access to clean and affordable energy sources, Sustainable Development Goal 7. Wildfires are an important factor in the degradation of the quality of public transmission service provision. This work sought to build a model to predict the outage of a transmission line when exposed to a wildfire. The characteristics analysed of the spans exposed to fires of twelve transmission lines at a voltage level of 500 kV in Brazil totalled 3,998 km. The logistic regression technique was used for the study. It was possible to reach a model with a hit rate higher than 73% for the occurrence of transmission line outages. The quantity of fire outbreaks, the climatic variables, and the type of biome of the spans were observed to be the best predictive variables available. The temperature rise can potentially increase the number of outages caused by wildfires.

Keywords: Fires. Interruption. Electric power.

RESUMO

As linhas de transmissão são essenciais para o acesso a fontes de energias limpas e acessíveis, Objetivo de Desenvolvimento Sustentável 7. Os incêndios florestais são um fator importante de degradação da qualidade da prestação do serviço público de transmissão. Este trabalho buscou construir um modelo para previsão de desligamento de uma linha de transmissão quando exposta a um incêndio florestal. Foram analisadas as características dos vãos expostos ao fogo de 12 linhas de transmissão em nível de tensão de 500 kV no Brasil, totalizando 3.998 km. Utilizou-se a técnica de regressão logística para o estudo. Foi possível chegar a um modelo com índice de acerto superior a 73% para a ocorrência de desligamentos de linhas de transmissão. Observou-se que o quantitativo de focos de incêndios, as variáveis climáticas e o tipo de bioma dos vãos são as melhores variáveis previsoras disponíveis. O aumento da temperatura tem potencial para elevar o número de desligamentos por incêndios florestais.

Palavras-chave: Queimadas. Interrupção. Energia elétrica.

1 INTRODUCTION

The consequences of wildfires on the electrical grid are quite significant (Operador Nacional do Sistema Elétrico, 2016b), highlighting the reduction of renewable energy generation. However, not every wildfire causes a transmission line outage. The study of this phenomenon involves different factors: climatic variables, land use, operating conditions and technical building characteristics.

The adequate performance of transmission lines greatly influences achieving the Sustainable Development Goal 7. Transmission lines are essential for transporting renewable energy production to large load centres, minimising the effect of intermittency of renewable sources and, thus, lowering energy costs for the consumer.

Transmission line outage can occur due to a short circuit in the presence of fire due to the reduction of the dielectric strength of the air between the phase conductors and between the phase conductors and the ground. Smoke and fly ash from a wildfire can also alter the insulating characteristics of air spaces, as conductive particles drastically lower the dielectric strength of the air (Khan; Ghassemi, 2022). Another factor is the high temperature of a flame, which can decrease the tensile strength of transmission line conductors and accelerate their ageing (Guo *et al.*, 2018).

The operating state of a transmission line subjected to a wildfire varies between on and off. Thus, the operating state of the installation is understood to be a dichotomous variable. Logistic regression is a potential mathematical model for this type of output, corresponding to one variable and with multiple continuous predictive variables (Field, 2017).

Logistic regression is a type of multiple regression with a dichotomous categorical output variable and continuous or categorical predictive variables (Field, 2017). Based on certain information, we can predict which of the two categories a variable belongs to.

In a linear regression, the observed data must have a linear relationship. However, this hypothesis is violated if the output variable is dichotomous (Berry, 1993). One way around this problem is to change the data through a logarithmic transformation (Packard, 2013; Zhang; Wang; Luo, 2015). The logistic regression equation expresses a multiple linear regression equation in logarithmic terms and solves the linearity hypothesis violation problem this way.

In a logistic regression, therefore, we predict the probability of Y occurring when the values of X or Xs are known according to Equation (1).

$$P(Y) = \frac{1}{1 + e^{-(b_0 + b_1 X_1 + b_2 X_2 + \cdots + b_n X_n + \varepsilon)}} \quad (1)$$

The probabilistic equation *P(Y)* of the logistic regression has several similarities with the linear regression equation. In reality, the exponent of the natural number *e* contains an expression identical to that of the multiple regression, where b_o is the Intercept, b_n corresponds to the coefficient of the predictive variable, x_n and ε is the residual term.

The resulting value of the equation is a probability and always varies between 0 and 1 (Heumann; Schomaker; Shalabh, 2016). A value close to 0 means that the occurrence of Y is very unlikely, and a value close to 1 that it is very likely.

Each predictive variable has its own coefficient in the logistic equation. These parameters are estimated by adjusting models based on the observed data. The model chosen will be the one where the values of the predictive variables result in the value of Y closest to the observed value. Specifically, the parameter values are calculated using maximum likelihood estimation (Brandt, 2014). One of the main advantages of this method is that its estimators are consistent, asymptotically normal and efficient (Guera *et al.*, 2018)Pinar del Río, Cuba. Para isso, foram ajustadas dez Funções de Densidade de Probabilidade (FDPs.

As with multiple correlation, it is possible to calculate a more appropriate version of the R-coefficient in logistic regression. This R-coefficient is the partial correlation between the output variable and each of the predictive variables and can range from -1 to 1, where values close to zero indicate no correlation, positive values represent direct correlation, and negative values represent inverse correlation. The R proposed by Cox and Snell (Cox; Snell, 2008), represented by the symbol R^2_{CS}, which is based on the log-likelihood (Brandt, 2014) of the model, the log-likelihood of the original model and the sample size, according to equation (2).

$$R^2_{CS} = 1 - e^{\left[-\frac{2}{n}(VL(Novo) - VL(Básico))\right]} \qquad (2)$$

However, this coefficient never reaches its maximum theoretical value of 1. As such, (Nagelkerke, 1991) suggested the following correction (Nagelkerke's R^2), according to equation (3).

$$R^2_N = \frac{R^2_{CS}}{1 - e^{\left[\frac{2(VL(Básico))}{n}\right]}} \qquad (3)$$

SPSS (IBM, 2020) uses the R-coefficient proposed by Cox and Snell (Cox; Snell, 2008), considering the correction of Nagelkerke (Nagelkerke, 1991). The terms of the exponent of the natural number of equation (3) come from the log-likelihood (VL) expression described in equation (4).

$$VL = \sum_{i=1}^{N} \{Y_i \ln(P(Y_i)) + (1 - Y_i) ln[1 - P(Y_i)]\} \qquad (4)$$

Equation (3) is associated with the probabilities derived from the model and the actual data. The result of the Equation indicates how much unexplained information still exists after the model has been adjusted.

Calculating means does not make sense for dichotomous variables. Thus, the basic value of the likelihood-log (VL(Basic)) of equation (4) corresponds to the category with the highest number of cases.

In logistic regression, a value called Wald presents a special distribution known as chi-square (Hastie; Tibshirani; Friedman, 2009). Wald tells us if the coefficient b_n of each predictor is significantly different from zero (Wald, 1943). If this occurs, we can assume that the predictor x_n is contributing significantly

to the prediction of the output variable. Equation (5) shows how Wald is calculated, and it is possible to see that it is equal to t in the linear regression.

$$Wald = \frac{b}{EP_b} \qquad (5)$$

Where b is the regression coefficient and EP_b is its standard error.

Another important variable for the interpretation of the logistic regression is the so-called exponent. This indicator represents the variation of the probability change before and after the inclusion of the analysed variable. When the indicator is greater than 1, it indicates that the increase in the predictor is directly related to the increase in the chance of an increase in the output variable (Field, 2017).

In our specific case, we will use logistic regression to predict whether a transmission line will suffer an outage caused by wildfires, given the characteristics of transmission line spans exposed to the fires.

2 MATERIALS AND METHODS

We analysed the forced outage data of the Brazilian transmission system in 2018 and 2019 that was declared by the transmission utilities to the national network operator (Operador Nacional do Sistema Elétrico, 2016b). The obtained data contained information on the date, time, installation, outage cause and declared location for the defect. Based on this data, the outages caused by wildfires were selected.

We selected six transmission line trunks with asymmetric performance in the period regarding outages caused by fires. The selected circuits are highlighted in Table 1.

Table 1 | Trunks and transmission lines selected for the study.

Trunks	*Installation*	*Length (km)*
1	TL 500 kV COLINAS / RIB.GONÇALVES C 1 TO/PI	379
	TL 500 kV COLINAS / RIB.GONÇALVES C 2 TO/PI	367
2	TL 500 kV IMPERATRIZ / COLINAS C 1 MA/TO	343
	TL 500 kV IMPERATRIZ / COLINAS C 2 MA/TO	343
3	TL 500 kV IMPERATRIZ / P. DUTRA C 1 MA	388
	TL 500 kV IMPERATRIZ / P. DUTRA C 2 MA	388
4	TL 500 kV RIB.GONCALVES / S. JOÃO PIAUÍ C L3 PI	353
	TL 500 kV RIB.GONCALVES / S. JOÃO PIAUÍ C L4 PI	353
5	TL 500 kV TERESINA II / P. DUTRA C C9 PI/MA	210
	TL 500 kV TERESINA II / P. DUTRA C C8 PI/MA	208
6	TL 500 kV TERESINA II / SOBRAL III C V8 PI/CE	334
	TL 500 kV TERESINA II / SOBRAL III C V9 PI/CE	332

Source: Operador Nacional do Sistema Elétrico, 2023.

The six selected trunks cover the states of Piauí, Tocantins, Maranhão and Ceará, as shown in Figure 1, and they correspond to twelve 500 kV transmission lines with a total of 3,998 km.

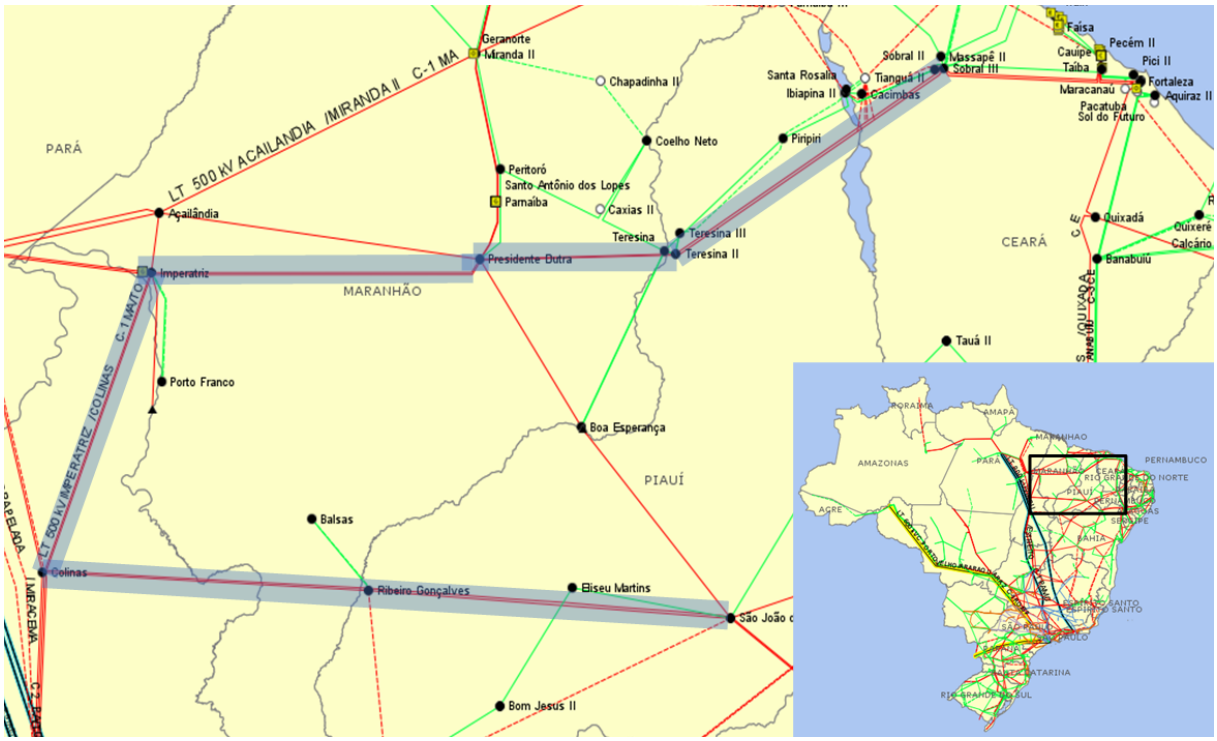

Figure 1 | Schematic of the analyzed transmission lines (ONS, 2017)

The information in granularity by span was gathered for the six selected trunks, highlighted in Table 2.

Spans are limited by transmission line towers and are analysed according to their area of influence. Each area is delimited by the width of the safety strip established in the environmental license and by the transmission line towers (Figure 2). Span analysis is a major innovation of this work, given that similar articles analysed theoretical models or transmission lines (Guo *et al.*, 2018; Khan; Ghassemi, 2022; Shi *et al.*, 2018).

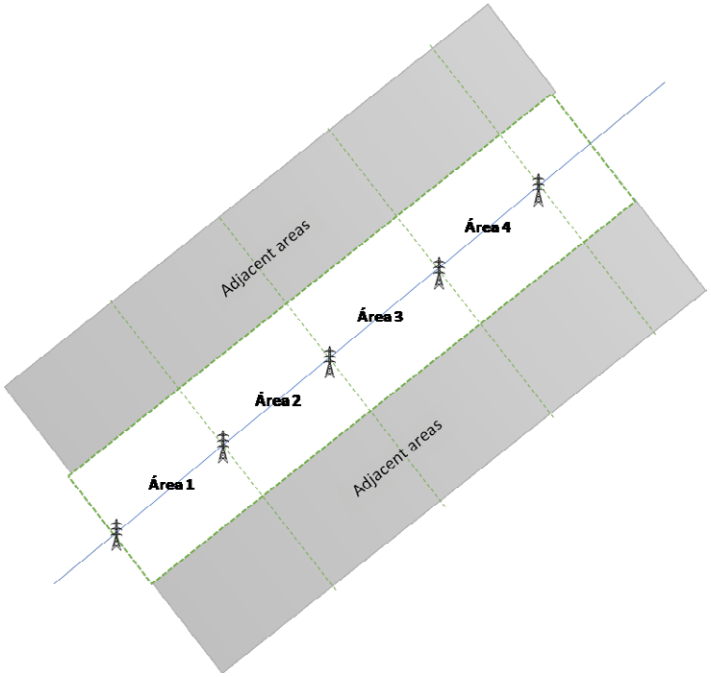

Figure 2 | Schematic representation of the areas of study

Source: Authors.

Table 2 | Analysed variables

Variable	*Measurement Scales*	*Type of characteristic*	*Unit*	*Origin*
Outages	Nominal	Performance	Not applicable	SIPER
Fire outbreaks	Ratio	Performance	Amount	Queimadas program
NDVI	Ratio	Performance	Dimensionless	GGT
Width	Ratio	Constructional	Meters	GGT
Height	Ratio	Constructional	Meters	GGT
Insulators	Ratio	Constructional	Amount	GGT
Days without rain	Ratio	Climatic	Not applicable	Inpe
Humidity	Ratio	Climatic	Percentage	Inpe
Temperature	Ratio	Climatic	Degrees Celsius	Inpe
Wind speed	Ratio	Climatic	Meters per second	Inpe
Biome	Nominal	Terrain	Not applicable	MapBiomas
Type of land	Nominal	Terrain	Not applicable	MapBiomas
Right-of-way clearing	Nominal	Performance	Not applicable	GGT

Source: Authors

The data in Table 2 were classified according to the measurement scales postulated by Stevens (Stevens, 1946). According to this classification, all measurement scales can be classified into nominal, ordinal, interval and ratio. Nominal and ratio data were used in the reported study. Nominal data corresponds to the independent dichotomous output variable. Ratio variables correspond to the continuous predictive variables.

The data of Table 2 was also classified regarding the type of characteristic reported: performance, constructive and climatic.

The performance characteristics are related to the operational dynamics of the transmission line. The forced outage data was obtained from the Integrated System of Disturbances (*Sistema Integrado de Perturbações*, SIPER) (Operador Nacional do Sistema Elétrico, 2016a). This variable represents whether or not forest fires caused a line trip.

The fire outbreak data were obtained from the Queimadas program (Instituto Nacional de Pesquisas Espaciais, 2017). The fire outbreak detection system for the polar orbit satellites can capture a fire front of about 30 m long by 1 m wide or larger. Therefore, the quantity of this variable represents the area affected by forest fire.

The Normalised Difference Vegetation Index (NDVI) index data and the right-of-way clearing data were obtained from the Geospatial Transmission Management System - GGT (Guido JR. *et al.*, 2018). NDVI is calculated by the difference in reflectance between the near infrared and red bands, normalised by the sum of the near infrared and red bands. The index varies on a scale of -1 to +1. The closer to 1, the greater the vegetation cover density; negative values represent bodies of water (Rouse *et al.*, 1973).

The constructive characteristics are those related to the design of the facilities. The width of the right-of-way for the span, the height of the towers at the ends of the span and the number of insulators per chain were obtained from the data of the GGT system (Guido JR. *et al.*, 2018). Although these variables have granularity by span, the available data reflect values by transmission line section.

The climatic data correspond to humidity, temperature, wind speed and number of days without rainfall for each span under analysis. All this information was obtained from the Brazilian Space Research Insititute (*Instituto Nacional de Pesquisas Espaciais*, Inpe). Data is available since 2000 at a resolution (pixel) of 25 km x 25 km. The data are derived from meteorological models of the *Global Forecast System* - GFS (Instituto Nacional de Pesquisas Espaciais, 2020; National Oceanic And Atmospheric Administration, 2020).

It is important to highlight that the temperature information cited in this work refers to the weather conditions and not the flame's temperature or the transmission line conductors. The nominal variables were analysed according to specific classifications, as shown in Table 3.

Table 3 | Categories of biome, land use and right-of-way clearing variables

Variables	*Dichotomous representation*	*Category*
Biome	0	Amazônia
	0	Caatinga
	1	Cerrado
Land use	0	Annual and Perennial Culture
	0	Countryside Training
	0	Forest Formation
	1	Savanna Formation
	0	Urban infrastructure
	0	Agriculture and Grassland Mosaic
	0	Other non-vegetated area
	0	Pasture
	0	River, Lake and Ocean
Right-of-way clearing	1	Authorised
	0	Authorised with restrictions
	0	Prohibited

Source: Authors

It should be stressed that the categories of the variables cited in Table 3 are not exhaustive and are limited to those listed in the database used. The dichotomous representation of the variables is necessary for the use in logistic regression models. The dichotomous representation criterion of Table 3 followed the results of the previous descriptive statistical analyses (Costa, 2021; Costa *et al.*, 2022).

It was found that 71% of the span area that caused outages is related to the land use category 'Savanna Formation'. As such, the value 1 was assigned to this variable for the dichotomous representation of the category 'Savanna Formation' and the value of 0 for the other categories. For the biome variable, the prevalence of span areas that caused outages is in the 'Cerrado' category (59%). Therefore, the dichotomous representation of the category 'Cerrado' gets value 1, and the other categories get value 0. For the right-of-way clearing variable, the 'Authorised' category got a value of 1, and the others got a value of 0.

Based on the data described in Table 2, it was possible to consolidate the data using the identifier code of the transmission line span as an identifying key. The SAS software (SAS, 2020) was used for this crosschecking.

The data were processed following the flow described in Figure 3.

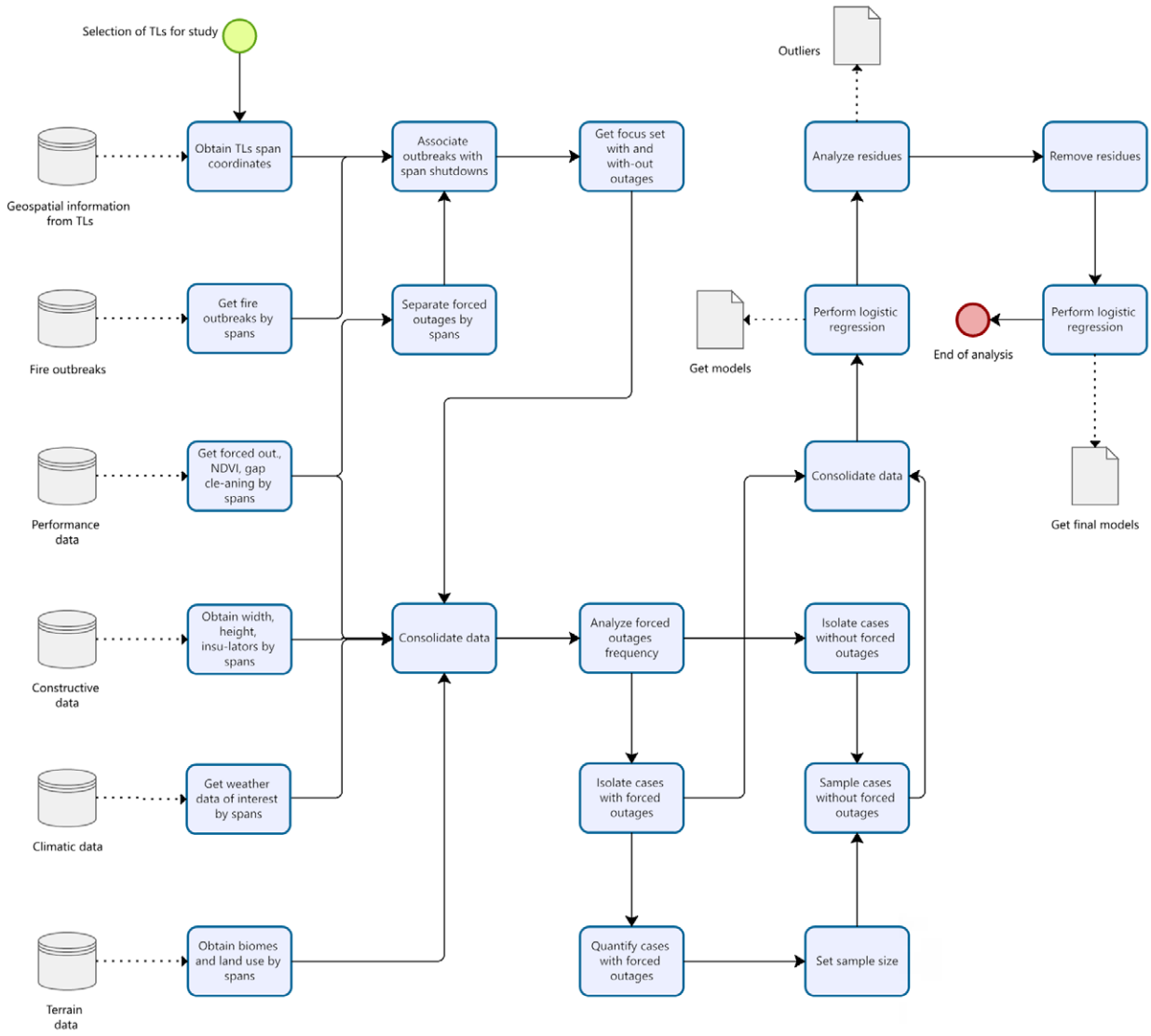

Figure 3 | Summary of the study's methodology

Source: Authors

After consolidation, the data were divided into two sets: those that caused TL outages when exposed to fire outbreaks and those that, under the same condition, did not cause outages.

Subsequently, a frequency analysis was made of the spans associated or not with outages. The spans associated with outages (smaller set) were used as a reference for the sample size of the spans associated with the absence of outages (larger set). The two data sets were once again consolidated, ensuring symmetry between the number of spans with and without outages. This initial analysis was considered a base model without including any of the variables under study.

The Wald value was calculated for the variables not included in the base model. The next step was the inclusion of the significant variable with the highest score in the base model. This model was stored with its R^2 coefficient and hit percentages being calculated.

Next, new Wald values were calculated for the variables not included in the first simulation step. The significant variable with the highest score was again selected for inclusion in the previous model. A new simulation step was generated, with the R2 coefficient and hit percentages calculated. This process was repeated until no significant variables remained outside the model.

At the end of *n* simulation steps, the model with the highest hit percentage for the occurrence of outages was selected. The residuals were also analysed to identify outliers with undue influence on the models. Standardised differences greater than ±2σ (standard deviations) were considered outliers. The outliers were removed from the database, and the logistic regression analysis was repeated, obtaining new probabilistic models.

The SPSS software was used (IBM, 2020) to construct the logistic regression models.

3 RESULTS AND DISCUSSIONS

The initial results of the logistic regression model, when only the constant of Equation (1) is included, indicate that the initial model without predictive variables has a hit probability of 94.8%, always predicting the non-occurrence of outages. However, this output does not have a valid significance. The number of observed fire outbreak events without transmission line outages is much higher than those with outages. As such, the model considers the most frequent event and associates it with the output value.

In order to prevent the difference in the number of observations from causing a bias in the frequencies of observations, the available data was subjected to prior preparation. Basically, the database contains 370 records with outages and 6754 records without outages. For this second set, 370 records were randomly selected.

Based on this consideration, the frequencies of cases with and without outages were forced to be equal. Consequently, the base probability of an outage occurring becomes 50%, and the complementary probability of an outage not occurring also becomes 50%.

Therefore, the first estimate of the model, when only the constant is included, was reviewed and described in Table 4.

Table 4 | Base Model

Observed			*Predicted*		
			Outages		*Correct percentage*
			0	*1*	
Step 0	Outages	0	0	370	0.00
		1	0	370	100.00
	Overall Percentage				50.00

Source: Authors

In Table 4, records with outages are indicated by the number 1, and records without outages are indicated by the number 0. As expected, the model could predict 50% of the occurrences correctly, given that the outage frequencies were the same. In this first step, the constant value used was zero and the results were insignificant (p>0.05).

The variables that were not considered in the model for Step 0 are presented in Table 5. The model's general statistic (chi-square) was 156.83 and was considered significant (p<0.005). This means that

variables that are not in the model are significantly different from zero or, in other words, that adding one or more of these variables to the model will significantly affect its predictive power.

Table 5 | Parameters of the variables outside the model in step 0 of the simulation

Variables	*Score*	*Df*	*Sig.*
Fire outbreaks	64.061	1	0.00
NDVI	6.305	1	0.01
Right-of-way width	3.065	1	0.08
Height	18.662	1	0.00
Insulators	7.830	1	0.01
Days without rain	61.089	1	0.00
Humidity	65.913	1	0.00
Temperature	45.525	1	0.00
Wind speed	1.843	1	0.17
Biome(1)	49.174	1	0.00
Type of land(1)	28.831	1	0.00
Right-of-way clearing(1)	16.520	1	0.00
Overall Statistics	156.830	12	0.00

Source: Authors

The score data of Table 5 represent the Wald values. This is a previous indicator used by SPSS to indicate the order of inclusion of the variables in each simulation step. For the analysed data, the Wald value was not significant ($p>0.05$) for the variables corresponding to the right-of-way width and wind speed. The other variables were considered significant, with the highest score corresponding to the variable humidity.

Table 5 also shows the dichotomous predictor variables: biome, land use and right-of-way clearing authorisation. Based on the results of a previous descriptive statistical analysis, we sought to investigate the Cerrado biome's effect on the performance of transmission lines. As such, the value 1 was assigned to all spans located in Cerrado areas. The value 0 was assigned to the spans located in other biomes. The same procedure was repeated for the land use classified as Savanna Formation, which received the value 1, and the other uses, which received the value 0. In the case of the authorisation variable, the value 1 was assigned to all spans without right-of-way clearing restrictions and 0 for the spans with partial restrictions or prohibition. The three dichotomous variables under analysis were considered significant ($p<0.05$) for the model.

The simulation is done by including one variable at a time, following the order imposed by the Wald value presented in Table 5. For example, in Step 1, the simulation was made considering the variable Humidity and the constant.

At each step of the simulation, the same parameters of Table 5 are recalculated, with the variable with the highest Wald value being included in the model and the non-significant variables ($p > 0.05$) discarded. The statistical summary of the new simulated models is presented in Table 6.

Table 6 | Statistics of the new model

Step	*-2 log-likelihood*	*R2 Cox & Snell*	*R2 Nagelkerke*
1	951.261a	0.096	0.128
2	896.682b	0.160	0.214
3	872.749b	0.187	0.249
4	855.190b	0.206	0.275
5	847.957b	0.214	0.285
6	848.302b	0.213	0.284
7	843.750b	0.218	0.291

a. The estimate was stopped in iteration number 4 because the parameter estimates changed by less than 0.001.

b. The estimate was stopped in iteration number 6 because the parameter estimates changed by less than 0.001.

Source: Authors

As the variables are included, Nagelkerke's R^2 increases so that at the end of the 7 steps, we get the value of 0.291 on a scale of 0 to 1. This result reveals that there are representative random factors that influence the probability of the occurrence of outages.

The results of the hit percentage at each simulation step are shown in Table 7.

Table 7 | Models generated at every step

Observed		*Predicted*		
		Outages		*Correct percentage*
		0	*1*	
Step 1	0	186	184	50.27
	1	118	252	68.11
				59.19
Step 2	0	257	113	69.46
	1	130	240	64.86
				67.16
Step 3	0	271	99	73.24
	1	131	239	64.59
				68.92
Step 4	0	271	99	73.24
	1	111	259	70.00
				71.62
Step 5	0	274	96	74.05
	1	113	257	69.46
				71.76
Step 6	0	279	91	75.41
	1	113	257	69.46
				72.43

Observed		Predicted		
		Outages		Correct percentage
		0	1	
Step 7	0	284	86	76.76
	1	120	250	67.57
				72.16

Table 7 shows that after seven steps, the simulation reached a model that can correctly predict 72.16% of cases. The best average result occurred in the sixth step, with an accuracy of 72.43%. Remembering that the base case (Table 4) reached a 50% hit percentage, we can state that the generated models managed to increase the outage prediction accuracy by up to 44.86%.

However, this work aims to predict the events that will generate transmission line outages with a greater hit probability. According to this objective, the model with the best result was obtained in Step 4, with 70.00% of correct predictions.

After presenting the model's statistical indicators, the equation coefficients' values are presented (1) to Step 4 of the simulation. These results are presented in Table 8.

Table 8 | Coefficients of the generated models

Step	Variable	B	Standard Error	Wald	df	Sig.	Exp(B)
4	Fire outbreaks	0.04	0.01	29.69	1.00	0.00	1.04
	Days without rain	0.01	0.00	19.46	1.00	0.00	1.01
	Humidity	-0.04	0.01	13.09	1.00	0.00	0.96
	Biome(1)	0.79	0.19	17.12	1.00	0.00	2.21
	Constant	0.01	0.37	0.00	1.00	0.97	1.01

In addition to the variable's coefficient, Table 8 provides the standard error information associated with each calculated coefficient, the Wald value, the degree of freedom, the significance level and B exponent.

Considering the model with the best fit to the objectives of this work, corresponding to step 4, we realised that it uses the continuous variables fire outbreaks, days without rain and humidity; the dichotomous variable biome; and the constant. That is, the climatic conditions, the terrain conditions, and the size of the wildfire are determinants for the occurrence of transmission line outages.

Considering the B exponent, the variable with the greatest chance of increasing the hit probability of the model is the type of Biome (2.21). With this variable, the influence on the performance of transmission lines with spans located in the Cerrado biome was studied. The results indicate that this type of biome has a higher probability of causing transmission line outages because of wildfires.

The absence of the transmission line's constructive variables in all the generated models stands out. The explanation may be the quality of the available data, which considered average values declared by the transmission concessionaires for the entire transmission line studied, which proved inadequate granularity for the proposed study.

Improving data quality depends on specific and ongoing regulatory action, which consists of building a technical database of transmission assets with a georeferenced basis and submetric accuracy (Agência Nacional de Energia Elétrica, 2019). It is reasonable to infer that a base with these characteristics will be

able to reduce the randomness of the models (higher Nagelkerke's R^2) and increase the hit probability of outage events caused by wildfires.

Regulatory incentives for transmission utilities can also be evaluated against results since they get paid only when their system is available. Revenue is discounted in the case of outages, and the goal is to ensure maximum system availability (Agência Nacional de Energia Elétrica, 2016).

Brazilian regulations treat the wildfire phenomenon as an exception to the general rule. Outages caused by these phenomena can be exempt from revenue discounts. This exception reflects an understanding of the Brazilian regulator regarding the limitation of the transmission utility's ability to take preventive actions against wildfires (Agência Nacional de Energia Elétrica, 2016).

The regulator's perspective received validation from the model to some extent. However, apart from the design phase, where the line's layout determines the biomes it traverses, the transmission utilities cannot proactively mitigate outages. The model primarily revealed that climate factors, independent of the transmission utilities' actions, influence outage occurrences.

It is also interesting to note that the environmental restrictions arising from licensing did not prove relevant. In all simulation steps, the right-of-way width variable was statistically insignificant ($p > 0.05$) for the model. The authorisation variable, which represents the existence or not of restrictions to right-of-way clearing along the span, only showed statistical significance ($p<0.05$) in the first step of the simulation. Still, as its Wald value was 5.96, it did not even enter the model corresponding to the simulated step.

It is also worth noting that the variables temperature and land use were considered significant, although they only entered the model after Step 5. Since step 4 obtained the best hit probabilities, these variables did not appear in the final model.

3.1 RESIDUAL ANALYSIS

A standardised residual analysis was performed. These values are the standardised differences between the observed data and the values that the model predicts. Differences greater than ±2σ (standard deviations) were considered discrepancies. Ten records considered atypical were found. These records

represent 1.35% of the database and were excluded because they unduly influenced the model.

3.2 NEW MODEL AFTER THE EXCLUSION OF THE RESIDUALS

The simulations were repeated, considering the remaining 730 records after excluding outliers. New models were obtained from 5 simulation steps. The statistics of the new models are described in Table 9.

Table 9 | Statistics of the new model

Step	*--2 log-likelihood*	*R2 Cox & Snell*	*R2 Nagelkerke*
1	883.116a	0.162	0.216
2	834.389a	0.216	0.288
3	802.387a	0.250	0.333
4	776.089a	0.276	0.368
5	770.014a	0.282	0.376

a. The estimate was stopped in iteration number 6 because the parameter estimates changed by less than 0.001. Source: Authors

Table 9 shows that the exclusion of outliers raised the values of Nagelkerke's R^2. That is, the residuals were confusing the models. Considering the best cases before and after removing the residuals, we can state that it was possible to increase Nagelkerke's R2 by 29,2% (0,291 to 0,976).

Regarding the hit percentage, the new results at each simulation step are shown in Table 10.

Table 10 | Hit percentage of the new models generated at each step

Observed		*Predicted*		
		Outages		*Correct percentage*
		0	*1*	
Step 1	0	296	67	81.5
	1	190	177	48.2
				64.8
Step 2	0	272	97	74.9
	1	126	241	65.7
				70.3
Step 3	0	271	92	74.7
	1	140	227	61.9
				68.2
Step 4	0	271	92	74.7
	1	98	269	73.3
				74.0
Step 5	0	276	87	76.0
	1	102	265	72.2
				74,1

Source: Authors

Table 10 shows that a model was reached after five steps of simulation that managed to hit 74.1% of the predictions. This means there was an improvement in the hit percentage of the order of 2.68% compared to simulations without removing residuals. For the base case (Table 4), we can say that the new models generated increased the outage prediction accuracy by up to 48.2%.

However, just as in the previous simulation, the model that achieved the highest hit rate for the occurrence of outages (output value 1) corresponds to step 4. The accuracy observed in this case was 73.3%, an improvement of 4.71% regarding the equivalent model with the presence of residuals.

The values of the coefficients of the equation (1) to step 4 of the simulation are presented below. These results are presented in Table 11.

Table 11 | Coefficients of the newly generated models

Step	Variables	B	Standard Error	Wald	df	Sig.	Exp(B)
4	Fire outbreaks	0.08	0.01	47.84	1.00	0.00	1.08
	Days without rain	0.01	0.00	22.82	1.00	0.00	1.01
	Temperature	0.25	0.05	26.66	1.00	0.00	1.29
	Biome(1)	1.02	0.20	25.31	1.00	0.00	2.78
	Constant	-10.46	1.75	35.79	1.00	0.00	0.00

Source: Authors

An important difference observed in the new simulations was removing the humidity variable in Step 4 and replacing it with the temperature variable. After the exclusion of outliers, the humidity variable presented non-significant values ($p>0.05$), which meant it was excluded from the simulations. The increase of the B exponent values for all variables can also be highlighted. In the case of the Biome variable, the value of the B exponent was 2.78, reinforcing the importance of this information for the model.

The model resulting from the reported simulation and corresponding to step 4 can be obtained by replacing the coefficients of Equation (1):

$$P(Y) = \frac{1}{1 + e^{-(-10{,}46+0{,}08X_1+0{,}01X_2+0{,}25X_3+1{,}02X_4)}} \quad (6)$$

The result of Equation (6) represents the probability of an outage occurring because of a wildfire. Numbers 1 to 4 represent the predictive variables corresponding to fire outbreaks, days without rain, temperature, and biome, respectively. The climatic variables of the obtained model coincide with the results of the probabilistic model of (Shi *et al.*, 2018), which studied the influence of forest fires on transmission lines in Hubei Province, China.

Considering Equation (6), it is possible to simulate some scenarios to understand how the performance of the studied transmission lines will be affected. In the first case, we evaluated the variation in the probability of outages due to wildfires in the Cerrado biome and other biomes (Caatinga and Amazon). For this scenario, the variables fire outbreaks (19.2) and days without rain (47.98) are kept constant, and the temperature is varied. Figure 4 shows the results.

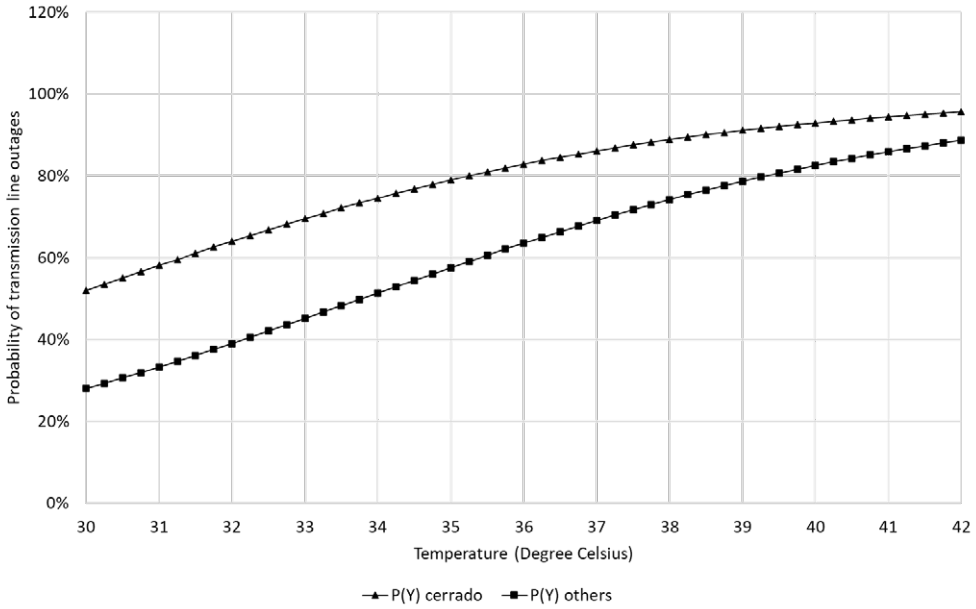

Figure 4 | Probability of outages versus temperature for the Cerrado and other biome scenarios.
Source: Authors.

The simulation demonstrates that the probability of transmission line outages in the Cerrado biome is consistently higher than in other biomes for a temperature range between 30oC and 42oC. It is important to highlight that the indicated temperatures refer to the climate and not the flame's temperature or the transmission lines' conductors.

For the temperature of 36°C, with the simulated parameters, the risk of outages in the Cerrado biome is 82.9% against 63.5% in other biomes. The probability of power outages on transmission lines is 30% higher in the Cerrado than in other biomes.

With the temperature of 36oC as a reference, Figure 4 shows that 1oC increases the outage probability by 4% in the Cerrado biome and 10% in the other biomes. Even if the UN global warming target below 1.5oC is maintained (Silva *et al.*, 2019), relevant impacts on the performance of the studied transmission lines will be observed.

In a second simulation, we evaluated the variation in the probability of line outages as a function of the number of fire outbreaks. For this scenario, the considered biome (Cerrado) and the days without rain (47.98) were kept constant. The temperature variable was again varied. Figure 4 Figure 5 shows the results.

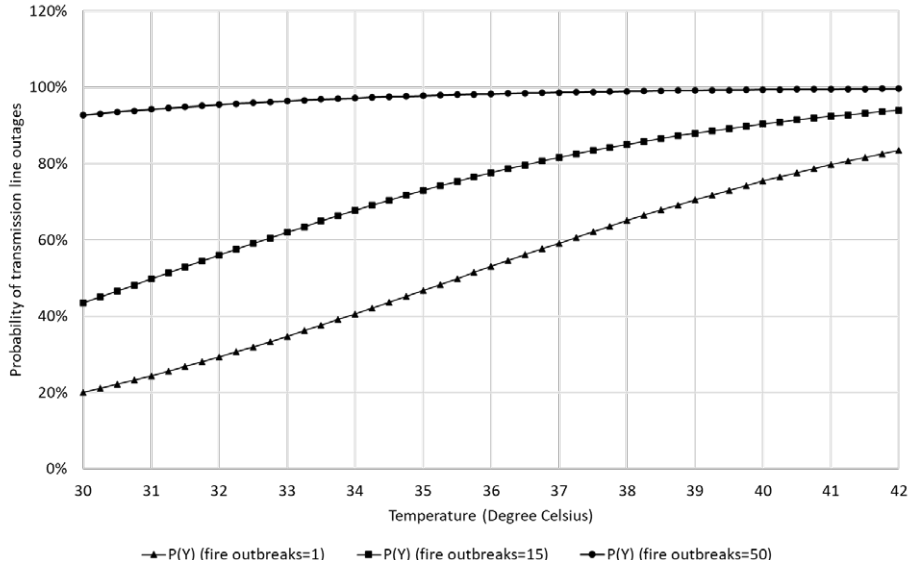

Figure 5 | Probability of outages versus temperature for the different fire outbreak scenarios
Source: Authors

Based on the simulation shown in Figure 5, we can conclude that the number of fire outbreaks, that is, the affected area, greatly influences the probability of transmission line outages. Considering the temperature of 36oC, the probability of outages is 46% higher for the situation with 15 detected outbreaks against 1 outbreak. At the same temperature, for a detection situation of 50 fire outbreaks, the probability of transmission line outages reaches 98.3%.

The last simulation presented in this work evaluates the probability of transmission line outages as a function of the number of days without rain. For this scenario, the biome considered was the Cerrado and the number of fire outbreaks (19,2) was kept constant. Figure 6 shows the results.

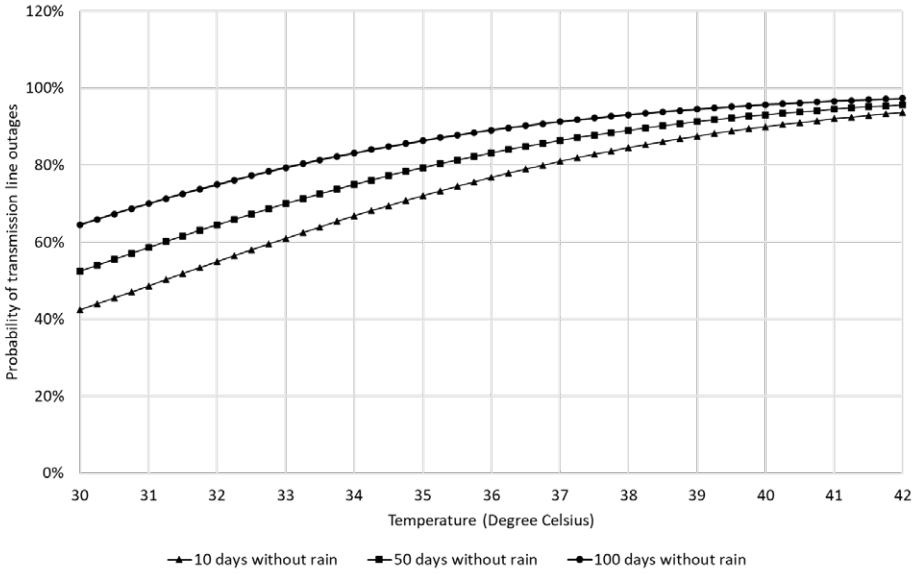

Figure 6 | Probability of outages versus temperature for the different scenarios of days without rain.
Source: Authors

The scenarios presented demonstrate that the influence of days without rain is greater in milder temperatures. With the temperature of 36°C as a reference, the variation in the probability of outages is 8.2% between 10 and 50 days without rain and 7.1% between 50 and 100 days without rain. At

a temperature of 40ºC, the probability difference of outages between the 10 and 100-day rain-free scenarios is only 6.3%.

The models found can be applied to improve the accuracy of business plans for new transmission lines, as a tool for choosing layouts for new transmission lines, and to improve the transmission line maintenance process.

4 CONCLUSION

It was possible to build a logistic regression model that calculates the outage probability of a transmission line from the characteristics of the spans exposed to the fire outbreaks. The built model revealed the importance of environmental and terrain characteristics for outages caused by wildfires. The constructive characteristics of the lines and the NDVI index proved inefficient for the proposed application. Simulations also demonstrated the impact of the analysed variables on the probability of transmission line outages. Higher temperatures will invariably cause increased outages of these facilities, with the greatest impacts observed in the biomes Caatinga and Amazon.

The methodology applied in this study can be replicated in other countries sensitive to the phenomenon of wildfires. In this way, the work can contribute significantly to the construction of resilient infrastructures at a global level.

The results of this study can be considered by regulators and planners in the electricity sector in new transmission line projects, reducing the likelihood of shutdowns caused by wildfires. This can be done by seeking to combine the technical needs of the projects with the most favourable climatic and terrain characteristics to ensure the operation of these facilities is not interrupted.

These measures can potentially increase the resilience of these installations, contributing to the fulfilment of SDG 7 in terms of increasing the reliability of electricity supply. Furthermore, there will be a positive economic impact for energy transmission concessionaires, which will avoid discounts on their revenues due to forced shutdowns.

REFERENCES

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. Resolução Normativa no 729, de 28 de junho de 2016. Estabelece as disposições relativas à qualidade do serviço público de transmissão de energia elétrica, associada à disponibilidade e à capacidade operativa das instalações sob responsabilidade de concessionária de transmissão integrantes da Rede Básica e das instalações de transmissão de energia elétrica destinadas a interligações internacionais que se conectam à Rede Básica, conforme Resolução Normativa no 442, de 26 de julho de 2011, e dá outras providências. **Diário Oficial da União – DOU**, [*S. l.: s. n.*], 2016. p. 97. Available at: http://www2.aneel.gov.br/cedoc/ren2016729.pdf. Accessed on: 15 out. 2020.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. Resolução Normativa no 861, de 26 de novembro de 2019. Dispõe sobre a definição da Base de Dados das Instalações de Transmissão de energia elétrica e dá outras providências. **Diário Oficial da União**, [S. l.: s. n.], 2019. p. 46. Available at: http://www2.aneel.gov.br/cedoc/ren2019861.pdf. Accessed on: 15 out. 2020.

BERRY, W. **Understanding Regression Assumptions**. California: Sage Publications, 1993. Available at: https://doi.org/10.4135/9781412986427

BRANDT, S. **Data Analysis**. Cham: Springer International Publishing, 2014. Available at: https://doi.org/10.1007/978-3-319-03762-2

COSTA, T. R. V. da. **Faixas de Segurança de Linhas de Transmissão e seu Modelo de Desempenho Frente aos Incêndios Florestais**. 130 f. 2021. Universidade de Brasília, [*s. l.*], 2021. Available at: https://repositorio.unb.br/handle/10482/41238

COSTA, T. R. V. da *et al.* Susceptibility Characteristics of 500 kV Transmission Lines to Forced Outages Caused by Wildfires. **Electric Power Systems Research**, [*s. l.*], v. 209, p. 107995, 2022. Available at: https://doi.org/10.1016/j.epsr.2022.107995

COX, D. R.; SNELL, E. J. Analysis of Binary Data. *In*: **The Concise Encyclopedia of Statistics**. New York, NY: Springer New York, 2008. p. 4–5. Available at: https://doi.org/10.1007/978-0-387-32833-1_5

FIELD, A. **Discovering Statistics Using IBM SPSS Statistics**. 5. ed. Thousand Oaks: Sage Publications Inc, 2017. v. 1, E-book.

GUERA, O. G. M. *et al.* Evolução da distribuição diamétrica em plantios de Pinus caribaea Morelet var. caribaea Barrett & Golfari. BIOFIX Scientific Journal, [*s. l.*], v. 3, n. 1, p. 161, 2018. Available at: https://doi.org/10.5380/biofix.v3i1.58132

GUIDO JR. P. *et al.* Sistema de Gestão Geoespacializada da Transmissão – GGT. **Eletro Evolução**, [*s. l.*], v. 6, n. 91, p. 45–52, 2018. Available at: https://drive.google.com/file/d/1l0A6ugM_bKdzQ-1VXRYOT3TBpAaYTolx/view?usp=sharing

GUO, Y. *et al.* Determination of the power transmission line ageing failure probability due to the impact of forest fire. **IET Generation, Transmission & Distribution**, [*s. l.*], v. 12, n. 16, p. 3812–3819, 2018. Available at: https://doi.org/10.1049/iet-gtd.2018.0039

HASTIE, T.; TIBSHIRANI, R.; FRIEDMAN, J. **The Elements of Statistical Learning**. 2. ed. New York, NY: Springer New York, 2009. (Springer Series in Statistics). Available at: https://doi.org/10.1007/b94608

HEUMANN, C.; SCHOMAKER, M.; SHALABH. **Introduction to Statistics and Data Analysis**. Cham: Springer International Publishing, 2016. Available at: https://doi.org/10.1007/978-3-319-46162-5

IBM. **Software IBM SPSS**. [S. l.], 2020. Available at: https://www.ibm.com/br-pt/analytics/spss-statistics-software. Accessed on: 4 oct. 2020.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. **Clima Monitoramento Brasil – Cptec/Inpe**. [*S. l.*], 2020. Available at: http://clima1.cptec.inpe.br/monitoramentobrasil/pt. Accessed on: 28 sept. 2020.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. **Programa de Monitoramento de Queimadas**. [*S. l.*], 2017. Available at: http://www.inpe.br/queimadas. Accessed on: 21 sept. 2017.

KHAN, I.; GHASSEMI, M. A probabilistic approach for analysis of line outage risk caused by wildfires. **International Journal of Electrical Power & Energy Systems**, [*s. l.*], v. 139, p. 108042, 2022. Available at: https://doi.org/10.1016/j.ijepes.2022.108042

NAGELKERKE, N. J. D. A Note on a General Definition of the Coefficient of Determination. **Biometrika**, [*s. l.*], v. 78, n. 3, p. 691, 1991. Available at: https://doi.org/10.2307/2337038

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. **National Centers for Environmental Information (NCEI) formerly known as National Climatic Data Center (NCDC)**. [*S. l.*], 2020. Available at: https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs. Accessed on: 28 sept. 2020.

OPERADOR NACIONAL DO SISTEMA ELÉTRICO. **SINDAT**. [*S. l.*], 2023. Available at: http://betasindat.ons.org.br/SINDAT/Home/ControleSistema. Accessed on: 1 sept. 2017.

OPERADOR NACIONAL DO SISTEMA ELÉTRICO. **Sistemas ONS**. [*S. l.*], 2016a. Available at: http://www.ons.org.br/agentes/sistemasons.aspx. Accessed on: 3 aug. 2017.

OPERADOR NACIONAL DO SISTEMA ELÉTRICO. **Submódulo 18.2 - Relação dos sistemas e modelos computacionais**. Brasil: [s. n.], 2016b. Available at: http://ons.org.br/paginas/sobre-o-ons/procedimentos-de-rede/vigentes.

PACKARD, G. C. Is logarithmic transformation necessary in allometry? **Biological Journal of the Linnean Society**, [s. l.], v. 109, n. 2, p. 476–486, 2013. Available at: https://doi.org/10.1111/bij.12038

ROUSE, J. W. *et al.* **Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation Progress Report RSC 1978-1**. Houston: [*s. n.*], 1973. Available at: https://ntrs.nasa.gov/citations/19730017588.

SAS. **Software de Business Analytics e Business Intelligence – SAS**. [*S. l.*], 2020. Available at: https://www.sas.com/pt_br/home.html. Accessed on: 5 oct. 2020.

SHI, S. *et al.* A Model Design for Risk Assessment of Line Tripping Caused by Wildfires. **Sensors**, [*s. l.*], v. 18, n. 6, p. 1941, 2018. Available at: https://doi.org/10.3390/s18061941

SILVA, P. S. *et al.* Impacts of the 1.5°C global warming target on future burned area in the Brazilian Cerrado. **Forest Ecology and Management**, [*s. l.*], v. 446, p. 193–203, 2019. Available at: https://doi.org/10.1016/j.foreco.2019.05.047

STEVENS, S. S. On the Theory of Scales of Measurement. **Science**, [*s. l.*], v. 103, n. 2684, p. 677–680, 1946. Available at: https://doi.org/10.1126/science.103.2684.677

WALD, A. Tests of Statistical Hypotheses Concerning Several Parameters When the Number of Observations is Large. **Transactions of the American Mathematical Society**, [*s. l.*], v. 54, n. 3, p. 426, 1943. Available at: https://doi.org/10.2307/1990256

ZHANG, Y.; WANG, J.; LUO, X. Probabilistic wind power forecasting based on logarithmic transformation and boundary kernel. **Energy Conversion and Management**, [*s. l.*], v. 96, p. 440–451, 2015. Available at: https://doi.org/10.1016/j.enconman.2015.03.012

Integrating geographic intelligence for sustainable powerline planning

Integrando inteligência geográfica para o planejamento sustentável de linhas de transmissão de energia

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ABSTRACT

This research explores the potential of geographic intelligence in modelling optimal corridors for assessing alternative locations for power transmission lines at different stages of the study. The difficulties verified in the environmental licensing of new projects, the expansion of the national transmission system, and the lack of work to research techniques for formulating locational alternatives are motivating questions for this research. The investigation employs a multicriteria decision-making approach integrated with a geographic information framework to compute and map the feasibility corridors based on environmental constraints and stakeholder inputs. Findings reveal that the current decision-making process for implementing new power transmission lines involves disparate public and private entities operating non-integratively in a multi-level analysis and decision-making process. Through a case study utilising multicriteria analysis and expert consultations, the research demonstrates the applicability of spatial modelling in the locational planning of transmission projects. It highlights the model's capacity to address the complexity inherent in such studies, aggregate analyses and decisions from various stakeholders, and enhance transparency in the decision-making process from energy planning to operational phases.

Keywords: AHP. Powerline planning. GIS. Conceptual model. Participatory model. Decision-making.

RESUMO

A pesquisa investiga o potencial da inteligência geográfica para modelagem de corredores preferenciais para a qualificação da etapa de estudos de alternativas locacionais de linhas de transmissão de energia. As dificuldades verificadas no licenciamento ambiental de novos projetos, a ampliação do sistema de transmissão nacional e a falta de trabalhos direcionados para a pesquisa de técnicas de formulação de alternativas locacionais são questões motivadoras desta pesquisa. O trabalho analisou o emprego de um sistema de decisão implementado em um sistema de informações geográficas baseado em ponderações de atores envolvidos. Constatou-se que o fluxo decisório atualmente instituído para a implantação de novas linhas de transmissão, desde as etapas de planejamento energético até a efetiva operação do empreendimento, envolve diferentes entidades públicas e privadas que atuam de forma não integrada em um processo multinível de análises e decisões. O estudo de caso apresentado envolve técnica de análise multicriterial e a consulta a especialistas. Demonstrou-se a aplicabilidade da modelagem espacial ao planejamento locacional de projetos de transmissão, a sua aptidão para considerar a complexificação presente em estudos desse porte, o seu potencial de agregação de análises e decisões dos diferentes atores que integram o processo decisório e sua capacidade de compreensão e transparência.

Palavras-chave: AHP. Planejamento de linha de transmissão. Geoprocessamento, modelo conceitual e modelo participativo. Tomada de decisão.

1 INTRODUCTION

Globalisation Sustainability is a pivotal policy in the contemporary energy sector, albeit posing a formidable challenge for critical infrastructure endeavours like Transmission Power Lines (TPL). The surge in investments in renewable generation facilities worldwide responds to the escalating demand for electrical energy. These renewable power plants, aligned with the 2023 Agenda of the United Nations and specifically contributing to SDG 7 (IEA, 2019), are predominantly located far from consumer centres. However, expanding the power line transmission network is a consequential outcome of these new power plant initiatives. A recent report from Brazil's Ministry of Mining and Energy underscores the imperative need for over 33,000 km of new TPL across the nation by 2031 (MME; EPE, 2022), with the primary driver being the accommodation of new solar and wind power plants, in addition to conventional hydroelectric facilities. Nonetheless, a meticulous analysis necessitates closer scrutiny of such an extensive infrastructural expansion's ramifications and potential environmental consequences.

The strategic planning process for expanding power lines entails considerations encompassing government regulation, socio-environmental impacts, and technological dimensions. The application of Multicriteria Decision Making (MCDM) methods in energy planning has gained widespread acceptance, driven by the intricate nature of the decision-making process (Biasotto *et al.*, 2022; Greening; Bernow, 2004; Kumar *et al.*, 2017; Pohekar; Ramachandran, 2004; WANG *et al.*, 2009). Integrating social and environmental factors, public engagement, and the dynamics of diverse stakeholders in decision-making processes is critical in shaping this complex landscape. Simultaneously, the ongoing global discourse on climate change and sustainable development accentuates the imperative to formulate sustainable design approaches for energy initiatives. Nevertheless, the effective integration of these considerations into energy planning and development practices warrants comprehensive investigation, particularly regarding the practical implementation and enforcement of such measures.

In the context of power lines, the conventional evaluation of alternatives aims to facilitate the identification of the optimal "route or path across a landscape or along existing facilities or rights-of-way in such a manner that criteria such as cost, safety, environmental impact, and aesthetics are all considered simultaneously" (Church; Loban; Lombard, 1992). This approach is the foundation for feasibility studies and, in many cases, has become a mandatory requirement for environmental regulatory agencies.

In the 1990s, authors such as Jankowski (1995) emphasised that addressing challenges associated with establishing a new right-of-way would be more effective through an integrated approach incorporating Geographic Information System (GIS) and Multicriteria Decision Making (MCDM) methods. Nearly two decades later, GIS gained popularity and widespread adoption among professionals in transportation, utilities, and power management fields (Salim *et al.*, 2023). This increased knowledge and evolving demands enabled developers to create geographically intelligent models to address new challenges, including those aligned with Sustainable Development Goals (SDGs). Given that the planning processes for critical infrastructure projects now encompass environmental, socioeconomic, and cultural perspectives in addition to the conventional engineering standpoint, achieving an effective balance of data, roles, and stakeholders has emerged as a fundamental challenge for the intricate decision-making process (Stich *et al.*, 2011). In pursuing comprehensive geospatial solutions, Araújo, Ajuz, and Ramos (2021) proposed an approach incorporating spatial modelling during the scoping phase of the environmental impact assessment. Their study yielded promising preliminary results within the framework of the Brazilian environmental permitting process for transmission lines.

These challenges prompted research from various perspectives, focusing on logical modelling concerning data and algorithms and physical modelling related to software implementation (Costa, 2023). Despite the ongoing advancements within the GIS realm, it is evident that conceptual modelling, crucial for effectively capturing the problem and conceptualising the solution, remains a significant challenge in the energy sector. This concern has led to questions such as: How can we identify options that encompass all stakeholders' input in the decision-making process? Therefore, we hypothesise that a logical approach rooted in a comprehensive conceptual model enables the solution to consider the synergy among different actors participating in the process, facilitating more effective deliberation, evaluation, and prioritisation of Transmission Line Project (TLP) alternatives.

One potential solution, forming the fundamental premise of this research, involves proactively addressing environmental concerns at the outset of decision-making processes related to the planning and executing the expansion of transmission networks. Cardoso Jr. and Hoffmann (2019), in their analysis of the reliability of the Brazilian electricity sector, advocate for, among other measures, the early consideration of environmental issues at the planning stage, incorporating environmental impact assessments into the decision-making process.

Within this context, the present study aims to introduce a spatial modelling framework designed to generate alternatives for power lines. This framework considers environmental, social, and economic criteria, aiming to facilitate the inclusive participation of key stakeholders. The conceptual foundation of this study is rooted in the methodological strategy of corridor planning proposed by Nóbrega *et al.* (2009), employing the Analytic Hierarchy Process (AHP). However, a rigorous examination of this approach is essential, necessitating a critical evaluation of its practical applicability in real-world scenarios and its potential limitations in addressing the intricate challenges inherent in infrastructure planning.

The Brazilian decision-making process was selected as a case study, and the model has been crafted to facilitate its adaptability to diverse decision-making scenarios, spanning various decision levels, stakeholders, and variables. The country presents distinctive characteristics that underscore the challenge of achieving a sustainable expansion of its transmission system, including:

- The escalating growth of renewable energy generation systems and the imperative to connect this surplus to consumer centres (Silva; Marchi Neto; Seifert, 2016; Manso *et al.*, 2012; RUDNICK *et al.*, 2012);
- The intricate relationship between land-use diversity and socio-environmental impacts associated with the implementation and operation of transmission lines;
- Delays in the execution of new projects, as indicated by sector studies (Aneel, 2019);

- The anticipation of an expansion in the current transmission network from 175,273 km to 208,907 km by 2031, entailing an investment of nearly R$ 126.4 billion (MME, 2022).

2 CASE STUDY

2.1 THE BRAZILIAN REGULATORY FRAMEWORK

In the current regulatory framework of the Brazilian energy sector, the implementation and operation of new Transmission Power Lines (TPLs) occur through public concession to private or public entities. Locational studies for the right-of-way are initiated during the project planning phase, with environmental licensing undertaken subsequently. Public institutions conduct the initial engineering planning studies to guide the bidding process, while environmental licensing commences after the bidding process with the first results provided by the concessionaires (Cardoso Júnior *et al.*, 2014). The National Electric Energy Agency (Aneel) oversees the TPL auction, which involves public bids for the concession of transmission lines. The concession establishes a contractual agreement between the awarded company and Aneel, focused on the construction and operation of the project for a specified period, considering an annual revenue stipulated in the contract.

In the planning stage, corridor alternatives are assessed in the first report (R1). The second report encompasses an internal process detailing the project's technical specifications. Subsequently, the third report (R3) provides a socio-environmental characterisation of the selected corridor and proposes a track guideline (EPE, 2005). Historically, R1 and R3 have faced criticism due to issues related to visibility and interdisciplinary interests, including external control. These documents furnish the auction with information regarding the potential location of the project.

Brazil's administrative procedure mandates that activities utilising environmental resources or contributing to environmental degradation undergo an authorisation process by a governmental environmental entity (Sanchéz, 2006). The development and analysis of locational alternative proposals for a new project occur in the initial stage when project proponents request the preliminary license. Federal or state environmental agencies can administer the licensing process as Brazilian law stipulates. The Environmental Impact Assessment (EIA) commences after the TPL auction. Typically, environmental licensing follows a three-phase model, issuing three licenses (Conama, 1997), as delineated in Table 1.

Table 1 | Phases of environmental licensing in Brazil

Environmental Licensing phase	*Description*
Preliminary License	Issued during the initial phase of the project or activity, the permit approves its location and design, verifies its environmental feasibility, and establishes the fundamental requirements and conditions to be fulfilled in the subsequent stages of implementation.
Installation License	Permits the installation of the project or activity under the specifications outlined in the approved plans, programs, and projects, encompassing environmental control measures and other stipulated conditions.
Operation License	The authorisation for the operation of the activity or project is subject to the verification of the actual fulfilment of the prerequisites stipulated in the preceding licenses and compliance with the specified environmental control measures and operational conditions.

Within the existing decision-making framework, locational studies are formulated during the planning stage and deliberated during the environmental licensing phase. This process engages diverse actors with distinct institutional roles, resulting in varying perspectives and interests in the project. The decision flow, spanning from design to operation, encourages the participation of a multitude of

public and private stakeholders who scrutinise technical studies and contribute to decision-making, as illustrated in Figure 1. The roles of the mentioned stakeholders in the decision-making process are delineated in Table 2.

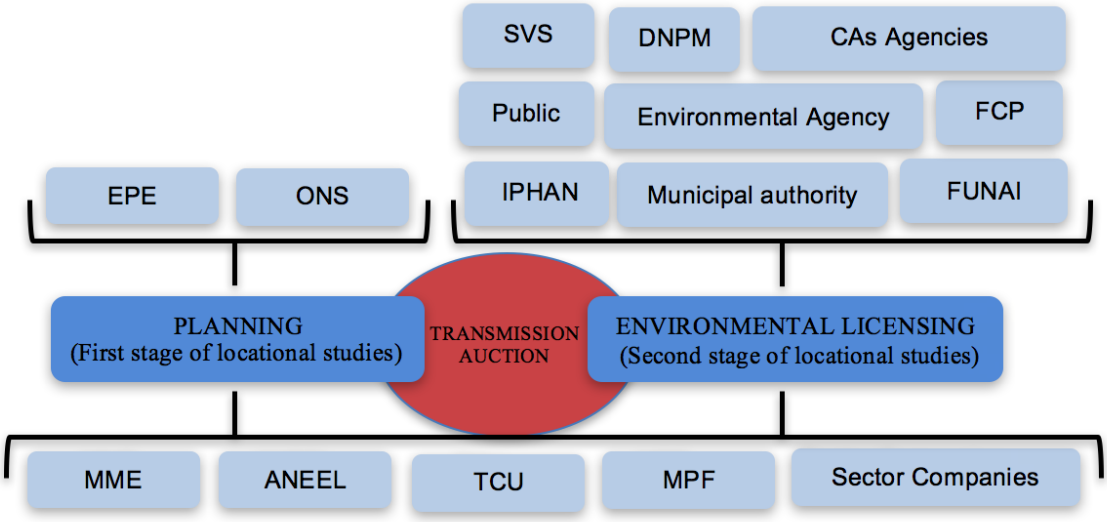

Figure 1 | Framework of stakeholders engaged in the planning and environmental permitting of Power Transmission Lines within the Brazilian regulatory framework.

Source: Adapted from Cardoso Júnior et al. (2014), Lima and Magrini (2010) and Silva (2009)

Table 2 | Entities engaged in the planning and licensing of transmission line projects within the Brazilian regulatory framework

Actors	*Attributions*
Ministry of Mines and Energy (MME)	A public entity responsible for the overall planning of energy generation, mining, and production of oil, gas, and biofuels.
National Electric Energy Agency (Aneel)	Aneel is linked to the MME and regulates and supervises electricity generation, transmission, distribution, and trading.
The Federal Court of Accounts (TCU)	Responsible for accounting, finances, budget, and property oversight of public bodies and entities of the country for their legality, legitimacy, and best value.
Federal Prosecution Service (MPF)	The MPF acts on federal matters regulated by the Constitution and federal laws whenever public interest is involved. The MPF is responsible for ensuring compliance with the laws, including international agreements. Furthermore, the MPF acts as a guardian of democracy, ensuring respect for principles and rules that guarantee popular participation.
Sector Companies	Private companies operating in the Brazilian energy sector
Energy Research Company (EPE)	Public Company linked to MME, responsible for the development of energy planning studies
National Electric System Operator (ONS)	Responsible for coordinating and controlling the operation of electricity generation and transmission facilities of the national power grid, called the National Interconnected System (SIN).
Environmental Agency (EA)	A public agency (federal, state or municipal) responsible for licensing projects with significant environmental impact and/or activities using environmental resources.
Municipal authority	Responsible for the management of public services in the municipality.
National Indian Foundation (Funai)	Responsible for overseeing actions and projects that can affect Indigenous peoples
Public	Citizens or groups of citizens impacted or interested in the project.

Actors	Attributions
National Institute of Historic and Artistic Heritage (Iphan)	Responsible for managing and preserving historic and cultural heritage
Palmares Cultural Foundation (FCP)	Responsible for preserving the heritage and socioeconomic viability of remnant communities of quilombos, remote communities formed by runaway slaves
Health Surveillance Secretariat (SVS)	An entity of the Ministry of Health responsible for minimising the incidence of communicable diseases, such as malaria and dengue fever
Conservation Areas (CAs) Agencies	Public agencies responsible for the management of environmental protected areas
National Department of Mineral Production (DNPM)	It aims to promote the planning and development of mineral exploitation

Source: Adapted from Cardoso Júnior et al. (2014).

2.2 TRANSMISSION POWER LINE CASE STUDY

We selected the Marimbondo II 500 kV project – Campinas and associated substations as a Brazilian case to apply the geographic modelling. The TPL was approximately 365 Km long (EPE, 2012) and aimed to provide electrical improvements to the southeast of the country through the connection of the UHE Belo Monte to the state of Minas Gerais (Ambientare Environmental Solutions and ATE XXII, 2014). Figure 2 illustrates the studied area, highlighting the electrical substations connected by the project, situated between the cities of Fronteira and Campinas.

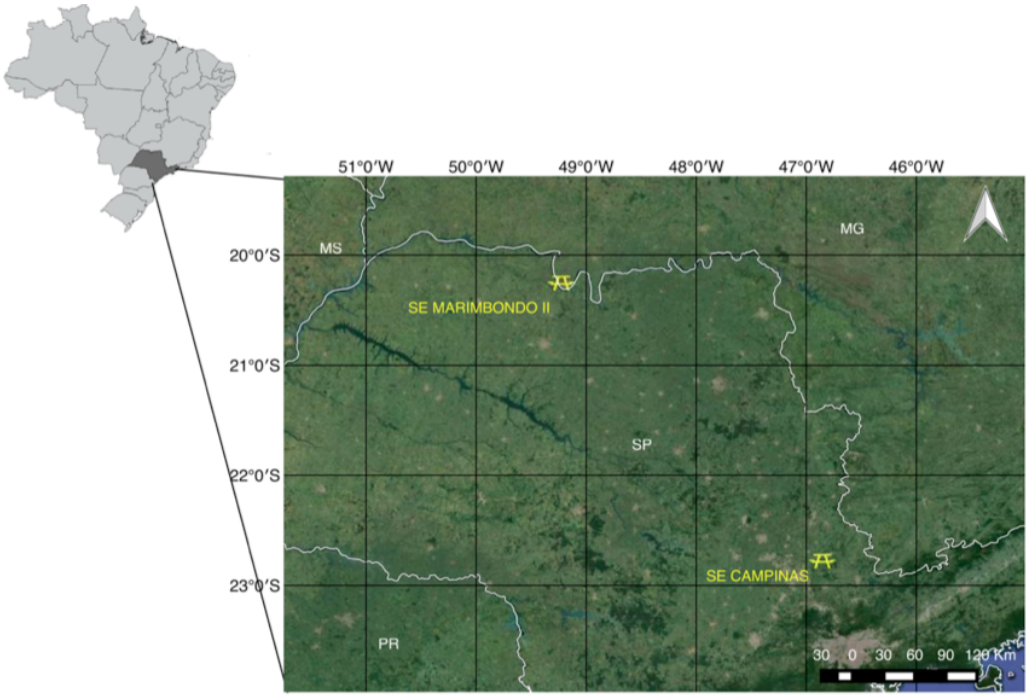

Figure 2 | Chosen study area for modelling: the 500 kV Marimbondo II – Campinas transmission line project and its related substations

Source: Autor's representation, background Google Earth ®.

This 500 kV project was proposed to provide electricity produced from the Belo Monte Dam hydroelectric power plant built in the north of the country, with an installed capacity of 11 GW, as part of the national plan to increase the electrical energy offer to Brazil's southeast region, which in turn demands projects of regional reinforcements in the power transmission (EPE, 2012). Marimbondo II is approximately 2,000 km away from Belo Monte Dam.

As presented in Figure 3, the depicted corridor spans approximately 20 km in width and 365 km in length, intersecting 32 municipalities and covering areas of savanna and semi-deciduous seasonal forest (EPE, 2012). It is worth mentioning that this project encountered challenges in its environmental licensing process, given its initial location overlapping with an area designated for airport expansion, an environmental legal reserve, and a zone earmarked for a free-flight project, tourism, and environmental conservation (Ibama, 2014).

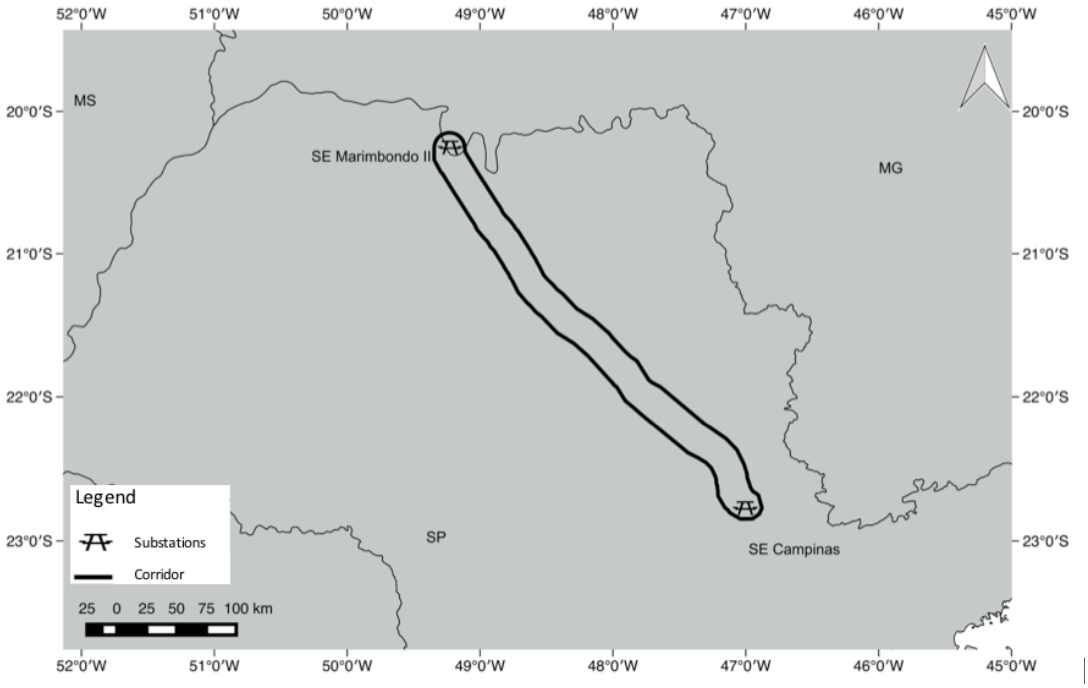

Figure 3 | The final corridor identified through the locational studies of the 500 kV Marimbondo II – Campinas transmission line project and its related substations planning..

Source: Autor's representation

3 METHODOLOGY

The model was developed according to the corridor approach advanced by Nóbrega *et al.* (2009), which integrates the Analytic Hierarchy Process (AHP) into the organisation of map algebra, thus enabling the determination of criterion weights. AHP is the most popular technique used in sustainable energy planning, especially for applications that aim to establish priorities and interaction with decision-makers (Araújo, 2016; Biassoto *et al.*, 2021; Ramachandran, 2004), therefore employed in the present work.

Thomas Saaty proposed AHP as a multicriteria approach founded on pairwise comparison for assigning weights to the criteria within a decision-making framework (Malczewski, 1999). The method assesses criterion pairs influencing the decision process and employs a hierarchical configuration to address problem-solving in formulating alternatives. In practice, the model is supported by three ranking levels, as illustrated in Figure 4. AHP is used as algebra preprocessor maps to formulate cost surfaces that will support the calculation of potentially lower cost alignments (Sadasivuni *et al.*, 2009).

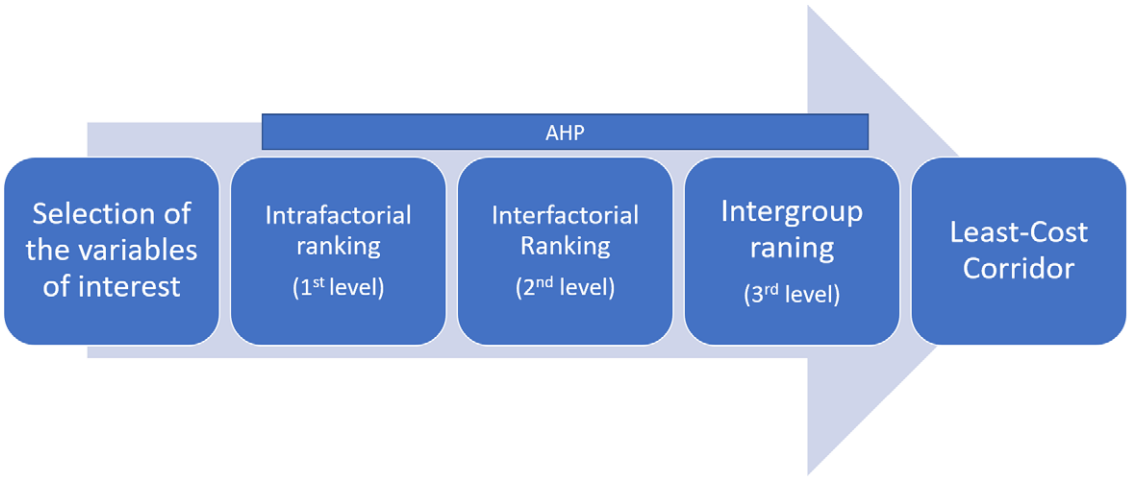

Figure 4 | The conceptual framework of the alternative corridor planning process is aimed at capturing the diverse values of the stakeholders and structuring the decision-making process into an analytical framework.

Source: Autor's representation.

Concerning the corridor approach, the conceptual model involves the computation of least-cost corridors based on spatial criteria facilitated by GIS techniques and multicriteria analysis (Sadasivuni *et al.*, 2009). The input data undergo thorough analysis, preprocessing, and organisation into spatial variables within the model. These variables are amalgamated with specific weighting roles to construct cumulative cost surfaces. Cost effort pertains to assessing each cell depicted in a map of weighting criteria, generating cost-surface maps (Van Leusen, 1998).

These maps, representing different variables of interest in a multicriteria analysis, are combined using map algebra to yield an accumulated cost surface. Cells with higher values indicate greater cost effort, implying a lesser preference for interception. Figure 5 illustrates the generation of a cumulative cost surface from individual cost surfaces derived from various information layers, each representing criteria considered in the decision process. Ultimately, the model employs a path algorithm from the final cost surface to determine lower-cost routes, yielding improved alternatives for connecting the specified points.

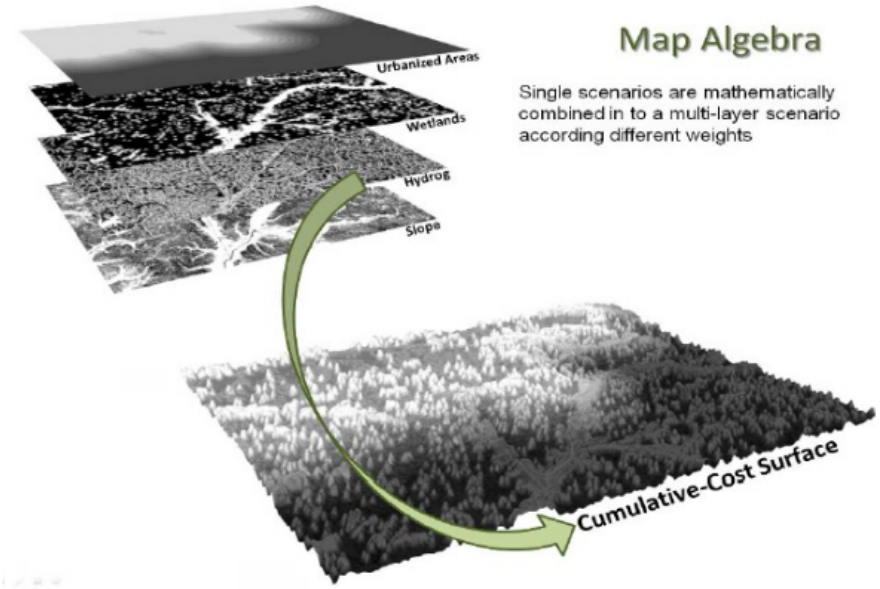

Figure 5 | Schematic aggregation of the cost surface through the integration of individual scenarios

Source: Sadasivuni et al. (2009).

Similar to the GIS least-cost path approach (Douglas, 1994), the corridor incorporates input variables and considerations to devise an optimised geographical solution for connecting origin and destination points. However, it is important to note that this approach does not impose a geometric design, which must be subject to local engineering analysis and decision-making (Nóbrega *et al.*, 2016). The geographical structure of the model, coupled with the multicriteria decision-making framework, allows for diverse solutions that can be tailored to different decision-making flows, including those related to Transmission Power Line (TPL) projects (Araújo *et al.*, 2021; Bagli *et al.*, 2011; Leon *et al.*, 2020).

The variables considered in the analysis were extracted from land cover, elevation, and vegetation, collectively called information layers (Nóbrega *et al.*, 2009). The process of selecting variables is inherently challenging, involving a literature review to identify variables influencing the study of transmission line alternatives, stakeholder interviews to determine pertinent variables for modelling and the availability of a suitable database at an appropriate scale for model execution. This study made efforts to incorporate as many variables as possible to assess the model's performance. The criteria followed established priorities, enabling a spatial analysis of combinations of factors and weights (Araújo, 2016). A total of 23 spatial variables that may impact TPL construction were selected, and Table 3 presents these variables along with their respective qualitative criteria.

Table 3 | Entities participating in the planning and licensing of transmission line projects within the Brazilian regulatory framework

	Variables	*Qualitative criteria*
Environmental variables	Protected Areas (PA)	Avoid interference in PA and their buffer zones
	Areas of permanent preservation (APP)	Avoid interference in APP
	Priority Areas for Biodiversity Conservation	Avoid interference in Priority Areas for Biodiversity Conservation
	Relevant areas for migratory bird	Avoid interference in Relevant areas for migratory bird
	Caves	Avoid interference in caves and their buffer zones
	Declivity	Avoid interference in a rugged/steep terrain area
	Parallelism with other linear projects	Proximity to other pre-existing linear projects
	Floodplain areas	Avoid interference in floodplain areas
	Native vegetation	Avoid Interference and fragmentation in areas with native vegetation
Social variables	Indigenous Lands	Avoid interference in Indigenous Lands
	Urban areas	Avoid interference in Urban areas
	Settlements	Avoid interference in settlements
	Quilombola territories	Avoid interference in quilombola (marrons) territories
	Areas of archaeological interest	Avoid interference in areas of archaeological interest
	Aerodromes	Avoid interference in aerodromes
	Visual impact	Minimise visual impact
	Areas of interest in mining	Avoid interference in areas of interest mining
	Areas of agriculture	Avoid interference in Areas of agriculture

	Variables	Qualitative criteria
Economic variables	Areas requiring the installation of freestanding towers or tower elevation	Avoid interference in areas that require the installation of freestanding towers or tower elevation
	Floodplain areas	Avoid interference in floodplain areas
	Declivity	Avoid interference in a rugged terrain area
	Parallelism with other linear projects	Proximity to other pre-existing linear projects
	Areas needing the removal of vegetation	Avoid interference in areas needing the removal of vegetation

Source: Adapted from Cardoso Júnior et al. (2014).

The first level of the model is the intra-factorial ranking. The 23 variables are divided into three thematic groups: environmental, social, and economic. Qualitative general criteria and sub-criteria were defined for each variable. In order to get the prioritisation of each sub-criterion in terms of cost effort to implement a TPL, the AHP was applied to each variable. Based on priorities resulting from the AHP, each variable was structured as factors (maps in raster format), where the values of each pixel represent the cost of effort. Each factor represents an individual cost surface referring to a variable and its respective criteria. Figure 6 illustrates the result of the intra-factorial ranking of one environmental variable -terrain slope- where the conceptual criteria establish that the higher the slope, the higher the cost of the effort to build a TPL.

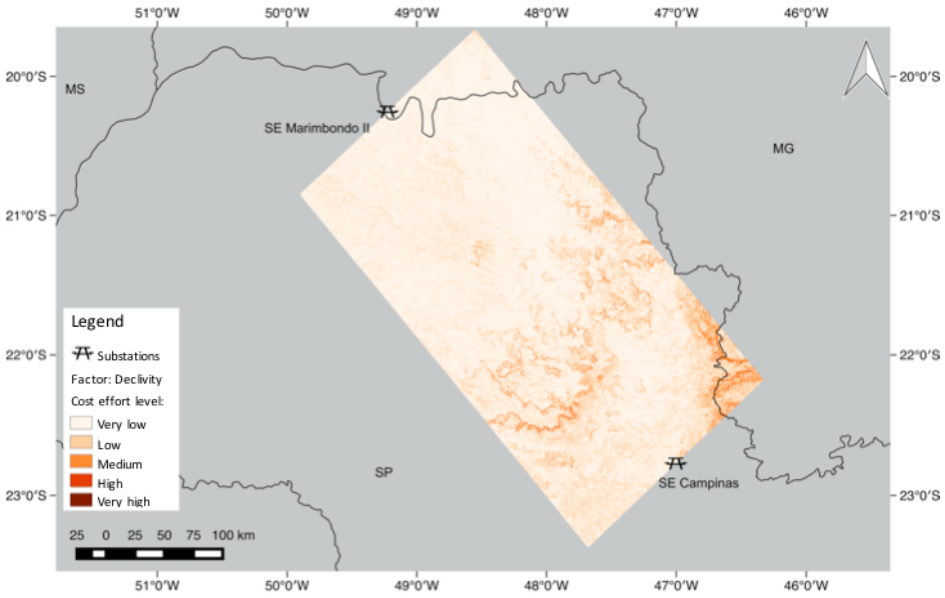

Figure 6 | Map derived from the intra-factorial ranking of the terrain slope factor

Source: Araújo (2016).

Drawing on the examination of the Brazilian decision-making flow outlined in section 2.1, the model's secondary and tertiary tier values are sourced from professionals affiliated with the organisations referenced in Figure 2. This strategic approach is designed to streamline the integration of a diverse array of stakeholders directly into the spatial decision-making process. The institutions actively involved in this process include the National Electric Energy Agency (Aneel), the Energy Research Company (EPE), the Federal Court of Accounts (TCU), and the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama).

At the second level, accumulated cost surfaces are computed for each group of factors by multiplying the maps with their corresponding weights. These weights are derived from implementing the Analytic Hierarchy Process (AHP), involving consultations with 14 experts employed by the organisations mentioned above. The AHP aims to determine inter-factorial priorities within each thematic group, once again regarding cost effort.

In a parallel fashion, the third ranking level calculates an overarching cost surface, with AHP applied to the accumulated cost surfaces generated in the previous step. Based on this comprehensive cost surface, the model computes and presents lower-cost alternative corridors between two points of interest.

The resolution demands establishing the degree of importance among the criteria. This relative importance is commonly expressed numerically, often called weights (Biassoto *et al.*, 2022; Chakhar; Mousseau, 2008). The Analytic Hierarchy Process (AHP) ranks criteria through peer comparison regarding their importance, adhering to the fundamental scale of comparison developed by Saaty (Saaty; Vargas, 2001). However, the decision-making process does not conclude merely after obtaining the AHP pairwise inputs from consultations with various groups of individuals, including experts, politicians, and affected communities. In practice, it is also imperative to integrate the results in a balanced way.

Forman and Peniwati (1998) delineate two methods for deriving the overall priority of elements in a group decision process: Aggregation of Individual Judgments (AIJ) and Aggregation of Individual Priority (AIP). AIJ is applicable when groups harmonise their judgments to function as a collective entity, while AIP is suitable when individuals in the group act independently with distinct value systems and no shared goals or objectives (Araújo, 2016). The fundamental distinction between the two approaches lies in the behaviour of the groups involved in the decision-making process. If the group can be treated as a unified individual due to synergy among its components, weights are calculated by AHP from a matrix where paired classifications represent the geometric mean of individual classifications. Conversely, if the group lacks common goals and objectives, weight calculation is determined by the geometric or arithmetic mean of weights obtained from each individual (Forman; Peniwati, 1998).

This study aims to showcase the model's effectiveness by integrating actors participating in the decision-making process of new projects and considering their knowledge profiles. Environmental and social factors are provided by EPE and Ibama specialists, economic factors are provided by Aneel and TCU specialists, and all specialists provide inputs for intergroup ranking. Weight consolidation incorporates both the AIJ and AIP methodologies. The AIJ technique computes weights among specialists within each group, considering collaborative teamwork. Subsequently, the AIP approach is applied to the results obtained since each institution holds its values, knowledge, and objectives regarding studying a preferred corridor. Figure 7 illustrates the sequential steps' structure with the application of map algebra and corridor calculation.

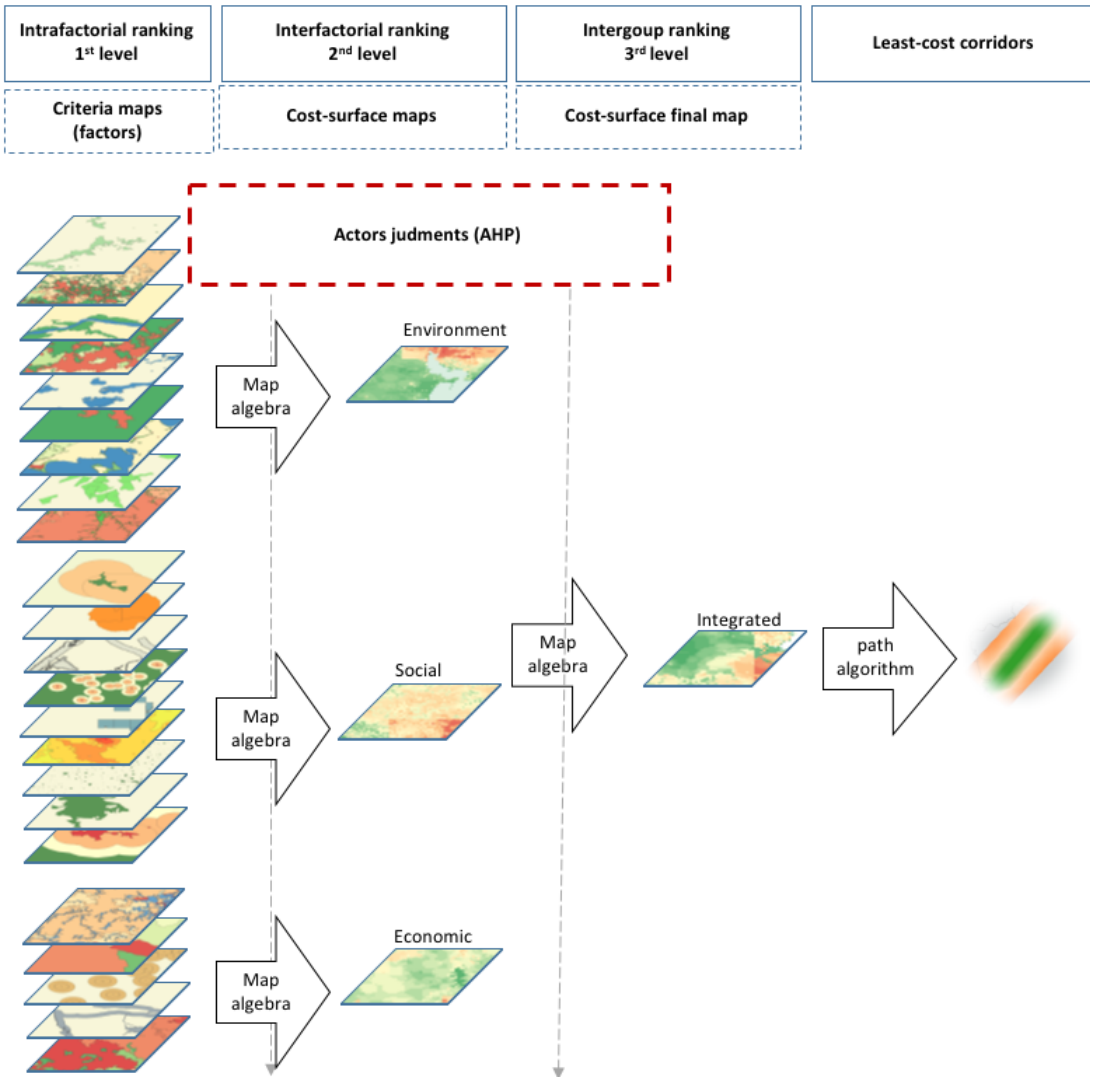

Figure 7 | Proposed multicriteria geographic intelligence aiming to integrate data, roles, and actors towards the sustainable planning of power transmission lines

Source: Araújo (2016).

4 RESULTS AND DISCUSSIONS

The application of AHP in problem structuring facilitates the integration of previously discussed variables, utilising its hierarchical structure centred on sustainability pillars. Actor weighting within the Brazilian regulatory model aligns with their respective stakes. Furthermore, the model's flexibility in accommodating diverse decision contexts allows for the inclusion of additional variables in the analysis. However, limitations arise from data accessibility and the selection of spatially influential factors. Configuring the model based on the diagnostic decision flow involves tailoring it with various actor levels and determining the dominant impact of the variable group. This adaptability is evident in the model's potential hierarchical expansion, reflecting the decision-making structure within its application context.

The detailed results in this section are sequentially and constructively organised. The context includes tables resulting from inputs provided by the consulted stakeholders and the ranking derived from the AHP process, followed by a series of illustrations depicting the progressive outcomes of the model compilation.

Since the research did not provide previous training for the developed classification (in fact, out of the 14 experts, only one had any experience working with AHP), results affirm the simplicity and ease of understanding of the paired classification method applied in the AHP (Wang *et al.*, 2009). Nevertheless, participants provided a consistent output in their classifications. The AHP calculates the Consistency Rate (CR) from a matrix algebra based on pairwise comparisons. It signifies the consistency of weights given by experts. Consistency is established if TC < 0.100; otherwise, the proportion is inconsistent and requires further development until it reaches consistent levels. Table 4 presents the CR values from the expert's inputs (participants), demonstrating the judgments' consistency.

Table 4 | Rates of consistency derived from experts' classifications using AHP

	Classification			
Consistency Ratio (Experts)	Interfactorial Ranking: Environmental criteria	Interfactorial Ranking: Social criteria	Interfactorial Ranking: Economic criteria	Intergroup ranking
E1	0.089	0.073	0.098	0.057
E2	0.075	0.088	0.098	0.000
E3	0.095	0.099	0.078	0.025
E4	0.035	0.019	0.029	0.000
E5	0.098	0.094	0.054	0.033
E6	0.004	0.095	0.099	0.000
E7	0.069	0.067	0.041	0.057
E8	0.017	0.048	0.079	0.000
E9	0.071	0.047	0.009	0.033
E10	0.061	0.066	0.071	0.056
E11	0.036	0.019	0.000	0.000
E12	0.029	0.053	0.073	0.025
E13	0.051	0.063	0.095	0.056
E14	0.037	0.076	0.091	0.000

Source: Author's calculation.

After completing the aggregation of judgments and priorities, as detailed in section 3, numerical values supporting the modelling are obtained. The intergroup sensitivity analysis reveals a balance among groups of factors in the model, with a slightly greater influence of the economic factor. The aggregation of values, guided by AIJ and AIP, operates with geometric means, enhancing the coherence of experts' judgments. In this approach, consulting the same number of experts from different stakeholders is not mandatory, as the JIA and AIP approach calculates and applies an average of the values. Figures 8, 9, 10, and 11 illustrate the resulting sensitivity analyses.

Commenting on the cross-applicability of the values discovered in this sensitivity analysis proves challenging. Since the cross-applicability relies on consultations with experts from institutions with a vested interest in the decision-making and is specifically tailored to the project under examination, varying results might arise with the participation of different experts or other stakeholders, particularly when applied to a different project. In essence, this methodology phase necessitates development for each distinct modelling, at least until applied research on the variables of interest and their relative importance in formulating locational alternatives for TLP is undertaken.

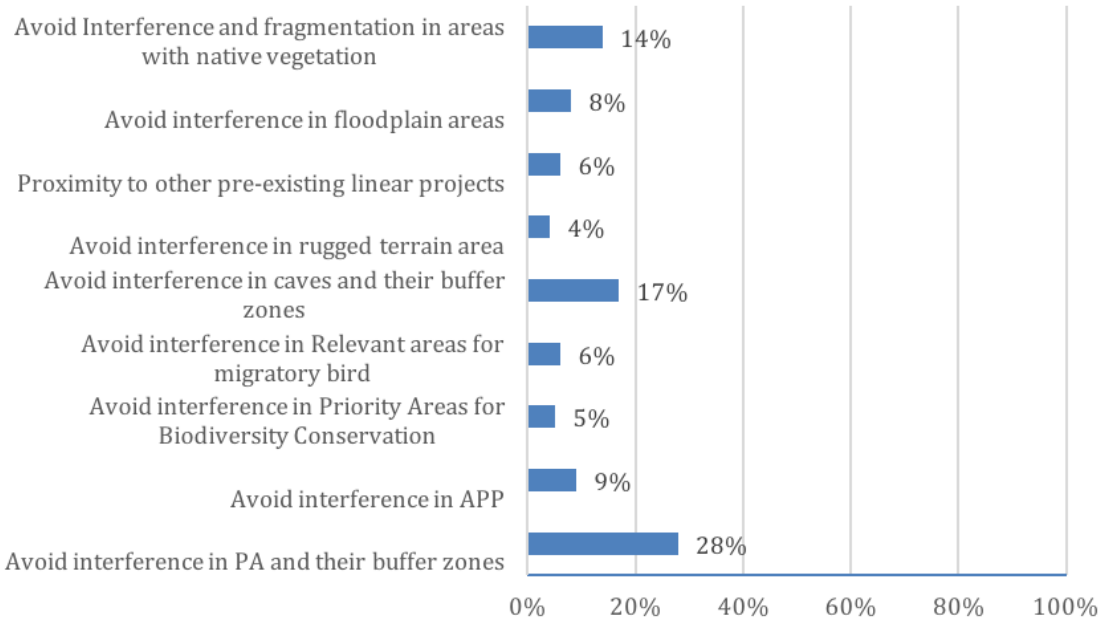

Figure 8 | Sensitivity analysis of the inter-factorial rank of the group of environmental factors

Source: Araújo (2016).

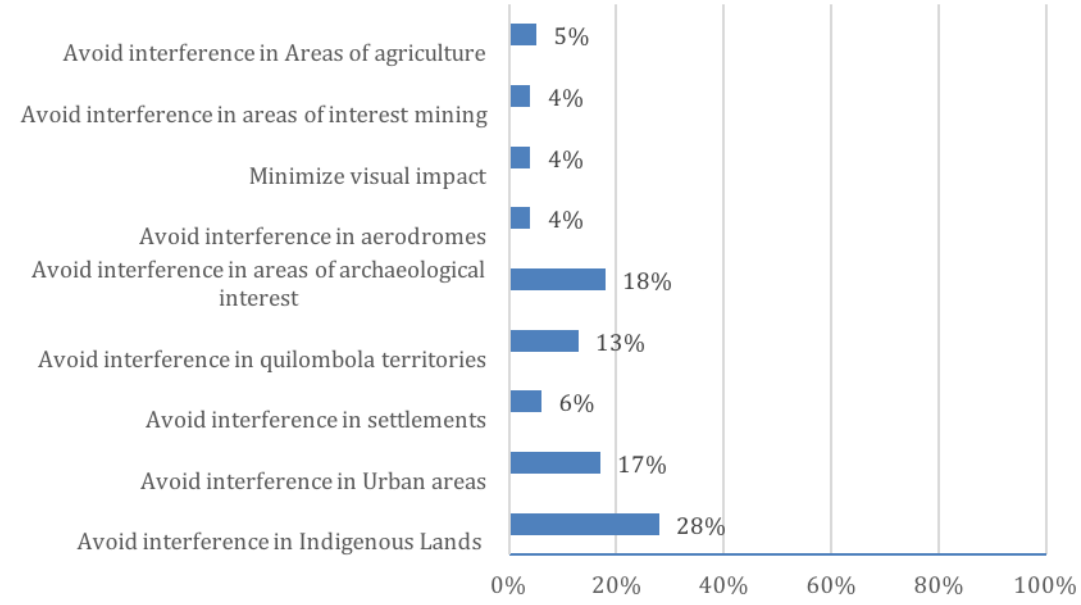

Figure 9 | Sensitivity analysis of the inter-factorial rank of the social factors group

Source: Araújo (2016).

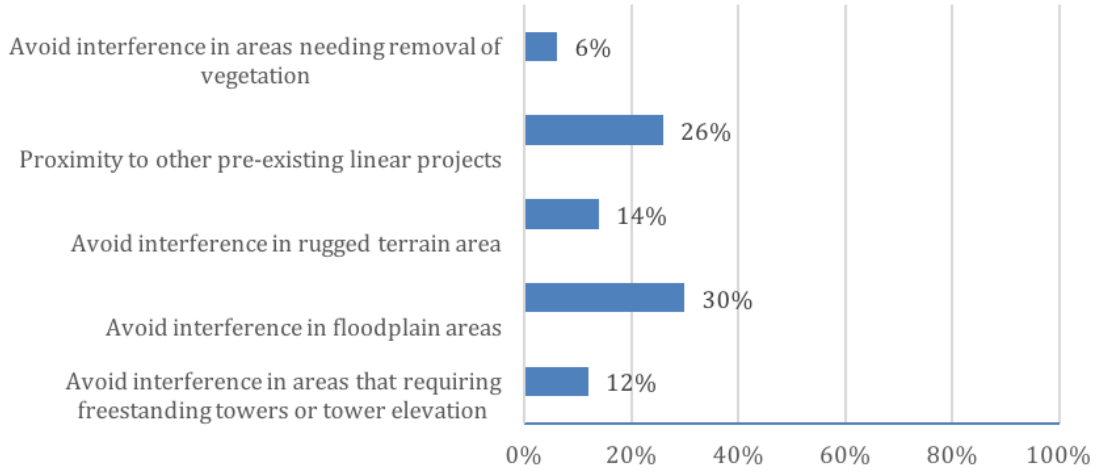

Figure 10 | Sensitivity analysis of the inter-factorial rank of the group of economic factors

Source: Araújo (2016).

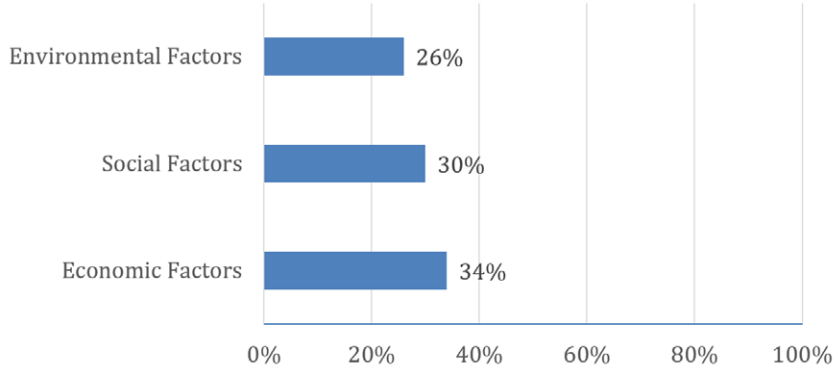

Figure 11 | Combined sensitivity analysis of intergroup ranking

Source: Araújo (2016).

Figure 12 presents the map of corridor alternatives derived from the modelling, incorporating the selected variables and the expert classifications. The alternatives are represented on an effort cost gradient, with the least cost of effort (preferred) shown in green, while other colours denote varying preference levels. The black line represents the corridor resulting from the planning studies, serving as a reference for the auction stage and environmental licensing. The model highlights a preferred alternative for decision-makers and presents other viable choices as the project progresses through its phases. Researching alternative corridors aims to support the project's planning and development. As the project progresses to executive phases and the definition of spatial data scale, including field trips and social participation, additional elements may surface, influencing decision-making. Given that a TLP occupies an area between 30 and 100 meters wide, depending on electric voltage, alternatives with slight differences in total length become crucial for final decision-making. The results also guide the project's engineering toward a more sustainable alternative, incorporating inputs from stakeholders earlier in the regulatory process than they would typically be involved.

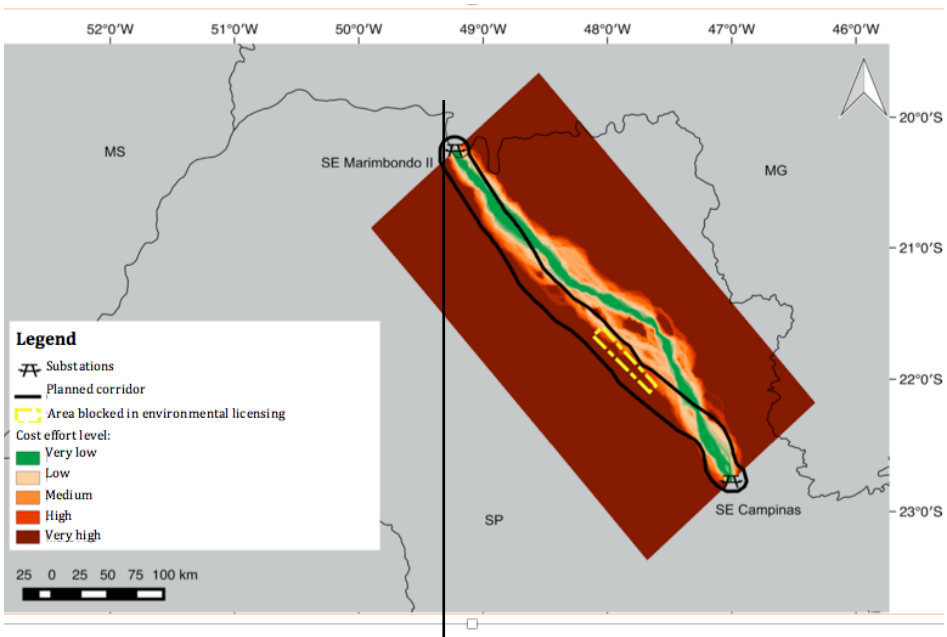

Figure 12 | Outcome derived from the feasibility corridor modelling for the transmission power line

Source: Araújo (2016).

The model operates without a predetermined number of alternatives or a fixed corridor width. Adapted to the spatial features of the studied region and criteria classifications, the model explores various alternatives with distinct levels of effort cost. For instance, the study's outcomes reveal a notable divergence in alternatives near the midpoint due to the presence of a protected area in the region. Figure 13 displays the individual cost surface map for the environmental protection areas, highlighting the region influencing the noted divergence. According to the modelling, this characteristic better captures the intricacies of the modelled real-world scenario, enhancing decision-making by enabling a focused allocation of efforts in areas previously identified as more viable.

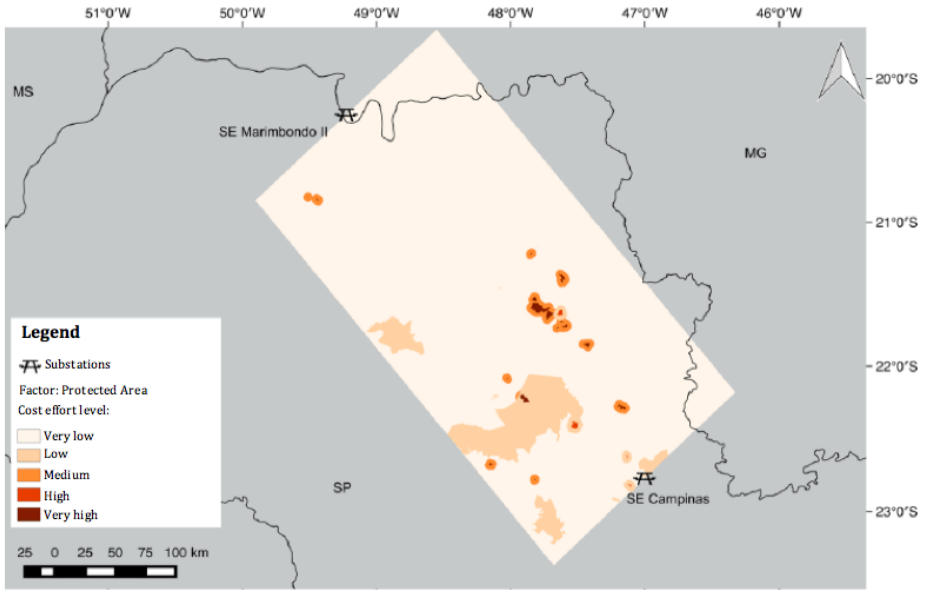

Figure 13 | Map resulting from the intra-factorial ranking of the factor associated with protected areas

Source: Araújo (2016).

Comparison with the corridor outlined during the planning phase reveals that the modelled corridor avoids interference with the problematic yellow segment, which has posed challenges in securing environmental licensing for the project. Notably, the results exhibit trends contrary to the official corridor, especially in the vicinity of SE Campinas, where it refrains from intersecting the yellow region. An examination of the individual cost maps for the variables considered in the modelling indicates that this divergence is attributed to the criterion of non-interference in urban areas, precisely addressing the concerns related to the yellow region. The environmental agency's technical team responsible for licensing the project attributes the obstruction to the potential impact on the planned free flight, tourism, and environmental conservation project in the Municipality of Taguaritingal (Ibama, 2014).

This outcome underscores the potential for identifying and addressing future issues during the designation of a right of way for TPL. Notably, this concern only surfaced during the environmental licensing phase of the power line, after planning studies and the auction. Figure 14 provides a visual representation of this analysis, depicting the overlap between the corridor studied during the planning stage, the contested segment in environmental licensing, and an individual cost surface for urban areas. While enhancing the TLP planning process is imperative, it is important to acknowledge that limitations constrain the approach and heavily depend on the availability of up-to-date and official geographic data.

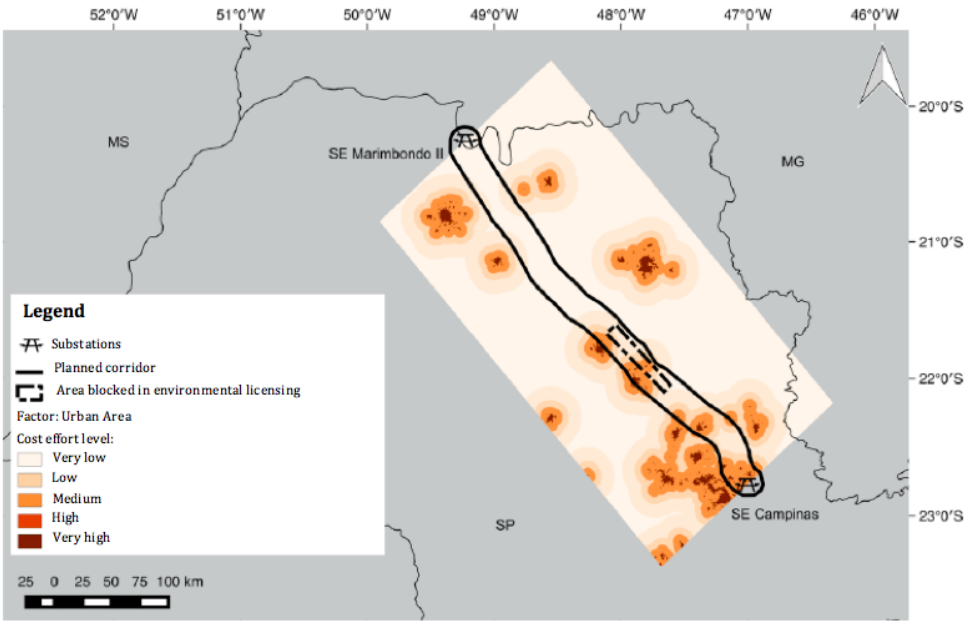

Figure 14 | Overlaying the corridor studied in the planning stage, the contested segment in the environmental licensing, and the distinct cost surface related to urban areas

Source: Araújo (2016).

Finally, the examination of the generated alternatives illustrates the model's capacity to (i) delineate lower-cost alternatives for connecting the origin and destination points, (ii) circumvent expansive areas categorised as medium and high effort cost, situated near the line connecting the two analysed points; and (iii) steer clear of regions with overlapping spatial factors, contributing to increased effort costs, such as areas where native vegetation and slope criteria intersect.

5 CONCLUSIONS AND POLICY IMPLICATIONS

In conclusion, the research sheds light on opportunities to enhance the evaluation of environmental concerns in planning new transmission power lines (TPL) in Brazil. The current regulatory model, primarily focused on technical and economic factors, demonstrates limitations in addressing social and environmental considerations comprehensively. The environmental licensing stage, the primary interface with society, occurs after crucial decisions have been made, hindering meaningful stakeholder participation.

The proposed multicriterial spatial modelling approach aims to overcome these limitations by providing a holistic corridor design early in the TPL planning. The model, developed through collaboration with stakeholders from various organisations, showcases its ability to integrate diverse perspectives and anticipate social and environmental demands throughout the decision-making process. Its strength lies in simplifying complex decision flows in energy policy structures while offering transparent and comprehensive results.

The model's presentation of alternative gradient maps, rather than a fixed corridor, enhances information dissemination and knowledge levelling among stakeholders, contributing to more informed decision-making. Despite the model's subjectivity, it is a valuable tool for informing top-down decisions about project viability. Recognising its limitations, such as reliance on spatialisable variables, the model holds significant potential to qualify decision-making processes in complex energy policy scenarios involving new TPL projects.

The model could modernise the TPL planning process by optimising the initial corridor to a few hundred meters during the engineering construction phase. Moreover, there is potential for future research to explore public participation, further democratising the decision-making process in energy infrastructure projects.

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REFERENCES

AMBIENTARE ENVIRONMENTAL SOLUTIONS, ATE XXII. **Simplified Environmental** Report: 500 kV Marimbondo II LT – Campinas and Associated Substations, 2014.

ARAÚJO, F. R. N. **Coordenação de dados, valores e participação de atores na tomada de decisão em estudos de alternativas locacionais de linhas de transmissão**: uma proposta utilizando modelagem espacial e análise multicriterial. (Dissertação de Mestrado) – Universidade Federal de Minas Gerais. 2016 p. 2016. Available at: https://repositorio.ufmg.br/handle/1843/IGCM-A9ZHNC.

ARAÚJO, F. R. N.; AJUZ, R. C. de A.; RAMOS, A, B. Metodologia de análise espacial de sistemas de transmissão de energia no licenciamento ambiental federal. In: VILELA, M. A. **Geoprocessamento no setor elétrico – aplicações práticas.** Editora Del Rey, 2021.

BAGLI, S.; GENELITTI, D.; ORSI, F. Routing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts. **Environmental Impact Assessment Review**, v. 31, n. 3, p. 234-239. DOI: https://doi.org/10.1016/j.eiar.2010.10.003

BIASOTTO, L. D. *et al.* Routing power lines: towards an environmental and engineering friendly framework for avoiding impacts and conflicts in the planning phase. **Environmental Impact Assessment Review**, v. 95, p. 106797-106808, 2022. DOI: https://doi.org/10.1016/j.eiar.2022.106797

BRAZILIAN INSTITUTE OF ENVIRONMENT AND RENEWABLE NATURAL RESOURCES. Technical Report n. 02015.000113/2014-15 NLA/MG/IBAMA, Belo Horizonte, 2014.

BRAZILIAN NATIONAL COUNCIL OF THE ENVIRONMENT. **Resolution no 237 of December 29, 1997**. 1997 Available at: http://www.mma.gov.br/port/conama/res/res97/res23797.html.

CARDOSO JÚNIOR, R. A. F.; MAGRINI, A.; DA HORA, A. F. Environmental licensing process of power transmission in Brazil update analysis: case study of the Madeira transmission system. **Energy Policy**, v. 67, p. 281–289. 2014. DOI: https://doi.org/10.1016/j.enpol.2013.12.040

CARDOSO JÚNIOR, R. A. F.; HOFFMANN, A. S. Environmental licensing for transmission systems and electricity sector planning in Brazil. **Energy Policy**, v. 132, p. 1155-1162. 2019. DOI: https://doi.org/10.1016/j.enpol.2019.06.018

CHAKHAR, S.; MOUSSEAU, V. Spatial Multicriteria Decision Making. **Control**, v. 20, n. 11, p. 1392. 2008.

CHURCH, R. L.; LOBAN, S. R.; LOMBARD, K. An interface for exploring spatial alternatives for a corridor location problem. **Computers and Geosciences**, v. 18, n. 8, p. 1095 –1105. 1992. DOI: https://doi.org/10.1016/0098-3004(92)90023-K

COSTA, W. L. S. Modelagem geográfica como recurso para transversalidade do planejamento de transportes. (Tese de Doutorado) – Universidade Federal de Minas Gerais, 241 p. 2023. Available at: https://repositorio.ufmg.br/handle/1843/53344

DOUGLAS, D. H. Least-cost path in GIS using an accumulated cost surface and slopelines. **Cartographica**, v. 18, n. 3, p. 37-51. 1994. Available at: https://www.utpjournals.press/doi/abs/10.3138/D327-0323-2JUT-016M DOI: 10.3138/D327-0323-2JUT-016M

EMPRESA DE PESQUISA ENERGÉTICA. **Diretrizes para elaboração dos relatórios técnicos referentes às novas instalações da rede básica**, Brasília. 2005. Available at: http://www.epe.gov.br/Transmissao/Paginas/Diretrizespara.aspx?CategoriaID=

EMPRESA DE PESQUISA ENERGÉTICA. **Estudos para licitação da expansão da transmissão**. Detalhamento da alternativa recomendada: relatório R1 – Expansão da interligação entre as regiões Norte-Sudeste e Norte-Nordeste, Brasília. 2012.

FORMAN, E.; PENIWATI, K. Aggregating individual judgments and priorities with the analytic hierarchy process. **European journal of operational research**, v. 1, n.1, p. 165-169. 1998. DOI: https://doi.org/10.1016/S0377-2217(97)00244-0

GREENING, L. A.; BERNOW, S. Design of coordinated energy and environmental policies: use of multicriteria decision-making. **Energy Policy**, v. 32, n. 6, p. 721–735. 2004. DOI: https://doi.org/10.1016/j.enpol.2003.08.017

JANKOWSKI, P. Integrating geographical information systems and multiple criteria decision-making methods. **International Journal of Geographical Information Science**, v. 9, n. 3, p. 251–273. 1995. DOI: https://doi.org/10.1080/02693799508902036

KUMAR, A. *et al.* A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. **Renewable and Sustainable Energy Reviews**, v. 69, p. 596-609, 2017. DOI: https://doi.org/10.1016/j.rser.2016.11.191

LEON, M. B.; COSTA, W. L. S.; NÓBREGA, R. A. A. Una perspectiva ambiental en el planeamiento de la Ferrovía Bioceánica: modelamiento cuantitativo de escenarios. **Revista Ibero-americana de Ciências Ambientais,** v. 11, p. 444-468, 2020. DOI: 10.6008/CBPC2179-6858.2020.003.0035

LEUSEN, M. V. **Viewshed and Cost Surface Analysis Using GIS**. Cartographic Modelling in a Cell-Based GIS. Proceedings of the 26th Conference, Barcelona, March 1998 (BAR International Series 757). Archaeopress, Oxford, p. 215-224.

LIMA, L. H.; MAGRINI, A. The Brazilian Audit Tribunal's role in improving the federal environmental licensing process. **Environmental Impact Assessment Review**, v. 30, n. 2, p. 108–115. 2010. DOI: https://doi.org/10.1016/j.eiar.2009.08.005

MALCZEWSKI, J. **GIS and multicriteria decision analysis**. John Wiley & Sons, New Jersey. 1999.

MANSO, L. A. F. *et al.* **Planejamento de Redes Elétricas considerando a Integração de Fontes Renováveis**. Simpósio de Especialistas em Planejamento da Operação Elétrica, 12. 2012.

MINISTRY OF MINES AND ENERGY. Energy Research Office (EPE). **Decennial energy expansion plan 2031**, Brasília. 2022. Available at: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2031.

NATIONAL ELECTRIC ENERGY AGENCY (Brazil). Jun 2019 *In*: **Differentiated Monitoring of the Expansion of Transmission.** National Electric Energy Agency. Aneel, Brasília. 2019.

NÓBREGA, R. A. A. *et al.* Inteligência geográfica para avaliação de propostas de projeto de concessão de corredores ferroviários. **Transportes**, v. 24, p. 75-84, 2016. DOI: https://doi.org/10.14295/transportes.v24i4.1077

NÓBREGA, R. A. A. *et al.* Bridging decision-making process and environmental needs in corridor planning. **Management of Environmental Quality**, v. 20, n. 6, p. 622–637. 2009. DOI: https://doi.org/10.1108/14777830910990744

POHEKAR, S. D.; RAMACHANDRAN, M. Application of multicriteria decision making to sustainable energy planning – A review. **Renewable and Sustainable Energy Reviews**, v. 8, n. 4, p. 365–381. 2004. DOI: https://doi.org/10.1016/j.rser.2003.12.007

RUDNICK, H. *et al.* Transmission expansion in fast-growing economies and the challenges of renewables integration. **IEEE Power and Energy Society General Meeting**, p. 1–8. 2012.

SAATY, T. L.; VARGAS, L. G. **Models, methods, concepts & applications of the analytic hierarchy process**. Springer Science & Business Media. 2001.

SADASIVUNI, R. *et al.* **A Transportation corridor case study for multicriteria background** – analytical hierarchy process. American Society for Photogrammetry and Remote Sensing. 2009. Available at: http://www.asprs.org/a/publications/proceedings/baltimore09/0082.pdf.

SALIM, D. H. C. *et al.* Unveiling Fernando de Noronha Island's photovoltaic potential with unmanned aerial survey and irradiation modeling. **Applied Energy**, v. 337, p. 120857-11, 2023. DOI: https://doi.org/10.1016/j.apenergy.2023.120857

SANCHÉZ, L. **Avaliação de Impacto Ambiental**: conceitos e métodos. Editora Oficina de Textos, São Paulo. 2006.

SILVA, A. L. T. **Transmission Lines and Substations Auctions for the Expansion of the National Interconnected System in Brazil**. School of Business and Public Management Institute of Brazilian Business and Public Management Issues – IBI nt. 29p. 2009. Available at: https://www2.gwu.edu/~ibi/minerva/Spring2009/Andre.pdf.

SILVA, R. C.; MARCHI NETO, I.; SEIFERT, S. S. Electricity supply security and the future role of renewable energy sources in Brazil. **Renewable and Sustainable Energy Reviews**, v. 59, p. 328-341, 2016. DOI: https://doi.org/10.1016/j.rser.2016.01.001

STICH, B. *et al.* Using multicriteria decision making to highlight stakeholders' values in the corridor planning process. **Journal of Transport and Land Use**, v. 4, p. 105-118, 2011. DOI: https://doi.org/10.5198/jtlu.v4i3.171

WANG, J. J. *et al.* Review on multicriteria decision analysis aid in sustainable energy decision-making. **Renewable and Sustainable Energy Reviews**, v. 13, n. 9, p. 2263–2278. 2009. DOI: https://doi.org/10.1016/j.rser.2009.06.021

Limits of sustainability in electric cars, qualification of goods based on symbolic values

Limites da sustentabilidade dos automóveis elétricos, qualificação de bens a partir de valores simbólicos

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ABSTRACT

The value of a good is not something fixed and objectively given but results from social valuation processes in which value is constructed. This process is fundamental for the functioning of markets, as they depend, among other things, on the ability of social actors to evaluate the qualities of goods and compare them in terms of value. In this way, the valuation process considers different criteria that often compete. The significant growth in the sale of electric cars in Brazil points to the formation of a market niche, with consumers willing to invest in new propulsion technologies, which, in theory, are more sustainable than conventional cars. From this context, the research seeks to investigate, through interviews with owners, the role of symbolic values in qualifying "sustainable" goods, such as electric cars. Data analysis points to the mobilisation of functional and symbolic values, although imaginatively appropriate, as fundamental criteria for the acquisition of cars.

Keywords: Market. Valuation. Electric Car. Sustainability.

RESUMO

Sabe-se que o valor de um bem não é algo fixo e objetivamente dado, mas resulta de processos de valoração social nos quais o valor é construído. Esse processo é fundamental para o funcionamento de mercados, pois estes dependem, entre outras coisas, da capacidade de os atores sociais avaliarem as qualidades de um bem, em relação umas às outras, e compará-las em termos de valor. Dessa forma, o processo de valoração leva em consideração diferentes critérios que muitas vezes concorrem entre si. O expressivo crescimento na venda de automóveis elétricos, no Brasil, aponta para a formação de um nicho de mercado, com consumidores dispostos a investir em novas tecnologias de propulsão, em tese, mais sustentáveis que os automóveis convencionais. A partir desse contexto, a pesquisa busca investigar, por meio de entrevistas com proprietários, o papel de valores simbólicos no processo de qualificação de bens "sustentáveis", como o automóvel elétrico. A análise dos dados aponta a mobilização de valores funcionais e simbólicos, ainda que imaginativamente apropriados, como critérios fundamentais para a aquisição dos automóveis.

Palavras-chave: Mercado. Valoração. Automóvel elétrico. Sustentabilidade.

1 INTRODUCTION

According to data from the International Energy Agency (IEA), the market share corresponding to the global sale of electric cars surpassed the mark of 10 million units (13%) in 2022, which represents a record and is considerable growth when compared with previous years (IEA, 2022). It is no coincidence that the resurgence of this form of motorisation occurs amid a series of social, political and economic issues that have put pressure on the automotive market and its modus operandi.

Despite being relatively distant from leading countries in electrification, Brazil has seen significant growth in the sale of electrified vehicles[1] in recent years. According to data from the Brazilian Electric Vehicle Association (ABVE), around 2.5% of cars sold in 2022 (49,245 units), including plug-in and conventional hybrids, were electrified. This represents 41% growth in comparison to 2021 (34,990) and 149% to 2020 (19,745) and becomes even more relevant when compared to the performance of the automobile and light commercial market as a whole (-0.85%) during the same year (Fenabrave, 2023).

This significant evolution of the electrified vehicle fleet indicates sustained growth in the sale of electrified cars in Brazil and the formation of a market niche, with consumers willing to invest in new vehicle propulsion technologies, which are theoretically more sustainable than conventional cars. Changes of this scale and nature have been framed within the sociotechnical transitions towards sustainability (Geels, 2019; Köhler *et al.*, 2019), since this change would involve radical transformations towards new types of sociotechnical systems. However, little is known about the motivations and criteria (economic, environmental) that have led consumers to make this choice. Therefore, it would be appropriate to investigate which factors influence the decision-making processes for purchasing these automobiles in Brazil and their consequences for a possible transition.

This type of questioning places us in an important debate about the role played by social relations, classification devices, rules and cultural meaning in market construction and functionality (Carneiro, 2017). More precisely, it places us within the debate on how values and forms of evaluation are constructed and given new meanings in market exchanges beyond price mechanisms. These exchanges would be mediated by judgment devices (Karpik, 2010) and permeated by more or less conscious efforts to categorise, standardise and naturalise socially constructed behaviours and rules (Fourcade; Healey, 2007).

Therefore, this research sought to investigate the experience of these owners with electrified cars and the values mobilised for their acquisition in the national context, as well as their relationship with climate-environmental aspects or other as of-yet unmapped reasons. The paper is part of a theoretical framework that explores evaluation criteria and reveals the devices, institutions, or social and cultural structures that support and activate them (Lamont, 2013). On that account, we seek to analyse the values mobilised to acquire electrified cars within the national context. And what is the role of instruments and symbolic values in the process of qualifying certain goods, such as the electric car, as being "sustainable" in this context?

The paper seeks to understand which factors influence the decision-making processes for purchasing electric cars and the role played by symbolic values in the valuation process by (1) identifying the meanings and values mobilised by electric car owners and (2) analysing the decision-making processes and criteria used to qualify their choices.

Considering this theoretical framework, and with the Brazilian electrified car market as the unit of analysis, semi-structured interviews were carried out with owners of electrified cars between November 2021 and June 2022. Interviewees were selected from intentional sampling (Flick, 2009) based on the ownership and type of vehicle propulsion. From this sample, eight owners of electrified cars with different types of propulsion, four battery electric vehicles (BEV) and four hybrids (PHEV+HEV), were interviewed.

The interviews were organised and categorised through content analysis, which made it possible to identify the meanings and values mobilised by consumers; the decision-making processes, and the criteria used to qualify their choices.

The proposed approach has great theoretical relevance for researchers of valuation and evaluation processes in markets that are permeated by environmental issues and values, such as with electrified automobiles. The topic is also important for those interested in the direction of the national automotive market and mobility in large urban centres. After all, this change potentially engenders a series of transformations in the means for transport and recharging. Furthermore, in social, economic and geopolitical terms, this is a significant issue for a country like Brazil, a climate powerhouse regarding renewable sources with a consolidated automotive industrial park, but without great relevance in the electric vehicle market, until now.

In addition to this introductory section, the article is organised into four more sections. The following section will present the mobilised theoretical framework and contextualise the market based on secondary data. After that, the following section will present the interlocutors and methodological procedures. This will be followed by an analysis of the meanings and values attributed by owners of electrified cars. Finally, concluding remarks will be made, pointing out some reflections on the process of valuing electric cars and the limits of symbolic values.

2 MARKET AND VALUATION

Markets are spaces of institutionalised social relations where a certain good or service is distributed through a commercial exchange. In turn, these relationships of social exchange presuppose the existence of prior agreements on the value of a good or service and the establishment of a process capable of transfiguring that good or service into something marketable.

According to Lamont (2013), these processes involve: intersubjective agreements on a matrix or set of references by which a "good" is compared; negotiations and conflicts over appropriate judging criteria and legitimate judges; and the establishment of value in a relational process (or by indexes) involving distinguishable and comparable "goods." In the case of markets, these elements are considered central to understanding both the processes of constituting goods and services into commodities and the mechanisms for producing the value of a good or service.

Brazil has the world's 7th largest domestic vehicle market (Anfavea, 2023). Since its origins, the sector has been a strategic area for the country's economic development and social modernisation projects. However, as mentioned above, the worsening of issues related to polluting emissions, public health, congestion in large cities and impacts on the environment, added to the recent international economic and health crises, have created major challenges for the automotive industry and driven important changes in the sector.

In response to these new regulatory requirements, social expectations and new competitors in the market, many automakers have invested in developing and offering electric models. In Brazil, as mentioned above, this can be seen in the significant growth in sales of electrified cars in recent years. This growth contrasts with the downward trend in new car sales in recent years, attributed by Fenabrave to the Covid-19 health crisis and the crisis in the supply of semiconductors for vehicle assembly.

According to data compiled by ABVE, the fleet of electrified cars in circulation in Brazil is 126,504 cars and light commercial vehicles (2012-2022). However, a detailed fleet analysis reveals some important characteristics of these vehicles. These include the predominance of conventional hybrid vehicles, with emphasis on Toyota as the leading manufacturer, responsible for around 60% of the electrified fleet in Brazil; the absence of models belonging to smaller categories (compact and sub-compact); and the

massive presence of several sport utility vehicles (SUV) and extra-large vehicles (Wolffenbuttel, 2021). This points to an increased value being given to larger and hybrid cars.

Another interesting aspect is the average price of cars and the significant number of premium manufacturers in the fleet. This reveals financially restricted access to electrified vehicles. In part, this is due to the production costs of electric cars, which are 10-30% higher than internal combustion cars (Bloomberg, 2021), but also to the national tax structure that tends to favour the import of electrified vehicles[2]. The reduction in import tax allows the additional price of the electric propulsion system to be absorbed in premium automobiles without a significant increase in the price for the final consumer since the propulsion system represents a smaller portion of the total cost compared to conventional automobiles. In other words, already expensive cars remain expensive, but now with greater energy efficiency and lower polluting emissions.

On the other hand, these data demonstrate that the strategy of national production of conventional flex fuel hybrid automobiles has proven successful. This strategy allows for a relatively lower production cost, as in these models, the batteries are less expensive, as they are only used to store the energy the regenerative braking system recovers. In addition, flex hybrid vehicles enjoy tax benefits – a reduction of three percentage points (3%) in the IPI (Tax on Industrialized Products) rate – in relation to conventional vehicles of similar class and category, under the Federal Government program "Rota 2030 - Mobilidade e Logística".

It is no coincidence that conventional hybrid cars (HEV) make up the majority of the electrified fleet, around 70% of the total. This type of propulsion is, in general, less efficient when compared to the energy consumption (in MJ/km) of 100% electric cars powered exclusively by batteries (BEV). However, it benefits from incentive policies (reduction in IPI, Import Tax and licensing in some States). However, this predominance of conventional hybrids has been threatened by the growth in sales of plug-in hybrids and the expansion in the supply of BEV models in Brazil, including the recent announcement of the installation of a factory by the Chinese automaker BYD in Camaçari (BA), on the premises of the former Ford factory.

Another important element for this market configuration is the incipient car charging infrastructure. According to the Alternative Fuels Infrastructure Directive (Afid), the recommended ratio of public chargers to electric vehicles is 0.1, that is, 1 charger for every 10 vehicles (IEA, 2021). In Brazil, estimates suggest that there are around 840 public and semi-public charging stations for 21,173 cars with connection to the external grid (BEV+PEHV), a ratio of 0.04 chargers per vehicle.

Much of this infrastructure is concentrated in large metropolises in the south and southeast of the country and strategic corridors, where vehicles travel to transport goods and passengers (PNME, 2022). This reinforces the preference for hybrid and plug-in hybrid cars, as the lack of publicly accessible fast chargers tends to block potential buyers of purely electric vehicles, especially when they do not have access to private charging. As stated below, the absence of an ample charging infrastructure appears to be one of the main disadvantages listed by interviewees.

In short, it is a relatively new and expanding market in which the issue of the opacity of commercial exchange (Granovetter, 1985; Polanyi, 2012) becomes even more relevant, given the various uncertainties emerging from its recent development and the differences between electric cars and conventional cars. Vehicle autonomy, safety regarding accidents, charging infrastructure, range anxiety, the electric resale market, environmental impacts, manufacturer warranty and after-sales services –all aspects intertwined with insecurity and decision-making involved in the exchange, which makes it possible to highlight the symbolic values and instruments mobilised to evaluate and qualify this product.

3 BUILDING THE VALUE OF ELECTRIC CARS FROM THE OWNERS' PERSPECTIVE

As previously stated, the value of a good is not something fixed and objectively given but results from social valuation processes in which value is constructed (Aspers; Beckert, 2011). This process is fundamental for the functioning of markets, as they depend, among other things, on the ability of social actors to evaluate the qualities of goods and compare them in terms of value. In this sense, evaluating something means measuring it and comparing it according to a scale; Valuing, in turn, is something more comprehensive, as it involves the different ways of valuing a product and the different scales through which the value of a good can be assessed (Stark, 2011).

The valuation process considers different criteria – aesthetic, moral and economic (monetary) – which often compete with each other and can lead to conflicts in assessing the value of an asset. This is why, in some situations, moral values can impede markets, as in the case of trafficking in people and organs. On the other hand, moral values can also contribute to the value of products on the market, as is the case with organic products (Niederle; Radomsky, 2017).

In the case of the electrified car market, the issue of environmental problems and the potential reduction in impacts caused by their use, compared to internal combustion cars, is something that, in theory, would increase the value of electric cars. According to a study carried out by Noppers *et al.*

(2014), in the Netherlands, the adoption of sustainable innovations is strongly driven by environmental and symbolic motives. Regarding electric cars, the analysis revealed that instrumental attributes (such as purchase price, car weight and the number of seats) were less important than environmental and symbolic attributes regarding owner purchasing decisions. The interest and acceptability of sustainable innovation increased when participants evaluated instrumental attributes more negatively, suggesting that instrumental disadvantages of sustainable innovations can sometimes reinforce their positive signal.

However, research conducted by Ingeborgrud and Ryghaug (2019) revealed a reinforcing dynamic between practical and symbolic values in the successful adoption of electric cars in Norway. The study was done using in-depth interviews with owners, and it showed that comfortable driving experiences and various economic benefits granted by the government were also fundamental from a symbolic point of view, as they encouraged the acquisition of electric vehicles and transmitted a strong signal by the national government that electric cars were an environmentally friendly mobility choice.

In Brazil, a recent survey commissioned by Google showed that the main reasons for purchasing electric cars among potential interested parties were: technological appeal, 37%; cost efficiency and exemptions, 35%, and concern for the environment, 27% (Carvalho; Bonazzi; Guedes, 2023). The interviews with the owners in this research pointed to similar values. However, the dynamics in the valuation process did not occur exclusively but sought to accommodate the different sources of value.

However, before delving deeper into the analysis of the interviews, it is worth discussing briefly the profile of the interviewees, taking into account the factors considered for selection. Table 1 summarises the main information collected about the interlocutors and their cars. The interviewees were selected based on recommendations from acquaintances, members of an owners' association, and participants in a network of people with a general interest in electric mobility. It should be noted that the intentional sample was concentrated in Brazil's south and southeast regions, where most electric cars are registered, and sought to cover different types of vehicles.

Table 1 | Profile of interlocutors

Name	*Age*	*City/State*	*Profession*	*Automobile*	*Type of Vehicle*
João	49	Caxias do Sul/RS	Mechanical Engineer	Volvo S60/2020	PHEV
Ana	66	Campinas/SP	University Professor	Toyota Prius/2013	HEV
Pedro	60	São Paulo/SP	Electronic Engineer	BMW i3 REX/2019	PHEV[3]
Rafael	42	Campo Limpo Paulista/SP	Mechanical Engineer	Caoa Chery Arrizo 5e/2019	BEV
Paulo	78	Curitiba/PR	Banker/ Retired	Toyota Corolla/2020	HEV
Edson	55	Guarulhos/SP	Hospital Manager	Mini Cooper/2021	BEV
Mauro	41	Petrópolis/RJ	Entrepreneur	Chevrolet Bolt/2017	BEV
Luiz	36	São Paulo/SP	Banker/App Driver/ Youtuber	JAC IEV40/2019	BEV

Source: Prepared by the author.

This is a relatively homogeneous group in which everyone has completed higher education, has the financial means to purchase a high-cost car, and has more than one car in their family (except Luiz, who owns just one car). Furthermore, the vast majority are men over 40 years old and occupy important positions in their work organisation. In other words, we are talking about a group with access to information and mostly from the upper classes.

Another important aspect to be mentioned is the fact that some of them (Mauro and Luiz) are members of an association of interests directly linked to the topic of electric mobility, the Brazilian Association of Innovative Electric Vehicle Owners (Abravei) - a network of contacts used to evaluate quality criteria, resolve common doubts and support owners.

4 THE INCREASED PERCEIVED VALUE OF ELECTRIC CARS

According to Aspers and Beckert (2011), the value of a good or service can be distinguished analytically between functional and symbolic value. Functional value derives from the good's property to change the world's state based on its physical effect. Symbolic value refers to the meaning of a good or service for its owner, its social environment, and its physical effects.

Beckert (2011) also distinguishes symbolic value into positional and imaginary dimensions. In both dimensions, the value of the good is based on the attributed qualities that transcend its materiality. However, in the case of positional value, others must attribute symbolic meaning to the property, thus serving as a basis for classifying the owner, giving him a certain social identity. The buyer himself attributes the imaginary, symbolic value, even though this reflects socially constituted values and moral orientations. The latter can be characterised as transcendental ideals and values that alter the owner's consciousness. That is, goods that evoke images based on symbolic associations with desired events, people, places or values but whose unity exists only as a mental construction (Beckert, 2011).

In this sense, goods such as the electric automobile would not only position their owners in social space through their symbolic significance, but they are also symbolic representations of adopted ideals and values (sustainability, freedom, efficiency) that can be imaginatively appropriated through their purchase (Aspers; Beckert, 2011). Table 2 summarises the values attributed by interviewees in this typology.

Table 2 | Types of values mobilised

	Value	
Functional	Symbolic	
	Positional	Imaginary
Less maintenance	Economically rational	Transportation efficiency
Less consumption		
Less taxes		
More safety	Technological vanguard	Individual freedom
Less noise/vibration		
Embedded technology		
Less CO2 emissions	Environmentally responsible	Sustainability
Renewable energy matrix		
Less polluting emissions		

Source: Prepared by the author.

Although symbolic values are not necessarily linked to functional values, it is possible to draw a relationship between them, as the material qualities acquire symbolic meanings. For example, functional values attributed to the electric car, such as lower CO2 and polluting emissions, contribute to creating an "environmentally responsible" identity for the owners and its association with intangible values, with somewhat unclear links to a sustainable future.

The values attributed by owners, whether functional or symbolic, are directly linked to the valuation process in the automobile market as they express intersubjectively shared qualifiers sought in commercial exchange. The analytical dimensions indeed overlap in the interviewees' valuation process, as can be seen in the statement below:

> I think, man, first of all, there's a sense of responsibility, you know, you're already thinking about polluting emissions, etc. I find the experience of driving an electric car very pleasant, in terms of silence, comfort, even performance, torque, acceleration, etc. I think the electric experience is really cool. So I think that a mix of all these things, you are already following a trend, in some way contributing to the reduction of emissions, and it is a pleasant experience, an experience of comfort and silence that the electric vehicle also provides (JOÃO, mechanical engineer, 49).

In this way, the functional value, the quieter and more comfortable car, aligns with the symbolic value and the desire to meet collective expectations of responsibility and emissions reduction. In some cases, the imaginary symbolic value is expressed as a desire to "improve the planet for those who are arriving" (Pedro, electronic engineer, 60).

However, the issue of the environmental impact of electric vehicles is widely controversial and full of contradictions. Mainly regarding the emissions calculation methodology used and the aspects considered (Messagie, 2014; Nordelöf *et al.*, 2014). Methodologies that consider GHG emissions associated with energy production and vehicle propulsion (weel-to-wheel) present more positive results than those that also consider the manufacturing of batteries and the end of their useful life (analysis of complete life cycle).

A second factor that directly affects this calculation is the electrical matrix in which these automobiles operate. In Brazil, where the electrical matrix comes 83% from renewable sources (EPE, 2021), the GHG emissions linked to electric cars end up being lower than in countries more dependent on fossil energy sources. This configuration aligns with the values of those interviewed who were concerned about GHG emissions and their personal energy matrix. A more radical example is homeowners who

understand the possibility of generating electricity at home through photovoltaic panels as a source of significant value, not only based on monetary criteria but also as a sustainable and independent form of supply.

> Everything in the house is electric, man, even the toothbrush [laughs]. When you have energy production in your home you begin to have the freedom that comes with it. You are producing energy locally. It is a whole concept, it is not just a car, it is a concept of sustainability: you produce, enjoy and do not pollute. And doing this in your private sphere is a libertarian way (Mauro, businessman, 41).

In the same sense, embedded technology and the possibility of using household electricity as a supply source are symbolically signified as attributes that would position owners in a technologically avant-garde social category. The aforementioned freedom concerning gas stations and possible stoppages and sudden fluctuations in fuel prices, seen as a form of "empowerment" for owners in the face of these possible fluctuations, is more of an imaginary value since, even if the "fuel is indoors" the transport system is collective and depends on a series of factors that go beyond the individual scope. This source of value was only reported by BEV vehicle owners.

On the other hand, owners of HEV and PHEV vehicles, when justifying their choices, pointed to the lower dependence on charging infrastructure, or independence in the case of conventional hybrids, as a positive aspect. In the case of plug-in hybrids, the possibility of running with the combustion engine or the electrical engine, alternatively, is seen as a source of value since the number of chargers available is still considered small, especially on highways and cities in the countryside. The incipient charging infrastructure is considered, together with the price of cars, the main disadvantage for owners.

The same can be seen when we look at the values linked to economic rationality. The electric car is valued for potentially reducing the emission of pollutants and greenhouse gases and enabling long-term savings (payback), as illustrated in the following answer on the decisive factors for choosing an electric car.

> First of all, not just me, but perhaps even the corporate world is recognising that it's a question of savings. If we calculate it, I saved 15 thousand BRL per year between fuel, IPVA and maintenance. So that was my savings per year. This means what, at first, is what companies are doing today, a company doesn't buy 1,200 electric trucks because it's going to... it's going to explore this too, the concept of sustainability, but it's not sustainability, it's business, it's pure capitalism in this relationship of savings and maintenance. [...] So if we analyse this first concept that leads someone, making a calculation, it is the issue of maintenance, the economic issue, and then comes the issue of sustainability, the environment, you stop emitting CO2, you contribute to everyone's environment, right (Edson, hospital manager, 55).

However, these symbolic values are not separated from the monetary value in the valuation process. Market research shows that consumers' willingness to pay more for electric cars, even though they agree with the potential of electric cars to reduce environmental impact, decreases as their price increases in relation to conventional cars. According to the study (Heineke, 2020), only 3% of respondents were willing to pay more than 30% more than vehicles with internal combustion engines for battery electric vehicles.

Again, the economic (monetary) criterion is considered relevant for the owners' evaluation. The mobility survey corroborates this data, carried out by SAE (SAE Brasil; KPMG; Autodata, 2021), which points out, among automotive industry executives and vehicle consumers, the acquisition cost is one of the main obstacles to electric vehicles in the market.

However, the issue of acquisition cost, when approached specifically, presents nuances related to other criteria (moral, technological, aesthetic) involved in the valuation process. In general, owners judge the price fair when considering factors such as the level of technology development, low sales volume, the

benefits involved, the tax burden and the benefits to health and the environment. The excerpt below exemplifies this attitude towards the issue of price.

> I made an extravaganza, I don't think it's fair, because it was very expensive, [...] but, on the other hand, I thought that to fulfill this desire I had, I wanted to have something more modern in terms of concept. Because I think we have to pay the costs of our impact on the planet. That's my point, so we have to pay for this. (Ana, university professor, 66).

In this case, we can see a movement towards objectification (pricing) of subjective values, such as the impacts of human activity on nature, increasing the subjectively experienced value. This is what Fourcade (2011), when studying civil cases involving oil spills in the United States and France, calls the feedback loop from monetary valuation to social representations and practices. Based on Simmel's sociology (1978), the author argues that the relationship between subjective value and objectified value is not unidirectional but dialectical. This is because the value people attribute to an object may be connected to the purchase conditions and the monetary sacrifice made at the time of purchase.

The same can be said about the cost of being at the forefront of a technological trend. There is a movement towards pricing value based on the level of development and diffusion of technology, which is then subjectively experienced as something positive and inherent to the role of a trend promoter.

> It's fair due to the level of technological development. I think it's a technology that still has a lot to evolve, the cost of batteries has to go down, more adoption, etc. I think this is also something I usually talk about, when you purchase an electric vehicle and promote this electric vehicle, in some way you are also contributing to this happening in the future in a more intense way and with that the entire cost goes down (João, mechanical engineer, 49).

This feedback dynamic from monetary valuation to social representations is mainly based on the symbolic value of some goods. That is, in intersubjectively shared meanings, which are established in the community and emerge in social practices.

Despite shared meanings, these values are mainly based on the individual use of cars. When faced with questions regarding the main problems and trends in urban mobility, most interviewees pointed to the individual use of cars as a problem to be overcome. In this sense, there is a certain awareness about the limits of the individual use of the electric car to respond to these problems and achieve the imaginary values associated with it (efficiency, freedom and sustainability). However, these problems are understood as collective and dependent on structural solutions.

> So, I don't know if changes for society would be something so dramatic. In fact, they will converge towards a less polluted environment, so in this sense, yes, this is the great contribution of the electric vehicle, right. Now, for example, the electric vehicle will not contribute to reducing traffic jams. This continues, because both electric or combustion continue to occupy the same space on the street. In this other aspect, absolutely nothing changes, it changes in the sense of being less contaminating, etc. I think so, but with this... with this limitation of vision. (Paulo, banker, 78).

In other words, even though the issue of socio-environmental problems can be superimposed as a source of relational and symbolic value, as a value attributed by the community and by the owner in the construction of their identity, the acquisition of an electric car for private use appears as an individual response that is thus subject to limits that only coordinated action could adequately respond to.

5 FINAL CONSIDERATIONS

As seen in the previous sections, although representing a modest portion of total car sales, the national market for electrified cars has shown significant growth in recent years. The fleet analysis revealed the predominance of conventional hybrid vehicles, with a special participation of flex-fuel hybrids produced by Toyota. This aspect points to a technological dispute still open in the fleet's composition and the continuity of the internal combustion engine, associated with renewable sources, as a "sustainable" alternative. The significant presence of premium cars belonging to large categories, such as SUVs and extra-large models, is another element that draws attention due to its apparent contradiction with the ideal of efficiency.

In a related manner, the profile of the owners interviewed corresponds mostly to men over 40 years old who have completed higher education, are well-informed, and have sufficient financial conditions to purchase a high-cost car. This profile is partly due to the cut proposed by the intentional sample, which sought to cover different types of vehicles. On the other hand, it reflects the willingness of this profile to participate in research on the topic and externalise their criteria and justifications for the acquisition.

Regarding the different types of propulsion, it was possible to perceive different expectations concerning the charging infrastructure network, with owners of HEVs and PHEVs being more reticent about this dependence. Another important difference was the fact that BEV owners perceived autonomy in relation to gas stations as a source of value, both monetary and symbolic, for the electric car.

Despite these differences concerning recharging, all owners mobilised functional and symbolic values as criteria for purchasing their cars. It is worth noting that the acquisition cost is perceived as a disadvantage, an initial barrier, but at the same time, it is something that can be subjectively valued as the price to be paid for the impact of human activity on the planet, or for being part of a technological vanguard. Therefore, there is an overlap between the functional value, the desire for a more economical, efficient, silent and comfortable automobile, and the symbolic value, the desire to meet collective expectations of responsibility and reduction of greenhouse gas or polluting emissions.

In turn, the analysis of the criteria mobilised in valuing the electric car showed that the symbolic representations of adopted ideals and values (sustainability, freedom, efficiency) are imaginatively appropriate and have a connection far from reality. This is especially true regarding greenhouse gas emissions and the life cycle analyses that calculate all-electric car production chain impacts, which are subject to methodological controversies.

It is worth mentioning here that although recent studies (Mera *et al.*, 2023) robustly point to lower GHG emissions (fuel/electricity cycle + vehicle cycle) from electric vehicles, the ideal of sustainability is not restricted to the emission of gases. In particular, in the case of SUVs and larger vehicles, it is worth highlighting that the Hummer EV cannot be considered a sustainable option because it is powered by electricity and emits fewer gases than the conventional version. Therefore, in these situations, there would be an accommodation of environmental contradictions, the result of a mismatch between awareness of the climate emergency and the effective change in daily practices (Giddens, 2009).

Therefore, sustainability and concern about pollutant and greenhouse gas emissions are essential for electric car owners to help position them in the social space through their symbolic significance. However, this value appears mainly as a consequence of the economic value and energy efficiency linked to the electric car. This look at the valuation process allows us to see a significant and growing weight of the socio-environmental agenda for owners, pointing to the value given to using renewable sources, including in the domestic sphere, and low emissions. On the other hand, the relevance of functional values linked to individual use shows that this consumption is unlikely to be translated, over the short term, into major sociotechnical transitions that correspond to the imaginary values of freedom, efficient transport and sustainability.

Finally, it is worth mentioning that the functional values mobilised for the acquisition of electrified cars are in relative agreement with the symbolic values and that most interviewees are aware of the limits of car electrification, especially regarding their individual use. These limits concern the differences in focus (individual and collective) in the use of means of transport and the contradictions related to political choices that prioritise certain modes over others.

NOTES

1| The electrified automobile category covers: battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and conventional hybrid electric vehicles (HEV), without recharging via the electrical grid.

2| Camex Resolutions No. 97/2015, 27/2016, eliminated the Import Tax (II), which was 35%, for electric propulsion or hydrogen-powered vehicles and reduced it between 0% to 7% for hybrid vehicles , depending on the level of energy efficiency.

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REFERENCES

ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

ASSOCIAÇÃO NACIONAL DOS FABRICANTES DE VEÍCULOS AUTOMOTORES. **Anuário da indústria automobilística brasileira**. São Paulo: 2023.

BECKERT, J. The Transcending Power of Goods: imaginative value in the economy. In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

BLOOMBERG. **Hitting the EV Inflection Point**. Electric vehicle price parity and phasing out combustion vehicle sales in Europe – Transport & Environment, may/2021.

CARNEIRO, M. S. O papel dos dispositivos de prescrição e julgamento no funcionamento dos mercados: o caso da certificação florestal. **Revista Tomo.** v. 30, p. 267-302, 2017.

CARVALHO, M.; BONAZZI, D.; GUEDES, L. **O futuro da mobilidade é tech**: veja como os setores de auto e viagens podem se preparar. Available at: https://www.thinkwithgoogle.com/intl/pt-br/tendencias-de-consumo/tendencias-de-comportamento/tecnologia-auto-viagem/. Access on: Oct. 16, 2023.

EMPRESA DE PESQUISA ENERGÉTICA. **Balanço Energético Nacional 2021**: Ano-base 2020 / Empresa de Pesquisa Energética. Rio de Janeiro: EPE, 2021.

FEDERAÇÃO NACIONAL DA DISTRIBUIÇÃO DE VEÍCULOS AUTOMOTORES. **Anuário do Setor de Distribuição de Veículos Automotores no Brasil 2022**. São Paulo, 2023.

FLICK, U. **Desenho da pesquisa qualitativa**. Porto Alegre: Artmed, 2009. 164 p.

FOURCADE, M.; HEALY, K. Moral Views of Market Society. **Annual Review of Sociology**, v. 33, 2007.

FOURCADE, M. Price and prejudice: on economics and the enchantment (and disentchantment) of nature. In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

GEELS, F. W. Sociotechnical transitions to sustainability: a review of criticisms and elaborations of the multi-level perspective. **Current Opinion in Environmental Sustainability**, Open Issue 2019. v. 39, p. 187–201, 2019.

GIDDENS, A. **The politics of climate change**. Cambridge, Polity Press, 2009.

GRANOVETTER, M. Economic Action and Social Structure: the problem of embeddedness. **American Journal of Sociology**, v. 91, n. 3, p. 481–510, 1 nov. 1985.

HEINEKE, K. *et al.* **ACES 2019 survey**: Can established auto manufacturers meet customer expectations for ACES? McKinsey & Company, 2020.

INGEBORGRUD, L.; RYGHAUG, M. The role of practical, cognitive and symbolic factors in the successful implementation of battery electric vehicles in Norway. **Transportation Research Part A:** policy and practice, v. 130, p. 507–516, 1 dez. 2019.

INTERNATIONAL ENERGY AGENCY. **Global EV Outlook 2022**, IEA, Paris, 2021.

INTERNATIONAL ENERGY AGENCY. **Electric cars fend off supply challenges to more than double global sales**, IEA, Paris, 2022. Available at: https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales . Accessed on: Mar. 10, 2022.

KARPIK, L. **Valuing the Unique**: the economics of singularities. Princeton University Press, 2010.

KÖHLER, J. *et al.* An agenda for sustainability transitions research: state of the art and future directions. **Environmental Innovation and Societal Transitions**, Amsterdam, v. 31, p. 1-32, 2019.

LAMONT, M. Para uma conexão necessária entre a Sociologia da Valoração e da Avaliação com a Sociologia Econômica e das Finanças (Tradução). **Norus**, v. 1, p. 1, 2013.

MERA, Z. *et al.* **Comparação das emissões de gases de efeito estufa no ciclo de vida de carros de passeio a combustão e elétricos no Brasil**. [s.l: s.n.]. Available at: www.theicct.org.

MESSAGIE, M. **Life Cycle Analysis of the Climate Impact of Electric Vehicles**. [s.l: s.n.].

NIEDERLE, P. A.; RADOMSKY, G. F. W. Quem governa por dispositivos? A produção das normas e padrões para os alimentos orgânicos no Brasil. **Revista Tomo**. v. 30, p. 267-302, 2017.

NOPPERS, E. H. *et al.* The adoption of sustainable innovations: driven by symbolic and environmental motives. **Global Environmental Change**, v. 25, n. 1, p. 52–62, 2014.

NORDELÖF, A. *et al.* Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—what can we learn from life cycle assessment? **International Journal of Life Cycle Assessment**. Springer Verlag, 14 out. 2014.

PLATAFORMA NACIONAL DE MOBILIDADE ELÉTRICA. **Anuário Brasileiro da Mobilidade Elétrica**, 2022.

POLANYI, K. **A subsistência do homem e ensaios correlatos**. 1. ed. Rio de Janeiro: Contraponto, 2012.

SAE BRASIL; KPMG; AUTODATA. **Pesquisa SAE Mobilidade**, 2021.

SECRETARIA NACIONAL DE TRÂNSITO. **Estatísticas – Frota de Veículos, (2015-2022)**, 2022. Available at: https://www.gov.br/infraestrutura/pt-br/assuntos/transito/conteudo-denatran/estatisticas-frota-de-veiculos-senatran. Accessed on: Apr. 25, 2022.

SIMMEL, G. **The Philosophy of Money**. Boston, MA: Routledge Kegan and Paul, 1978.

STARK, D. What's valuable? In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

WOLFFENBUTTEL, R. **A Produção Social da Inovação**: o automóvel elétrico e as redes de inovação no Brasil. Porto Alegre, Cirkula, 2021.

Limites da sustentabilidade dos automóveis elétricos, qualificação de bens a partir de valores simbólicos

Limits of sustainability in electric cars, qualification of goods based on symbolic values

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ARTICLE- DOSSIER

RESUMO

Sabe-se que o valor de um bem não é algo fixo e objetivamente dado, mas resulta de processos de valoração social nos quais o valor é construído. Esse processo é fundamental para o funcionamento de mercados, pois estes dependem, entre outras coisas, da capacidade de os atores sociais avaliarem as qualidades de um bem, em relação umas às outras e compará-las em termos de valor. Dessa forma, o processo de valoração leva em consideração diferentes critérios que muitas vezes concorrem entre si. O expressivo crescimento na venda de automóveis elétricos no país aponta para a formação de um nicho de mercado, com consumidores dispostos a investir em novas tecnologias de propulsão, em tese, mais sustentáveis que os automóveis convencionais. A partir desse contexto, a pesquisa busca investigar, por meio de entrevistas com proprietários, o papel de valores simbólicos no processo de qualificação de bens "sustentáveis", como o automóvel elétrico. A análise dos dados aponta a mobilização de valores funcionais e simbólicos, ainda que imaginativamente apropriados, como critérios fundamentais para a aquisição dos automóveis.

Palavras-chave: Mercado. Valoração. Automóvel elétrico. Sustentabilidade

ABSTRACT

The value of a good is not something fixed and objectively given but results from social valuation processes in which value is constructed. This process is fundamental for the functioning of markets, as they depend, among other things, on the ability of social actors to evaluate the qualities of goods and compare them in terms of value. In this way, the valuation process considers different criteria that often compete. The significant growth in the sale of electric cars in Brazil points to the formation of a market niche, with consumers willing to invest in new propulsion technologies, which, in theory, are more sustainable than conventional cars. From this context, the research seeks to investigate, through interviews with owners, the role of symbolic values in qualifying "sustainable" goods, such as electric cars. Data analysis points to the mobilisation of functional and symbolic values, although imaginatively appropriate, as fundamental criteria for the acquisition of cars.

Keywords: Market. Valuation. Electric Car. Sustainability.

1 INTRODUÇÃO

Segundo dados da Agência de Energia Internacional (IEA), a fatia de mercado correspondente à venda global de automóveis elétricos, em 2022, ultrapassou a marca de 10 milhões de unidades (13%), o que representa um recorde e um crescimento considerável quando comparado com anos anteriores (IEA, 2022). Não por acaso, o ressurgimento dessa forma de motorização ocorre em meio a uma série de questões sociais, políticas e econômicas que têm pressionado o mercado automotivo e seu *modus operandi*.

O Brasil, apesar de estar relativamente distante de países líderes em eletrificação, observa um crescimento expressivo na venda de veículos eletrificados[1] nos últimos anos. Segundo dados da Associação Brasileira do Veículo Elétrico (ABVE), cerca de 2,5% dos automóveis vendidos, em 2022 (49.245 unidades), eram eletrificados, incluindo híbridos *plug-in* e convencionais. O que representa um crescimento de 41% sobre 2021 (34.990) e 149% sobre 2020 (19.745). Crescimento que se torna ainda mais relevante quando comparado ao desempenho do mercado de automóveis e comerciais leves como um todo (-0,85%) no mesmo ano (Fenabrave, 2023).

Essa expressiva evolução da frota de eletrificados indica um movimento sustentado de crescimento na venda de automóveis eletrificados no país e a formação de um nicho de mercado, com consumidores dispostos a investir em novas tecnologias de propulsão veicular, em tese, mais sustentáveis que os automóveis convencionais. Mudanças dessa escala e natureza têm sido enquadradas no conceito de transições sociotécnicas para a sustentabilidade (Geels, 2019; Köhler *et al.*, 2019), pois trata-se de uma mudança que envolveria transformações radicais em direção a novos tipos de sistemas sociotécnicos. Todavia, pouco se sabe sobre as motivações e os critérios (econômicos e ambientais) que têm levado os consumidores a essa escolha. Dessa forma, caberia investigar quais fatores influenciam os processos decisórios de aquisição desses automóveis no Brasil e suas consequências para uma possível transição.

Esse tipo de questionamento situa-nos no interior de um importante debate sobre o papel desempenhado por relações sociais, dispositivos de classificação, regras e significados culturais no processo de construção e funcionamento dos mercados (Carneiro, 2017). Mais precisamente, no interior do debate sobre como valores e formas de avaliações são construídos e ressignificados, para além dos mecanismos de preços, nas trocas de mercado. Trocas, essas, que seriam mediadas por dispositivos de julgamento (Karpik, 2010) e permeadas por esforços mais ou menos conscientes para categorizar, normatizar e naturalizar comportamentos e regras construídas socialmente (Fourcade; Healey, 2007).

Logo, a presente pesquisa buscou investigar a experiência desses proprietários com os automóveis eletrificados e os valores mobilizados para sua aquisição no contexto nacional, bem como sua relação com aspectos climático-ambientais e com outras razões ainda não mapeadas. Com isso, o trabalho inscreve-se no interior de um marco teórico que busca explorar os critérios de avaliação e revelar os dispositivos, instituições, ou estruturas sociais e culturais que os sustentam e os acionam (Lamont, 2013). Dessa maneira, busca-se analisar quais são os valores mobilizados para aquisição de automóveis eletrificados no contexto nacional e qual o papel de instrumentos e de valores simbólicos no processo de qualificação de bens "sustentáveis", como o automóvel elétrico, neste contexto.

Portanto, o trabalho busca compreender quais fatores influenciam os processos decisórios de aquisição de automóveis elétricos e o papel desempenhado pelos valores simbólicos no processo de valoração por meio: (1) da identificação dos sentidos e valores mobilizados pelos proprietários de automóveis elétricos; e (2) da análise dos processos decisórios e critérios utilizados para qualificar suas escolhas.

À luz desse marco teórico, e tendo o mercado brasileiro de automóveis eletrificados como unidade de análise, foram realizadas entrevistas semiestruturadas com proprietários de automóveis eletrificados, entre novembro de 2021 e junho de 2022. Os entrevistados foram selecionados a partir de uma amostragem intencional (Flick, 2009) baseada na propriedade e tipo de propulsão do automóvel.

A partir desse recorte, foram entrevistados 8 (oito) proprietários de automóveis eletrificados com diferentes tipos de propulsão, 4 (quatro) elétricos a bateria (BEV) e 4 (quatro) híbridos (PHEV+HEV).

As entrevistas foram organizadas e categorizadas por meio da análise de conteúdo, o que possibilitou identificar os sentidos e valores mobilizados pelos consumidores, os processos decisórios e critérios utilizados para qualificar suas escolhas.

A abordagem proposta tem grande relevância teórica para pesquisadores de processos de valoração e avaliação em mercados permeados por questões e valores ambientais, como no caso dos automóveis eletrificados. O tema também importa para os interessados nos rumos do mercado automotivo nacional e da mobilidade em grandes centros urbanos. Afinal, trata-se de uma mudança que potencialmente engendra uma série de transformações nos meios de transporte e recarga. Além disso, em termos sociais, econômicos e geopolíticos, trata-se de uma questão significativa para um país como o Brasil, uma potência climática em termos de fontes renováveis, com um parque industrial automotivo consolidado, mas sem grande relevância no mercado de veículos elétricos até o momento.

Além desta seção introdutória, o artigo está organizado em mais quatro seções. A próxima seção apresenta o marco teórico mobilizado e contextualiza o referido mercado a partir de dados secundários. Na seção seguinte, são apresentados os interlocutores e os procedimentos metodológicos para, na próxima, serem analisados os sentidos e valores atribuídos pelos proprietários de automóveis eletrificados. Por fim, são realizadas as considerações finais, apontando algumas reflexões sobre o processo de valoração do automóvel elétrico e os limites em relação aos valores simbólicos.

2 MERCADO E VALORAÇÃO

Mercados são espaços de relações sociais institucionalizadas, onde se realiza a distribuição de um determinado bem ou serviço, por intermédio de troca comercial. Por seu turno, essas relações sociais de troca pressupõem a existência de acordos prévios sobre o valor de um bem ou serviço e a constituição de um processo capaz de transfigurar esse bem ou serviço em algo comercializável.

Segundo Lamont (2013), esses processos envolvem: acordos intersubjetivos sobre uma matriz ou conjunto de referências com os quais um "bem" é comparado; negociações e conflitos sobre critérios de julgamento apropriados e juízes legítimos; e o estabelecimento do valor em um processo relacional (ou por índices) envolvendo "bens" distinguíveis e comparáveis. No caso dos mercados, esses elementos são considerados centrais para a compreensão, tanto dos processos de constituição de bens e serviços em mercadorias quanto dos mecanismos de produção do valor de um bem ou serviço.

O Brasil é o 7º maior mercado interno de autoveículos do mundo (Anfavea, 2023). Desde suas origens, o setor configura-se como uma área estratégica para os projetos de desenvolvimento econômico e modernização social do país. No entanto, o referido agravamento de questões relacionadas a emissões de poluentes, saúde pública, congestionamento nas grandes metrópoles e impactos ao ambiente, somado às recentes crises econômicas e sanitárias internacionais, tem criado grandes desafios para a indústria automotiva e impulsionado importantes mudanças no setor.

Como resposta a essas novas exigências regulatórias, expectativas sociais e novos concorrentes no mercado, muitas montadoras têm apostado no desenvolvimento e na oferta de modelos elétricos. No Brasil, conforme mencionado acima, isso pode ser visto no expressivo crescimento nas vendas de automóveis eletrificados nos últimos anos. Crescimento que contrasta com a tendência de queda na venda de automóveis novos nos últimos anos, atribuída pela Fenabrave à crise sanitária da Covid-19 e à crise de fornecimento de semicondutores para a montagem dos veículos.

Segundo dados compilados pela ABVE, a frota de automóveis eletrificados em circulação no país é de 126.504 automóveis e comerciais leves (2012-2022). Todavia, uma análise detalhada da frota revela algumas características importantes desses veículos, tais como: o predomínio de veículos híbridos convencionais, com o destaque para a Toyota como o principal fabricante, responsável por cerca de 60% da frota de eletrificados no país; a ausência de modelos pertencentes a categorias menores (compacto e subcompacto); e a presença massiva de diversos veículos utilitários esportivos (SUV) e veículos extragrandes (Wolffenbuttel, 2021). O que aponta para uma valorização dos automóveis maiores e híbridos.

Outro aspecto interessante é o preço médio dos automóveis e a expressiva quantidade de fabricantes *premium* na frota. Dado que revela um acesso financeiramente restrito aos automóveis eletrificados. Em parte, isso é devido aos custos de produção dos automóveis elétricos, 10% a 30% mais elevados que os automóveis a combustão interna (Bloomberg, 2021), mas também à estrutura fiscal nacional que tende a favorecer a importação de eletrificados[2]. O abatimento no imposto de importação permite que o preço adicional do sistema de propulsão elétrico seja absorvido nos automóveis *premium*, sem elevação expressiva do preço para o consumidor final, pois, nesse caso, o sistema de propulsão representa uma parcela menor do custo total em comparação com os automóveis convencionais. Em outras palavras, os automóveis que já eram caros, seguem caros, mas agora com maior eficiência energética e menor emissão de poluentes.

Por outro lado, esses dados demonstram que a estratégia de produção nacional de automóveis híbridos convencionais *flex fuel* tem se mostrado bem-sucedida. Essa estratégia possibilita um custo de produção relativamente menor, pois nesses modelos as baterias são menos dispendiosas, uma vez que são utilizadas apenas para armazenar a energia recuperada pelo sistema de frenagem regenerativa. Além disso, os veículos híbridos *flex* usufruem de benefícios fiscais – redução de três pontos percentuais (3%) na alíquota do Imposto sobre Produtos Industrializados (IPI) – em relação aos veículos convencionais, de classe e categoria similares, de acordo com o Programa Rota 2030 – Mobilidade e Logística, do governo federal.

Não por acaso os automóveis híbridos convencionais (HEV) compõem a maioria da frota de eletrificados, cerca de 70% do total. Esse tipo de propulsão é, em geral, menos eficiente, quando comparado ao consumo energético, em MJ/km, dos automóveis 100% elétricos, movidos exclusivamente a bateria (BEV). Porém, se beneficia de políticas de incentivo (redução no IPI, Imposto de Importação e licenciamento em alguns estados). No entanto, esse predomínio dos híbridos convencionais vem sendo ameaçado pelo crescimento nas vendas de híbridos *plug-in* e pela expansão na oferta de modelos BEV no contexto nacional, inclusive com o recente anúncio da instalação de uma fábrica da montadora chinesa BYD em Camaçari (BA), nas instalações da antiga fábrica da Ford.

Outro importante elemento para essa configuração do mercado é a incipiente infraestrutura de recarga dos automóveis. Segundo a Diretiva de Infraestrutura de Combustíveis Alternativos (Afid), a razão recomendada de carregadores públicos por veículos elétricos é de 0,1, isto é, 1 carregador para cada 10 veículos (IEA, 2021). No Brasil, estima-se que exista cerca de 840 postos de recarga, públicos e semipúblicos, para 21.173 automóveis com conexão com a rede externa (BEV+PEHV), uma razão de 0,04 carregador por veículo.

Grande parte dessa infraestrutura encontra-se concentrada em grandes metrópoles, no eixo Sul e Sudeste do país e em corredores estratégicos, onde há o deslocamento de veículos para transporte de bens e de passageiros (PNME, 2022). Esse dado reforça a preferência por automóveis híbridos e híbridos *plug-in*, uma vez que a ausência de carregadores rápidos acessíveis ao público tende a bloquear potenciais compradores de veículos puramente elétricos, principalmente quando não possuem acesso a carregamento privado. Como será visto a seguir, a ausência de uma ampla infraestrutura de recarga aparece como uma das principais desvantagens elencadas pelos entrevistados.

Em suma, trata-se de um mercado relativamente novo e em expansão, no qual a questão da opacidade da troca mercantil (Granovetter, 1985; Polanyi, 2012) se torna ainda mais relevante, dadas as diversas incertezas emergentes de seu recente desenvolvimento e das diferenças dos carros elétricos em relação aos automóveis convencionais. A autonomia dos veículos, a segurança contra acidentes, a infraestrutura de recarga, o *range anxiety* (ansiedade pela recarga), o mercado de revenda dos elétricos, os impactos ao ambiente, a garantia do fabricante e os serviços de pós-venda são aspectos imbricados à insegurança e à tomada de decisão envolvidas na troca, que permitem evidenciar quais são os valores simbólicos e instrumentos mobilizados para se avaliar e qualificar esse produto.

3 CONSTRUÇÃO DE VALOR DOS AUTOMÓVEIS ELÉTRICOS NA VISÃO DOS PROPRIETÁRIOS

Conforme visto, o valor de um bem não é algo fixo e objetivamente dado, mas resulta de processos de valoração social por meio dos quais o valor é construído (Aspers; Beckert, 2011). Esse processo é fundamental para o funcionamento de mercados, pois estes dependem, entre outras coisas, da capacidade dos atores sociais de avaliar as qualidades de um bem, em relação umas às outras, e compará-las em termos de valor. Nesse sentido, avaliar algo significa medi-lo e compará-lo de acordo com uma escala; valorar, por seu turno, é algo mais abrangente, pois envolve as diferentes formas de valorização de um produto, e as diferentes escalas mediante as quais o valor de um bem pode ser avaliado (Stark, 2011).

O processo de valoração leva em consideração diferentes critérios – estéticos, morais e econômicos (monetário) – que muitas vezes concorrem entre si e podem levar a conflitos na avaliação do valor de um bem. É por isso que em algumas situações os valores morais podem obstaculizar os mercados, como no caso de tráfico de pessoas e órgãos. Por outro lado, os valores morais também podem contribuir para o valor dos produtos no mercado, como o caso dos produtos orgânicos (Niederle; Radomsky, 2017).

No caso do mercado de automóveis eletrificados, a questão dos problemas ambientais e a potencial redução nos impactos provocados pelo seu uso, em comparação com os automóveis a combustão interna, é algo que, em tese, valorizaria os elétricos. Segundo estudo realizado por Noppers *et al.* (2014), nos Países Baixos, a adoção de inovações sustentáveis seria fortemente puxada por motivos ambientais e simbólicos. Em relação aos carros elétricos, a análise dos pesquisadores revelou que atributos instrumentais (tais como preço de compra, peso do carro e número de assentos) seriam menos importantes do que os atributos ambientais e simbólicos para as decisões de adoção dos proprietários. Inclusive, o interesse e a aceitabilidade da inovação sustentável aumentariam quando os participantes avaliam os atributos instrumentais de forma mais negativa, sugerindo que desvantagens instrumentais das inovações sustentáveis podem, por vezes, reforçar o seu sinal positivo.

Já a pesquisa conduzida por Ingeborgrud e Ryghaug (2019) revela uma dinâmica de reforço entre valores práticos e simbólicos na adoção bem-sucedida de carros elétricos na Noruega. O estudo realizado, por meio de entrevistas em profundidade com proprietários, mostrou que as experiências de condução confortáveis e os diversos benefícios econômicos concedidos pelo governo foram fundamentais, também, do ponto de vista simbólico, pois encorajavam a aquisição dos elétricos e transmitiam uma forte sinalização, por parte do governo nacional, de que os carros elétricos eram uma escolha de mobilidade ambientalmente correta.

No Brasil, uma pesquisa recente, encomendada pela Google, apontou que os principais motivos para a aquisição de carros elétricos, entre potenciais interessados, são: o apelo tecnológico, 37%; eficiência de custos e isenções, 35%, e preocupação com o meio ambiente, 27% (Bonazzi; Carvalho; Guedes, 2023). As entrevistas realizadas com os proprietários, na presente pesquisa, apontam para valores similares, todavia, a dinâmica no processo de valoração não ocorre de forma excludente, mas busca acomodar as diferentes fontes de valor.

Porém, antes de aprofundar a análise das entrevistas, convém discorrer brevemente sobre o perfil dos entrevistados, tendo em vista os fatores considerados para a seleção. O Quadro 1 resume as principais informações levantadas sobre os interlocutores e seus automóveis. Os entrevistados foram selecionados a partir da indicação de conhecidos, membros de uma associação de proprietários e participantes de uma rede de interessados em geral sobre mobilidade elétrica. Cabe salientar que a amostra intencional se concentrou nas regiões Sul e Sudeste do país, onde está registrada a maioria dos automóveis elétricos, e buscou abranger diferentes tipos de veículos.

Tabela 1 | Perfil dos interlocutores

Nome	*Idade*	*Cidade/Estado*	*Profissão*	*Automóvel*	*Tipo de Veículo*
João	49	Caxias do Sul/RS	Engenheiro Mecânico	Volvo S60/2020	PHEV
Ana	66	Campinas/SP	Professora Universitária	Toyota Prius/2013	HEV
Pedro	60	São Paulo/SP	Engenheiro Eletrônico	BMW i3 REX/2019	PHEV[3]
Rafael	42	Campo Limpo Paulista/SP	Engenheiro Mecânico	Caoa Chery Arrizo 5e/2019	BEV
Paulo	78	Curitiba/PR	Bancário/ Aposentado	Toyota Corolla/2020	HEV
Edson	55	Guarulhos/SP	Gestor Hospitalar	Mini Cooper/2021	BEV
Mauro	41	Petrópolis/RJ	Empresário	Chevrolet Bolt/2017	BEV
Luiz	36	São Paulo/SP	Bancário/Motorista Aplicativo/Youtuber	JAC IEV40/2019	BEV

Fonte: Elaborado pelo autor.

Trata-se de um grupo relativamente homogêneo, em que todos têm ensino superior completo, condições financeiras para adquirir um automóvel de custo elevado e mais de um automóvel na família (com exceção do Luiz, que possui um único carro). Ademais, a maioria é formada por homens, com mais de 40 anos e ocupa alguma posição importante na organização onde trabalha. Em outras palavras, estamos falando de um grupo com acesso à informação e de classes mais abastadas em sua maior parte.

Outro aspecto importante a ser mencionado é o fato de alguns deles (Mauro e Luiz) serem membros de uma associação de interesses diretamente ligados ao tema da mobilidade elétrica, a Associação Brasileira dos Proprietários de Veículos Elétricos Inovadores (Abravei). Uma rede de contatos empregada na avaliação de critérios de qualidade, na resolução de dúvidas comuns e no suporte aos proprietários.

4 A VALORIZAÇÃO DOS AUTOMÓVEIS ELÉTRICOS

Segundo Aspers e Beckert (2011), o valor de um bem ou serviço pode ser distinguido, analiticamente, entre valor funcional e simbólico. O valor funcional deriva da propriedade do bem em alterar um estado do mundo, com base no seu efeito físico. Já o valor simbólico refere-se ao significado de um bem, ou serviço, para seu proprietário e para seu ambiente social, para além de seus efeitos físicos.

Beckert (2011) distingue, ainda, o valor simbólico em duas dimensões: posicional e imaginário. Nas duas dimensões, o valor do bem se baseia nas qualidades atribuídas que transcendem sua materialidade. Porém, no caso do valor posicional, é necessário que outros atribuam significado simbólico ao bem, servindo, dessa forma de base para classificar o proprietário, conferindo-lhe certa identidade social. Ao passo que o valor simbólico imaginário é atribuído pelo próprio comprador, ainda que isso reflita valores e orientações morais socialmente constituídos. Este último pode ser caracterizado como ideais e valores transcendentais que alteram o estado de consciência do proprietário, isto é, bens que evocam imagens baseadas em associações simbólicas com eventos, pessoas, lugares ou valores desejados, mas cuja unidade existe apenas como uma construção mental (Beckert, 2011).

Nesse sentido, bens como o automóvel elétrico não apenas posicionariam seus proprietários no espaço social por meio de sua significação simbólica, mas também são representações simbólicas de ideais e valores adotados (sustentabilidade, liberdade e eficiência) que podem ser imaginativamente apropriados por meio de sua compra (Aspers; Beckert, 2011). O Quadro 2 sintetiza os valores atribuídos pelos entrevistados nesta tipologia.

Tabela 2 | Tipos de valores mobilizados

	Valor	
Funcional	Simbólico	
	Posicional	Imaginário
Menos manutenção	Economicamente racional	Eficiência no transporte
Menor consumo		
Menos impostos		
Maior segurança	Vanguarda tecnológica	Liberdade individual
Menos ruído/vibração		
Tecnologia embarcada		
Menor emissão de CO2	Ambientalmente responsável	Sustentabilidade
Matriz energética renovável		
Menos emissão de poluentes		

Fonte: Elaborado pelo autor.

Apesar dos valores simbólicos não serem necessariamente vinculados aos valores funcionais, nesse caso é possível traçar uma relação entre eles, pois as próprias qualidades materiais adquirem significados simbólicos. Por exemplo, valores funcionais atribuídos ao automóvel elétrico, como menor emissão de CO_2 e poluentes, contribuem para constituição de uma identidade "ambientalmente responsável" dos proprietários e, num movimento seguinte, para sua associação com valores intangíveis, com vínculos não muito claros com um futuro sustentável.

Os valores atribuídos pelos proprietários, funcionais ou simbólicos, vinculam-se diretamente ao processo de valoração no mercado de automóveis, na medida em que expressam qualificadores compartilhados intersubjetivamente, buscados na troca comercial. É verdade que as dimensões analíticas se sobrepõem no processo de valoração dos entrevistados, como pode ser observado na fala abaixo:

> Eu acho que, cara, primeiro, tem uma pegada assim de responsabilidade né, de você já estar pensando em emissão de poluentes, etc. Eu acho a experiência de dirigir o elétrico muito agradável, em termos de silêncio, de conforto, até de performance, de torque, aceleração, etc. Eu acho a experiência do elétrico muito legal. Então eu acho que é um mix dessas coisas todas, você já está seguindo uma tendência, de alguma forma contribuindo com a redução de emissão, e por uma experiência agradável, uma experiência de conforto e silêncio que o elétrico te traz também (João, engenheiro mecânico, 49).

Dessa forma, o valor funcional, o automóvel mais silencioso e confortável, encontra-se em consonância com o valor simbólico e o desejo de atender a expectativas coletivas de responsabilidade e redução das emissões. Em alguns casos, o valor simbólico imaginário é expresso na forma de um desejo de "melhorar o planeta para quem está chegando" (Pedro, Engenheiro Eletrônico, 60).

Porém, a questão do impacto ambiental dos elétricos é amplamente controversa e repleta de contradições. Principalmente quanto à metodologia de cálculo de emissões utilizada e quais aspectos considerados (Messagie, 2014; Nordelöf *et al.*, 2014). Metodologias que consideram a emissão de GEE associada à produção da energia e à propulsão dos veículos (*weel-to-wheel*) apresentam resultados

mais positivos do que as que levam em conta também a fabricação das baterias e o fim da sua vida útil (análises de ciclo de vida completas).

Um segundo fator que afeta diretamente esse cálculo é a matriz elétrica em que operam esses automóveis. No caso brasileiro, em que a matriz elétrica é 83% originada de fontes renováveis (EPE, 2021), a emissão de GEE vinculada aos automóveis elétricos acaba sendo menor do que em países mais dependentes de fontes de energia fóssil. Configuração que se encontra em consonância com valores dos entrevistados preocupados com as emissões de GEE e com sua matriz energética pessoal. Um exemplo mais radical disso são os proprietários que entendem a possibilidade de geração domiciliar de energia elétrica, através de painéis fotovoltaicos, como uma fonte de valor significativo, não apenas com base em critérios monetários, mas também como uma forma sustentável e independente de abastecimento.

> Tudo lá em casa é elétrico cara, até a escova de dentes [risos]. Quando você tem uma produção de energia na sua casa você começa a ter a liberdade que se dá né, você está produzindo localmente a energia, é todo um conceito, não é só um carro, é um conceito de sustentabilidade: você produzir, usufruir e não poluir. E fazer isso no teu âmbito privado, é uma forma libertária (Mauro, empresário, 41).

Nesse mesmo sentido, a tecnologia embarcada e a possibilidade de uso de energia elétrica domiciliar para abastecimento são significados simbolicamente como atributos que posicionariam os proprietários em uma categoria social de vanguarda tecnológica. Já a referida liberdade em relação aos postos de combustíveis e eventuais paralisações e flutuações bruscas nos preços dos combustíveis, apontada como uma forma de "empoderamento" dos proprietários em face dessas eventuais oscilações, está mais para um valor imaginário, pois, mesmo que o "combustível esteja dentro de casa" o sistema de transporte é coletivo e depende de uma série de fatores que extrapolam o âmbito individual. Obviamente, essa fonte de valor foi relatada apenas por proprietários de veículos BEV.

Por outro lado, os proprietários de veículos HEV e PHEV, ao justificarem suas escolhas, apontaram a menor dependência da infraestrutura de recarga, ou independência no caso dos híbridos convencionais, como um aspecto positivo. No caso dos híbridos *plug-in*, a possibilidade de rodarem com o motor a combustão ou com o elétrico, alternadamente, é vista como uma fonte de valor, uma vez que o número de carregadores disponíveis ainda é considerado pequeno, principalmente em rodovias e cidades do interior. Aliás, a infraestrutura de recarga incipiente é considerada, com o preço dos automóveis, a principal desvantagem para os proprietários.

O mesmo pode ser constatado quando observamos os valores vinculados à racionalidade econômica. O automóvel elétrico é valorizado por potencialmente reduzir a emissão de poluentes e gases de efeito estufa, mas, também, por viabilizar uma economia de longo prazo (*payback*), conforme ilustra a resposta a seguir, sobre os fatores decisivos para a escolha do elétrico.

> Em um primeiro momento, não só eu, como talvez até o mundo corporativo que está vendo hoje, é a questão de economia, se a gente for computar eu tive uma economia de 15 mil reais ano entre combustível, IPVA e manutenção. Então essa era minha economia ano. Isso quer dizer que, no primeiro momento, é o que as empresas hoje estão fazendo, uma empresa não compra 1.200 caminhões elétricos porque vai... vai explorar isso também, o conceito de sustentabilidade, mas não é sustentabilidade, é negócio, é capitalismo puro nessa relação de economia e de manutenção. [...] Então se nós analisarmos esse primeiro conceito que leva alguém, fazendo um cálculo, é a questão da manutenção, a questão econômica mesmo, e depois vem a questão da sustentabilidade, meio ambiente, você deixa de emitir CO_2 e contribui para o meio ambiente de todos, né (Edson, gestor hospitalar, 55).

Todavia, esses valores simbólicos não são descolados do valor monetário no processo de valoração. Pesquisas de mercado mostram que a disposição dos consumidores em pagar mais caro pelos elétricos, mesmo concordando com o potencial dos elétricos em reduzir o impacto ambiental, diminui conforme

aumenta o valor excedente destes em relação aos automóveis convencionais. Segundo o estudo (Heineke, 2020), apenas 3% dos entrevistados estavam dispostos a pagar mais de 30% do valor, em relação a veículos com motores de combustão interna, em veículos elétricos a bateria.

Novamente, observa-se o critério econômico (monetário) como algo relevante para a avaliação dos proprietários. Esse dado é corroborado pela pesquisa de mobilidade, realizada pela SAE (SAE Brasil; KPMG; Autodata, 2021), que aponta, entre executivos da indústria automotiva e consumidores de veículos, o custo de aquisição como um dos principais entraves dos veículos elétricos no mercado.

Contudo, a questão do custo de aquisição, quando abordada de forma específica, apresenta matizes relacionados aos demais critérios (morais, tecnológicos e estéticos) envolvidos no processo de valoração. De maneira geral, os proprietários julgam o preço justo se considerados fatores como o nível de desenvolvimento da tecnologia, o baixo volume de vendas, as vantagens implicadas, a carga tributária e os benefícios à saúde e ao ambiente. O trecho abaixo exemplifica essa atitude diante da questão do preço.

> Eu fiz uma extravagância, não acho justo não, porque era muito caro, [...] mas, por outro lado, eu achava que para atender essa coisa que eu queria, eu queria ter uma coisa mais moderna em termos de conceito. Porque eu acho que a gente tem de pagar os custos do nosso impacto no planeta. Esse que é o meu ponto, então, a gente tem que pagar por isso. (Ana, professora universitária, 66).

Nesse caso, percebe-se um movimento de objetificação (precificação) de valores subjetivos, como os impactos da atividade humana na natureza, que acaba aumentando o valor experimentado subjetivamente. É o que Fourcade (2011), ao estudar processos civis envolvendo derramamentos de óleo nos Estados Unidos e França, chama de ciclo de retroalimentação da avaliação monetária para as representações e práticas sociais. Com base na sociologia de Simmel (1978), a autora defende que a relação entre valor subjetivo e valor objetivado não é unidirecional, mas dialética. Isso porque o valor que as pessoas atribuem a um objeto pode estar conectado às condições de compra e ao sacrifício monetário realizado no momento da compra.

O mesmo pode ser dito em relação ao custo de ser vanguarda em uma tendência tecnológica. Há um movimento de precificação do valor com base no nível de desenvolvimento e difusão da tecnologia, que em seguida é experimentado subjetivamente como algo positivo, como algo inerente ao papel de promotor de tendências

> É justo em função do nível de desenvolvimento da tecnologia, eu acho que é uma tecnologia que ainda tem muito a evoluir, o custo de baterias tem que baixar, por mais adoção, etc. Acho que isso também, é algo que eu costumo falar, quando você adota um veículo elétrico e promove esse veículo elétrico, de alguma forma também está colaborando para que isso aconteça no futuro de uma forma mais intensa e com isso todo o custo baixe (João, engenheiro mecânico, 49)..

Essa dinâmica de retroalimentação da avaliação monetária para as representações sociais baseia-se, principalmente, no valor simbólico de alguns bens, isto é, nos significados compartilhados intersubjetivamente, que são estabelecidos na comunidade e emergem nas práticas sociais.

Apesar dos significados compartilhados, esses valores fundamentam-se, principalmente, no uso individual dos automóveis. Quando confrontados com questões referentes aos principais problemas e tendências da mobilidade urbana, grande parte dos entrevistados apontou o uso individual de automóveis como um problema a ser superado. Nesse sentido, percebe-se uma certa consciência sobre os limites do uso individual do automóvel elétrico como forma de responder a esses problemas e alcançar os valores imaginários associados a ele (eficiência, liberdade e sustentabilidade). Todavia, entendem-se esses problemas como algo coletivo, dependente de soluções estruturais.

> Assim, mudanças para a sociedade eu não sei se seria algo tão dramático. De fato, eles vão confluir para um ambiente menos poluído, então nesse sentido sim, essa é a grade contribuição do veículo elétrico, né. Agora, por exemplo, o veículo elétrico não vai contribuir para a redução dos engarrafamentos, isso continua, porque elétrico ou a combustão, ele continua ocupando o mesmo espaço na rua. Nesse outro aspecto não muda absolutamente nada, ele muda no sentido de ser menos contaminante, etc. Acho que sim, mas com essa... com essa limitação de visão. (Paulo, bancário, 78).

Ou seja, ainda que a questão dos problemas socioambientais possa ser sobreposta como uma fonte de valor relacional e simbólica, como um valor atribuído pela coletividade e pelo proprietário na construção de sua identidade, a aquisição de um automóvel elétrico para uso particular figura como uma resposta individual e, portanto, sujeita a limites que só uma ação coordenada poderia responder de forma adequada.

5 CONSIDERAÇÕES FINAIS

Conforme visto nas seções anteriores, o mercado nacional de automóveis eletrificados, ainda que represente uma parcela modesta no total de vendas de automóveis, apresentou, nos últimos anos, um crescimento significativo. A análise da frota revelou o predomínio de veículos híbridos convencionais, com especial participação dos híbridos *flex fuel* produzidos pela Toyota, aspecto que aponta para uma disputa tecnológica ainda em aberto na composição da frota e para a continuidade do motor a combustão interna, associado a fontes renováveis, como alternativa "sustentável". A expressiva presença de automóveis *premium* e pertencentes a categorias grandes, como SUVs e modelos extragrandes, é outro elemento que chama atenção pela aparente contradição com o ideal de eficiência.

De forma correlata, observou-se que o perfil dos proprietários entrevistados corresponde, em sua maioria, a homens, acima de 40 anos, com ensino superior completo, bem-informados e com condições financeiras suficientes para adquirir um automóvel de custo elevado. Em parte, esse perfil é devido ao recorte proposto pela amostra intencional, que buscou abranger diferentes tipos de veículos. Por outro lado, ele reflete a disposição desse perfil em participar de pesquisas sobre o tema e externalizar seus critérios e justificativas para a aquisição.

Sobre os diferentes tipos de propulsão, foi possível perceber variadas expectativas em relação à rede de infraestrutura de recarga, com os proprietários de HEVs e PHEVs se mostrando mais reticentes em relação a essa dependência. Outra diferença importante foi o fato de os proprietários de BEVs perceberem a autonomia em relação aos postos de combustíveis com uma fonte de valor, monetário e simbólico, para o automóvel elétrico.

Apesar dessas diferenças em relação à recarga, todos os proprietários mobilizaram valores funcionais e simbólicos como critérios para a aquisição de seus automóveis. Cabe salientar que o custo de aquisição é percebido como uma desvantagem, uma barreira inicial, mas que, ao mesmo tempo, é algo passível de ser subjetivamente valorizado, como o preço a ser pago pelo impacto da atividade humana no planeta, ou para fazer parte de uma vanguarda tecnológica. Percebe-se, com isso, o imbricamento entre o valor funcional, o desejo por um automóvel mais econômico, eficiente, silencioso e confortável, e o valor simbólico, o desejo de atender a expectativas coletivas de responsabilidade e redução das emissões de poluentes e gases de efeito estufa.

Por sua vez, a análise dos critérios mobilizados no processo de valoração do automóvel elétrico mostrou que as representações simbólicas de ideais e valores adotados (sustentabilidade, liberdade e eficiência) são imaginativamente apropriadas e possuem uma conexão distante da realidade. Principalmente no que se refere às emissões de gases de efeito estufa e análises de ciclo de vida que calculam todos os impactos da cadeia produtiva dos automóveis elétricos, sujeitas a controvérsias metodológicas.

Aqui cabe referir, ainda que estudos recentes (Mera *et al.*, 2023) apontem de forma robusta para uma menor emissão de GEE (ciclo do combustível/eletricidade + ciclo do veículo) oriunda dos elétricos, o ideal de sustentabilidade não se restringe à emissão de gases. Em especial, no caso dos SUVs e de veículos maiores, é bom destacar: o Hummer EV não pode ser considerado uma opção sustentável por ser movido a energia elétrica e emitir menos gases em comparação com a versão convencional. Logo, haveria, nessas situações, uma acomodação das contradições ambientais, fruto de um desencaixe entre a consciência da emergência climática e a efetiva alteração das práticas cotidianas (Giddens, 2009).

Dessa forma, entende-se a sustentabilidade e a preocupação com as emissões de poluentes e gases do efeito estufa como uma fonte de valor importante para os proprietários de automóveis elétricos, para auxiliar no seu posicionamento no espaço social por meio de sua significação simbólica. Todavia, trata-se de um valor que aparece, principalmente, como consequência do valor econômico e da eficiência energética vinculada ao automóvel elétrico. Esse olhar sobre o processo de valoração permite constatar um expressivo e crescente peso da pauta socioambiental para os proprietários, apontando para a valorização do uso de fontes renováveis, inclusive na esfera doméstica, e da baixa emissão de poluentes. Por outro lado, a relevância de valores funcionais, vinculados ao uso individual, mostra que dificilmente esse consumo será traduzido, no curto prazo, em grandes transições sociotécnicas que correspondam aos valores imaginários de liberdade, transporte eficiente e sustentabilidade.

Por fim, cabe referir que os valores funcionais mobilizados para aquisição de automóveis eletrificados estão em relativa consonância com os valores simbólicos e que a maioria dos entrevistados tem ciência dos limites da eletrificação de automóveis, vinculados, especialmente, ao uso individual destes. Esses limites dizem respeito às diferenças de enfoque (individual e coletivo) no uso dos meios de transporte e às contradições relacionadas às escolhas políticas que priorizam determinados modais em detrimento de outros.

NOTAS

1| A categoria automóvel eletrificado abrange: veículos elétricos a bateria (BEV), veículos elétricos híbridos *plug-in* (PHEV) e veículos elétricos híbridos convencionais (HEV), sem recarga via rede elétrica.

2| As Resoluções Camex nº 97/2015 e 27/2016 zeraram o Imposto de Importação (II), que era de 35%, para veículos a propulsão elétrica ou movidos a hidrogênio, e reduziram de 0% a 7% para veículos híbridos, conforme o nível de eficiência energética.

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REFERÊNCIAS

ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

ASSOCIAÇÃO NACIONAL DOS FABRICANTES DE VEÍCULOS AUTOMOTORES. **Anuário da indústria automobilística brasileira**. São Paulo: 2023.

BECKERT, J. The Transcending Power of Goods: imaginative value in the economy. In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

BLOOMBERG. **Hitting the EV Inflection Point**. Electric vehicle price parity and phasing out combustion vehicle sales in Europe – Transport & Environment, may/2021.

CARNEIRO, M. S. O papel dos dispositivos de prescrição e julgamento no funcionamento dos mercados: o caso da certificação florestal. **Revista Tomo.** v. 30, p. 267-302, 2017.

CARVALHO, M.; BONAZZI, D.; GUEDES, L. **O futuro da mobilidade é tech**: veja como os setores de auto e viagens podem se preparar. Available at: https://www.thinkwithgoogle.com/intl/pt-br/tendencias-de-consumo/tendencias-de-comportamento/tecnologia-auto-viagem/. Access on: Oct. 16, 2023.

EMPRESA DE PESQUISA ENERGÉTICA. **Balanço Energético Nacional 2021**: Ano-base 2020 / Empresa de Pesquisa Energética. Rio de Janeiro: EPE, 2021.

FEDERAÇÃO NACIONAL DA DISTRIBUIÇÃO DE VEÍCULOS AUTOMOTORES. **Anuário do Setor de Distribuição de Veículos Automotores no Brasil 2022**. São Paulo, 2023.

FLICK, U. **Desenho da pesquisa qualitativa**. Porto Alegre: Artmed, 2009. 164 p.

FOURCADE, M.; HEALY, K. Moral Views of Market Society. **Annual Review of Sociology**, v. 33, 2007.

FOURCADE, M. Price and prejudice: on economics and the enchantment (and disentchantment) of nature. In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

GEELS, F. W. Sociotechnical transitions to sustainability: a review of criticisms and elaborations of the multi-level perspective. **Current Opinion in Environmental Sustainability**, Open Issue 2019. v. 39, p. 187–201, 2019.

GIDDENS, A. **The politics of climate change**. Cambridge, Polity Press, 2009.

GRANOVETTER, M. Economic Action and Social Structure: the problem of embeddedness. **American Journal of Sociology**, v. 91, n. 3, p. 481–510, 1 nov. 1985.

HEINEKE, K. *et al.* **ACES 2019 survey**: Can established auto manufacturers meet customer expectations for ACES? McKinsey & Company, 2020.

INGEBORGRUD, L.; RYGHAUG, M. The role of practical, cognitive and symbolic factors in the successful implementation of battery electric vehicles in Norway. **Transportation Research Part A:** policy and practice, v. 130, p. 507–516, 1 dez. 2019.

INTERNATIONAL ENERGY AGENCY. **Global EV Outlook 2022**, IEA, Paris, 2021.

INTERNATIONAL ENERGY AGENCY. **Electric cars fend off supply challenges to more than double global sales**, IEA, Paris, 2022. Available at: https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales . Accessed on: Mar. 10, 2022.

KARPIK, L. **Valuing the Unique**: the economics of singularities. Princeton University Press, 2010.

KÖHLER, J. *et al.* An agenda for sustainability transitions research: state of the art and future directions. **Environmental Innovation and Societal Transitions**, Amsterdam, v. 31, p. 1-32, 2019.

LAMONT, M. Para uma conexão necessária entre a Sociologia da Valoração e da Avaliação com a Sociologia Econômica e das Finanças (Tradução). **Norus**, v. 1, p. 1, 2013.

MERA, Z. *et al.* **Comparação das emissões de gases de efeito estufa no ciclo de vida de carros de passeio a combustão e elétricos no Brasil**. [s.l: s.n.]. Available at: www.theicct.org.

MESSAGIE, M. **Life Cycle Analysis of the Climate Impact of Electric Vehicles**. [s.l: s.n.].

NIEDERLE, P. A.; RADOMSKY, G. F. W. Quem governa por dispositivos? A produção das normas e padrões para os alimentos orgânicos no Brasil. **Revista Tomo**. v. 30, p. 267-302, 2017.

NOPPERS, E. H. *et al.* The adoption of sustainable innovations: driven by symbolic and environmental motives. **Global Environmental Change**, v. 25, n. 1, p. 52–62, 2014.

NORDELÖF, A. *et al.* Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—what can we learn from life cycle assessment? **International Journal of Life Cycle Assessment**. Springer Verlag, 14 out. 2014.

PLATAFORMA NACIONAL DE MOBILIDADE ELÉTRICA. **Anuário Brasileiro da Mobilidade Elétrica**, 2022.

POLANYI, K. **A subsistência do homem e ensaios correlatos**. 1. ed. Rio de Janeiro: Contraponto, 2012.

SAE BRASIL; KPMG; AUTODATA. **Pesquisa SAE Mobilidade**, 2021.

SECRETARIA NACIONAL DE TRÂNSITO. **Estatísticas – Frota de Veículos, (2015-2022)**, 2022. Available at: https://www.gov.br/infraestrutura/pt-br/assuntos/transito/conteudo-denatran/estatisticas-frota-de-veiculos-senatran. Accessed on: Apr. 25, 2022.

SIMMEL, G. **The Philosophy of Money**. Boston, MA: Routledge Kegan and Paul, 1978.

STARK, D. What's valuable? In: ASPERS, P.; BECKERT, J. (Org.). **The Worth of Goods**: valuation and pricing in the economy. New York: Oxford University Press, 2011.

WOLFFENBUTTEL, R. **A Produção Social da Inovação**: o automóvel elétrico e as redes de inovação no Brasil. Porto Alegre, Cirkula, 2021.

The hidden vulnerabilities behind financial sustainability: a case study of a sugarcane farm business in Pemalang City, Central Java, Indonesia

As vulnerabilidades ocultas por trás da sustentabilidade financeira: um estudo de caso de uma fazenda de cana-de-açúcar na cidade de Pemalang, Java Central, Indonésia

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ABSTRACT

This study assesses the financial viability of a 4-hectare sugarcane farming enterprise operated by Perhutani, an Indonesian State-Owned Enterprise. The farm is situated in the geographical limits of Pemalang City, which is located in the Central Java Province of Indonesia. This study employs a financial feasibility analysis approach that involves the computation of key financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Pay Back Period (PBP), Benefit Cost Ratio (BCR), and the application of sensitivity analysis. Overall, the assessment of the viability of a 4-hectare sugarcane farming enterprise indicates that it is financially feasible and has the potential to operate as a sustainable business. This conclusion is drawn from the positive numerical values obtained through various financial analysis techniques. Nevertheless, it is evident from the conducted sensitivity analysis that sugarcane farming is a highly susceptible business to fluctuations in prevailing conditions. When molasses production experienced reductions of 10% and 15%, most financial feasibility analysis estimates yielded negative values. The issue of production vulnerability extending beyond economic feasibility has been rendered inconspicuous by many reasons, including climate change.

Keywords: Vulnerability. Climate Change. Financial. Feasible Study. Sugarcane. Farm Business.

RESUMO

O objetivo deste estudo é avaliar a viabilidade financeira de uma empresa agrícola de cana-de-açúcar de quatro hectares operada pela Perhutani, uma empresa estatal da Indonésia. A fazenda está situada nos limites geográficos da cidade de Pemalang, localizada na província de Java Central, na Indonésia. O estudo emprega uma abordagem de análise de viabilidade financeira que envolve o cálculo dos principais indicadores financeiros, como Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR), Período de Retorno (PBP), Relação Custo-Benefício (BCR) e a aplicação de análise de sensibilidade. No geral, a avaliação da viabilidade de um empreendimento agrícola de cana-de-açúcar de quatro hectares indicou que é financeiramente viável e tem potencial para funcionar como um negócio sustentável. Essa conclusão é tirada dos valores numéricos positivos obtidos por meio de diversas técnicas de análise financeira. No entanto, é evidente, a partir da análise de sensibilidade realizada, que o cultivo da cana-de-açúcar é um negócio altamente suscetível a flutuações nas condições prevalecentes. Quando a produção de melaço sofreu reduções de 10% e 15%, a maioria das estimativas de análises de viabilidade financeira produziu valores negativos. A questão da vulnerabilidade da produção, que vai além da viabilidade econômica, tornou-se imperceptível por uma série de razões, incluindo as alterações climáticas.

Palavras-chave: Vulnerabilidade. Mudanças Climáticas. Financeiro. Estudo de Viabilidade. Cana-de-Açúcar. Negócios Agrícolas.

1 INTRODUCTION

Sugar is a globally consumed commodity, with notable consumption levels observed in Indonesia. The notable surge in sugar consumption in Indonesia has correspondingly led to an escalation in the volume of sugar imports from diverse nations to meet domestic demands. According to the data from the Indonesia Bureau of Statistics in 2022, there has been a notable increase of 971,044.8 tons in the volume of imported sugar between 2017 and 2021. One potential measure that might be undertaken in this case is to augment sugar output to fulfil domestic demands. Indonesia's State-owned enterprise, Perhutani, engages in the agricultural sector. Perhutani division of Pemalang City, located in the Central Java Province, possesses a 4-hectare plot of land dedicated to cultivating sugarcane crops. The extension of sugarcane crop territory is associated with both good and negative impacts (Machado *et al.*, 2014). We conducted a financial viability assessment to determine the feasibility of maintaining operations for a four-hectare sugarcane plantation. A sensitivity analysis was conducted to assess the susceptibility of the four-hectare plant to future alterations. This study reveals that the sugar cane industry exhibits considerable financial profitability over an extended period of 11 years. The time range for conducting financial profitability analysis was selected to align with the duration of sugar cane's life cycle before replanting with fresh seeds. According to Verheye (2010), the duration of effective sugarcane planting typically spans four years in cases of highly intensive and mechanised cropping or 10 to 12 years in the setting of large agricultural or smallholder farming. However, the outcomes of the sensitivity analysis yielded.

The cultivation of a 4-hectare canopy is highly susceptible to ongoing changes, specifically the decrease in productivity. There exist various factors that can contribute to the occurrence of this phenomenon, with climate change being identified as one of them. The sugarcane production is highly susceptible to excessive rainfall since water overflow in the soil can hinder crop nutrient uptake, impeding the plants' optimal growth. The issue of climate change is a significant challenge in the context of sugarcane agriculture since it can lead to the occurrence of extreme heat events and heavy precipitation (Santos *et al.*, 2020). These climatic disturbances can potentially affect crops' growth and reduce their productivity. Drought has emerged as a significant contributing factor to the susceptibility of industrial production (Roy *et al.*, 2022). The physiological processes involved in sugarcane growth, which necessitate increased water intake during periods of limited precipitation, might be negatively impacted by extreme heat. The alteration in meteorological conditions leads to a decrease in sugarcane production, resulting in a corresponding decline in the revenue generated by the industry. The study by Cristina *et al.* (2021) on Reunion Island provides further empirical proof that climate change has substantially influenced worldwide agricultural output, as demonstrated by the 20-year decrease in sugarcane yields. The sensitivity analysis conducted on the decline in sugarcane production provides empirical support for the presence of an underlying issue pertaining to the substantial profitability and favourable financial feasibility of the sugarcane plantation occupying a 4-hectare tract of land. The existence of these imperceptible vulnerabilities might serve as a point of consideration for all stakeholders engaged in decision-making processes, as well as for the implementation of precautionary or mitigating strategies. This is crucial to ensure the sustainability and financial resilience of sugarcane production.

2 MATERIALS AND METHODS

2.1 DATA COLLECTION

The research was conducted at Pemalang, a city in the Central Java Province of Indonesia. The sugarcane cultivation area in this region spans 4 hectares and is managed by Perhutani, an Indonesian State-owned enterprise agency.

2.2 DATA ANALYSIS

- Production Performance Analysis

The calculation of total receipts involves determining the discrepancy between the sales revenue generated from the sale of sugarcane and the combined costs of variable and fixed expenses. The analysis of farm business is conducted for a single agricultural season.

- Financial Feasibility Analysis

The financial feasibility analysis is a comprehensive evaluation of the financial viability of a project or investment. Financial viability analysis encompasses various calculations, such as the Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR), Pay Back Period (PBP), and sensitivity analysis. Financial sustainability refers to the situation where a business is considered viable due to its ability to provide suitable earnings and survive potential fluctuations in environmental and economic circumstances. This resilience allows the business to yield returns beyond the initial investment. An assessment of financial sustainability was conducted over a span of 11 years, employing a 7% interest rate. In June 2023, the exchange rate between the United States Dollar (US$) and the Indonesian Rupiah (IDR) was 1 US$ = 14,980 IDR. The formulas used to calculate NPV, BCR, PBP, and IRR are as follows:

- Present Value Net (NPV)

The concept of Net Present Value (NPV) refers to a financial metric used to evaluate the profitability of an investment by calculating the difference between the present value of cash inflows and outflows over a given time. The Net Present Value (NPV) is the present value of the net cash flows expected to be generated in the future. The Net Present Value (NPV) is computed using the following mathematical equation:

$$NPV = \sum_{n}^{t=11} \frac{(Bt - Ct)}{(1+i)^t}$$

Bt = Profit per annum

Ct = Total annual expenditure

N = Quantity of years

R = Discount Rate

t = year

- Benefit-to-Cost Ratio (BCR)

The benefit-to-cost ratio is a comparison between a positive and negative NPV. If the comparison result is greater than 1, it can be concluded that the NPV merits execution. Calculate BCR using the following formula:

$$\mathbf{BCR} = \frac{\sum_{t=11}^{n} \frac{(Bt-Ct)}{(1+i)^t}}{\sum_{t=11}^{n} \frac{(Ct-Bt)}{(1+i)^t}}$$

- Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is derived as the interest rate at which an investment's Net Present Value (NPV) becomes equal. In order to deem a business worthwhile, the internal rate of return (IRR) must exceed the interest rate. The computation of the internal rate of return (IRR) is conducted in the following manner:

$$\textbf{IRR} = i + \frac{NPV}{(NPV' - NPV'')} x(i' - i'')$$

i' = the interest rate at the time when NPV is positive

i'' = interest rates at the time of negative net present value

NPV' = Negative NPV

NPV'' =Positive NPV

- Pay Back Period (PBP)

The Pay Back Period (PBP) is a financial metric used to evaluate the time required for an investment to generate sufficient cash flows to recover the initial investment cost. The Pay Back Period (PBP) is a quantitative measure used to estimate the time required for a significant investment to generate sufficient returns to recoup the initial investment. A smaller payback period (PBP) number is preferable as it indicates a faster capital return time. The calculation of Payback Period (PBP) is determined using the following formula:

$$\textbf{PBP} = t' + \frac{Rv''}{Rv'}$$

t' = The year preceding the occurrence of positive income.

Rv' = The most recent instance of negative income.

Rv'' = Positive income.

- Sensitivity Analysis

Sensitivity analysis is a quantitative technique used to assess the impact of changes in input variables on the output of a mathematical model or system. Following the completion of the financial viability calculations, a sensitivity analysis was conducted to ascertain the potential financial vulnerability of the farm business. The present section provides an overview of the results obtained in this study, followed by a discussion of their implications and potential limitations. A comparative analysis was conducted to assess the financial feasibility of the farm business by implementing a reduction of 10% and 15% in sugarcane production. The percentages of 10% and 15% were selected as the reduction in sugar cane crops based on the findings of (Saunders, 1983), which suggests that little changes in a financial data analyst approach can yield significant variations in the outcomes. An initial sensitivity analysis was conducted, focusing on minimum reductions, to assess the feasibility vulnerability resulting from little variations in the quantity of sugarcane harvested. Sensitivity analysis is a technique applied to inform investment decisions by considering the potential impact of uncertain input values, such as revenue, cost, and investment value (Khan *et al.*, 2017; Peter, 2020)while assuming an annualised interest rate

of 7%. The Central Bank of Indonesia determines the interest rate in September 2023, with a range of 5.75% - 6.5% (Indonesian Central Bank, 2023). The interest rate applied as a benchmark is 7%, representing the most possible escalation in the interest rate employed in Indonesia.

3 RESULTS AND DISCUSSION

In the context of State-Owned Corporate Entities, the cultivation of a four-hectare sugarcane plantation represents a substantial land allocation. Compared to the average agricultural land ownership in Indonesia, which is approximately 0.95 hectares, the land in consideration can be characterised as a substantial expanse of land ownership. Additionally, it is noteworthy that the average annual income derived from farming activities in Indonesia is reported to be $333.5 (Indonesia Central Bureau of Statistics, 2021). It is anticipated that the utilisation of land by sugarcane will result in optimal agricultural productivity. Nevertheless, there exists a disparity between the assertions made by Aragón *et al.* (2022) and Gautam and Ahmed (2019) regarding the inability of economic outcomes to directly elucidate the positive correlation between land area and productivity. Additional examination of the financial sustainability of the sugarcane industry pertains to the generation of sugarcane yields and the expenses incurred in the annual production of sugarcane. The primary component of spending in this farm business is the acquisition of agricultural equipment, encompassing both fixed and variable costs. Variable costs encompass various expenses, including land preparation, planting, fertilisers, seasoning, and other miscellaneous charges. The expenditure on agricultural equipment represents an initial investment in the firm, the entirety of which is not depleted throughout the course of output. According to Araya and Asafu-Adjaye (1999), the level of operational costs is directly influenced by the degree of risk associated with the operations being conducted.

Table 1 | Operational Cost Structure of Sugarcane Farming in 1 Year

Cost		*US$*
Fixed Cost	Farm Equipment	$ 2,517
Total Fixed Cost		**$ 2,517**
Variable Cost	Land Preparation	$ 1,175
	Plantation	$ 1,623
	Pesticides, Fertiliser	$ 4,711
	General Fees	$ 1,308
Total Variable Cost		**$ 8,817**
Total Cost		**$ 11,334**

The aggregate fixed cost amounts to $2,517. The subsequent expense incurred within the sugarcane farm business is classified as a variable cost. The variable cost is subject to the effect of the manufacturing process associated with the input and the resulting output. The sum of the variable cost component amounts to $8,817. The aggregate expenditure of establishing 4 hectares of sugarcane farm business amounts to $11,334. Upon examination, it is observed that the aggregate fixed cost accounts for 22% of the whole, while the collective variable cost constitutes 78%. Based on the findings of Kumar *et al.* (2020), it has been shown that variable costs in typical businesses exhibit a range of 79% to 87%, with variable costs being much higher than fixed costs, which range from 13% to 21%. In a study conducted by Diatin *et al.* (2021), it was found that the variable cost accounted for the highest proportion of effort. In sugarcane production, fertilisers and pesticides are the most significant expense. This is because these inputs are crucial for promoting higher yields of sugarcane. In contemporary times, agriculture relies significantly on the supplementation of foreign nutrients via fertilisation Moshkin *et al.* (2023).

Consequently, this practice contributes to an escalation in the variable cost associated with planting. However, an alternative perspective is presented in a study conducted by Liverpool-Tasi (2017), which

posits that the heightened use of fertilisers does not necessarily guarantee the instant augmentation of earnings for farmers. This is due to the presence of various other factors that exert influence on farmers' income levels.

Table 2 | The Annual Profit for Sugarcane Farming

Items	*Amount*
Yield Molasses (tonnes)	850
Price Molasses (US$)/ton	$40,7
Total Revenue (4ha)	$13.842
Total Cost	$11.334
Profit	$2.509

The sugarcane farm business has the potential to undergo two harvests annually, so indicating the existence of two distinct growing seasons, each spanning a duration of six months. The annual sugarcane harvest on a 4-hectare plot of land yields a total of 85 tonnes of molasses, which are then sold at $40,7 per ton. The annual net profit resulting from the sale of a molasses, which generated a total income of $13,842, amounts to $2,509.

Table 3 | Financial Feasibility Analysis of Sugarcane Farming

Items	*US$*
Total Cost	$11,334
Total Revenue	$13,842
Profit	$2,509
NPV (i=7%)	$7,477
BCR	1.66
IRR	19%
PBP	5.1

Farming is an integral component of the broader business landscape, necessitating a comprehensive financial analysis framework for effective management and operation. The financial analysis estimates for this sugarcane farm business are presented in Table 3. Upon acquiring a business profit calculation of $2,509, the initial step in the financial analysis involved computing the net present value utilising a 7% interest rate. The net present value (NPV) estimate was derived from the cumulative profit over an 11-year period, resulting in a positive figure. This positive value signifies the viability and profitability of the business.

The following analysis examines the comparison between positive net present value (NPV) and negative NPV, with the Business Cost Ratio (BCR) serving as the metric. If the BCR number exceeds 1, it indicates that the farm business is considered financially viable.

The Internal Rate of Return (IRR) is a financial metric representing the interest rate at which an investment's Net Present Value (NPV) becomes zero. In order to evaluate if the capital invested in beet cultivation yields a higher profit than the bank interest, the internal rate of return (IRR) must exceed the discount rate employed in the net present value (NPV) calculation. It is evident that the Internal Rate of Return (IRR) is 19%, surpassing the interest rate (i) by 7%.

The subsequent computation involves the Pay Back Period calculation, which assesses the duration required for the initial capital invested in the business to be recovered and for the business to commence generating profits. The duration of the farm business capital returns is five years and one month. Based

on the elapsed duration of 5 years and 1 month, it may be inferred that the sugarcane farm business capital will be restored, leading to the commencement of profitable operations for the business.

Table 4 | Sensitivity Analysis in Sugarcane Farming

Molasses Production Decreased (%)	*NPV*	*BCR*	*IRR*	*PBP*
10%	-$2,903	0.74	-4%	10.1
15%	-$8,092	0.29	-70%	26.3

The sensitivity analysis regarding the utilisation of sugarcane is evident through the observed reduction in the volume of molasses generated. The decrease in the production of molasses has a direct and significant impact on the outcomes of the financial viability study of the farm business.

The prevailing interest rate remains at 7%, which is a significant concern for the sugarcane farm business due to the fluctuating yields. This issue has emerged as a prominent factor affecting the business's sensitivity. Vulnerability refers to a state in which an entity is directly exposed to risk and stress resulting from environmental and social changes, accompanied by an inability to effectively adjust (Adger, 2006). Based on the data presented in Table 4, it can be observed that when business income decreases to 10% and 15% of the financial analysis calculations employing the Net Present Value (NPV) and Internal Rate of Return (IRR) metrics yield a value below zero. This means that the venture lacks viability and is not feasible. The assertion that an endeavour with a high net present value (NPV) is inherently worthwhile cannot be made without careful consideration of several factors. Additionally, if the investment is currently unfeasible, it may be prudent to delay it for a period of around three years because the implementation of the site-specific crop management (SSCM) program demonstrated a numerical simulation indicating that a positive net present value (NPV) required a delay in investment of three years until the average soil quality reached a high level, alongside substantial variability in soil quality and fertility (Khanna *et al.*, 2000). Similarly, while calculating the Benefit-Cost Ratio (BCR), if the reduction in molasses results in a decrease of 10% and 15 of the BCR values are lower than that, it suggests that the undertaking of the business is not economically viable.

The PBP approach was employed to calculate the return on capital for a business that experienced a 10% decline in production. The analysis revealed that the business's capital would take 10 years to recover before generating a profit. Based on the sensitivity calculation, it is evident that the financial challenges faced by the sugarcane farming industry are becoming increasingly apparent, indicating a certain level of susceptibility to changing conditions, albeit not significantly so. It is evident that a reduction in output by a mere 10% might render the evaluation of the viability of the sugarcane enterprise unfavourable and unviable.

Indeed, the computation of farm business analytics, when conducted under standard settings, ensures the certain profitability and sustainability of farm business. The occurrence of sugarcane farm business in this particular scenario strongly correlates with the ongoing climate change phenomenon. The vulnerability of farm businesses has been observed to escalate due to climate change (Bernal *et al.*, 2022; Dungumaro; Hyden, 2010). One contributing factor to this vulnerability is the persistent utilisation of inorganic inputs, which can result in various issues, including diminished fertility and degradation of soil, the heightened prevalence of pests and diseases, and additional social and cultural challenges. According to a recent study conducted by Etongo *et al.* (2022), progress has been seen in enhancing farmers' agricultural vulnerability in three dimensions: exposure, sensitivity, and adaptive capacity, over a span of 10 to 20 years.

Sugarcane growth is primarily vulnerable to climate change, with an emphasis on the impact of rising carbon dioxide levels that contribute to elevated air temperatures and humidity (Baez-Gonzalez *et al.*, 2018; Linnenluecke *et al.*, 2018; Zhao; Li, 2015). Sugarcane crops require high water levels; therefore, the increase in temperature and CO2 due to climate change might enhance the vulnerability and sensitivity

of sugarcane crop yields. According to a study conducted by Flack-Prain *et al.* (2021), the elevation of carbon dioxide (CO2) and other greenhouse gases in the atmosphere of the Earth can raise the Earth's surface temperature, thereby instigating climate change. This phenomenon, in turn, leads to natural calamities and has a disruptive influence on economic endeavours. The issue under consideration is not expected to assume significant prominence in the immediate future, but it is anticipated to become a matter of substantial gravity in the foreseeable future. This phenomenon is evident in our conducted sensitivity analysis, which reveals that even a minor decrease in molasses production has the potential to significantly undermine the overall profitability and sustainability of the enterprise. One potential strategy for addressing the impacts of climate change is the implementation of mitigation and appropriate adaptation measures (Verma *et al.*, 2018). The primary objective of mitigation technology is to diminish the release of greenhouse gas emissions emerging from agricultural land by using strategies such as cultivating low-emission crop types and using water and land management techniques. Various adaptation technologies can be implemented to address the challenges caused by climate change. These technologies involve altering planting schedules, utilising advanced drought-resistant crop types, and advancing water management techniques.

4 CONCLUSION

Generally, the financial viability analysis of the sugarcane farm business indicates that it is economically feasible and has the potential to operate as a sustainable venture. This conclusion is drawn from the good results obtained through various financial analysis methods. Nevertheless, it is evident that the sugarcane farm business exhibits a high degree of vulnerability to fluctuations in circumstances, as indicated by the conducted sensitivity analysis. When molasses production decreased to 10% and 15%, the financial viability study indicated predominantly negative statistics across the board. The potential benefits of the sugarcane farm business for farmers may not be readily apparent at first (Gambelli *et al.*, 2014; Khanna *et al.*, 2000). However, it is crucial to emphasise and promote farm business as a valuable social asset for advancing sustainable agriculture in the coming years. The study determines that the degree of tolerance towards susceptibility to alterations in farming is significantly elevated and necessitates proactive anticipation and mature planning. According to Akinyi *et al.* (2021), crop management, land management, water management, risk management, and livestock management are the five areas that encompass climate change adaptation. Another essential aspect to consider is the necessity of establishing effective collaboration between the forestry company and local farmers, considering that the forestry business is still predominantly managed by the latter. Enhancing farmers' understanding of contemporary climate change (Conceição *et al.*, 2019; Lebel *et al.*, 2015) is imperative to enhance the efficacy of agriculture management practices. Potential collaboration may encompass targeted climate-related management and mitigation efforts, as exemplified by the expansion of media accessibility to pertinent information (Antwi-Agyei; Stringer, 2021; Mendes *et al.*, 2022), the implementation of cutting-edge technological applications (Vasquez-Arroyo *et al.*, 2021) can be employed to alleviate the adverse effects on the food industry, social dynamics, and climate change. Furthermore, fostering transparency among farmers and stakeholders within the sugarcane farm business is crucial.

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REFERENCIAS

ADGER, W. N. Vulnerability. **Global Environmental Change**, v. 16, n. 3, p. 268–281, 2006. Available at: https://www.sciencedirect.com/science/article/pii/S0959378006000422.

AKINYI, D. P.; NG'ANG'A, S. K.; GIRVETZ, E. H. Trade-offs and synergies of climate change adaptation strategies among smallholder farmers in sub-Saharan Africa: a systematic review. **Regional Sustainability**, v. 2, n. 2, p. 130–143, 2021. Available at: https://doi.org/10.1016/j.regsus.2021.05.002.

ANTWI-AGYEI, P.; STRINGER, L. C. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: insights from northeastern Ghana. **Climate Risk Management**, v. 32, n. May 2020, p. 100304, 2021. Available at: https://doi.org/10.1016/j.crm.2021.100304.

ARAGÓN, F. M.; RESTUCCIA, D.; RUD, J. P. Are small farms really more productive than large farms? **Food Policy**, v. 106, 1 Jan 2022.

ARAYA, B.; ASAFU-ADJAYE, J. Returns to Farm-Level Soil Conservation on Tropical Steep Slopes: the case of the Eritrean Highlands. **Journal of Agricultural Economics**, v. 50, n. 3, p. 589–605, 1 Set 1999. Available at: https://doi.org/10.1111/j.1477-9552.1999.tb00900.x.

BAEZ-GONZALEZ, A. D. *et al.* Potential impact of future climate change on sugarcane under dryland conditions in Mexico. **Journal of Agronomy and Crop Science**, v. 204, n. 5, p. 515–528, 1 Out 2018. Available at: https://doi.org/10.1111/jac.12278.

BERNAL, N. *et al.* Impact of heat waves on cardiovascular and respiratory morbidity and mortality in municipalities of Northeast Brazil. **Sustainability in Debate**, v. 13, n. 2, SE-Articles-Varia, p. 96–122, 30 Ago 2022. Available at: https://periodicos.unb.br/index.php/sust/article/view/42228.

CHRISTINA, M. *et al.* Impact of climate variability and extreme rainfall events on sugarcane yield gap in a tropical Island. **Field Crops Research**, v. 274, p. 108326, 2021. Available at: https://www.sciencedirect.com/science/article/pii/S0378429021002720.

CONCEIÇÃO, M. C. G. *et al.* International climate change negotiation: the role of Brazil. **Sustainability in Debate**, v. 10, n. 3, SE-Articles-Varia, p. 379–395, 31 Dez 2019. Available at: https://periodicos.unb.br/index.php/sust/article/view/27962.

DIATIN, I. *et al.* Production performance and financial feasibility analysis of farming catfish (Clarias gariepinus) utilising water exchange system, aquaponic, and biofloc technology. **Journal of the Saudi Society of Agricultural Sciences**, v. 20, n. 5, p. 344–351, 1 Jul 2021.

DUNGUMARO, E. W.; HYDEN, G. Challenges and Opportunities to Climate Change Adaptation and Sustainable Development Among Tanzanian Rural Communities. **Sustainability in Debate**, v. 1, n. 2, SE-Dossier, p. 77, 22 Dez 2010. Available at: https://periodicos.unb.br/index.php/sust/article/view/15274.

ETONGO, D. *et al.* Risk perceptions, vulnerability and adaptation to climate change at farm level across four agricultural zones in Seychelles. **World Development Sustainability**, v. 1, n. July, p. 100025, 2022. Available at: https://doi.org/10.1016/j.wds.2022.100025.

FLACK-PRAIN, S. *et al.* The impact of climate change and climate extremes on sugarcane production. **GCB Bioenergy,** v. 13, n. 3, p. 408–424, 1 Mar 2021. Available at: https://doi.org/10.1111/gcbb.12797.

GAMBELLI, D.; SOLFANELLI, F.; ZANOLI, R. Feasibility of risk-based inspections in organic farming: results from a probabilistic model. **Agricultural Economics**, v. 45, n. 3, p. 267–277, 1 Mai 2014. Available at: https://doi.org/10.1111/agec.12063.

GAUTAM, M.; AHMED, M. Too small to be beautiful? The farm size and productivity relationship in Bangladesh. **Food Policy,** v. 84, p. 165–175, 2019. Available at: https://www.sciencedirect.com/science/article/pii/S0306919218302434.

INDONESIA CENTRAL BUREAU OF STATISTICS. **Indonesia Agriculture Survey**. Jakarta: [s.n.], 2021.

INDONESIAN CENTRAL BANK. **BI 7-Day Reverse Repo Rate in 5,75**. Jakarta: [s.n.], 21 Set 2023.

KHAN, M. A. *et al.* Sensitivity Analysis for the Determinants of Investment Appraisal. **Audit. Financiar.**, 1 Jan 2017.

KHANNA, M.; ISIK, M.; WINTER-NELSON, A. Investment in site-specific crop management under uncertainty: implications for nitrogen pollution control and environmental policy. **Agricultural Economics**, v. 24, n. 1, p. 9–12, 1 Dez 2000. Available at: https://doi.org/10.1111/j.1574-0862.2000.tb00089.x.

KUMAR, G. *et al.* Economics of U.S. catfish farming practices: profitability, economies of size, and liquidity. **Journal of the World Aquaculture Society**, v. 51, n. 4, p. 829–846, 1 Ago 2020. Available at: https://doi.org/10.1111/jwas.12717.

LEBEL, P. *et al.* Perceptions of climate-related risks and awareness of climate change of fish cage farmers in northern Thailand. **Risk Management**, v. 17, n. 1, p. 1–22, 2015. Available at: https://doi.org/10.1057/rm.2015.4.

LINNENLUECKE, M. K.; NUCIFORA, N.; THOMPSON, N. Implications of climate change for the sugarcane industry. **WIREs Climate Change**, v. 9, n. 1, p. e498, 1 Jan 2018. Available at: https://doi.org/10.1002/wcc.498.

LIVERPOOL-TASIE, L. S. O. Is fertiliser use inconsistent with expected profit maximisation in sub-Saharan Africa? "Evidence from Nigeria". **Journal of Agricultural Economics**, v. 68, n. 1, p. 22–44, 1 Fev 2017. Available at: https://doi.org/10.1111/1477-9552.12162.

MACHADO, P. G. *et al.* Assessment of the Expansion of Sugar Cane: application of the sustainability barometer in the municipalities of Barretos and Jaboticabal, São Paulo State, Brazil. **Sustainability in Debate**, v. 5, n. 1, SE-, p. 16–28, 30 Abr 2014. Available at: https://periodicos.unb.br/index.php/sust/article/view/15586.

MENDES, P. D. A. G. *et al.* Public policies and adaptation to climate change: three case studies in the Brazilian Semi-Arid region. **Sustainability in Debate**, v. 13, n. 3, SE-Articles-Varia, p. 209–245, 29 Dez 2022. Available at: https://periodicos.unb.br/index.php/sust/article/view/46064.

MOSHKIN, E. *et al.* Assessment of willingness-to-pay for bio-based fertilisers among farmers and agricultural advisors in the EU. **Journal of Cleaner Production**, v. 414, p. 137548, 15 Ago 2023. Accessed on: 16 jun. 2023.

PETER, J. Risk Analysis in Corporate Financial Modelling. **Economy and Finance**, v. 7, n. 1, Mar 2020.

ROY, P. *et al.* Climate change and groundwater overdraft impacts on agricultural drought in India: vulnerability assessment, food security measures and policy recommendation. **Science of The Total Environment**, v. 849, p. 157850, 2022. Available at: https://www.sciencedirect.com/science/article/pii/S004896972204949X.

SANTOS, D. J. dos *et al.* Future rainfall and temperature changes in Brazil under global warming levels of 1.5oC, 2oC and 4oC. **Sustainability in Debate**, v. 11, n. 3, SE-Dossier, p. 57–90, 31 Dez 2020. Available at: https://periodicos.unb.br/index.php/sust/article/view/33933.

SAUNDERS. Simple Sensitivity Analysis by Financial Modelling. **International Journal of the IMA**, v. 2, n. 1, Jan 1983.

VASQUEZ-ARROYO, E. *et al.* Climate impacts in the Brazilian energy security: analysis of observed events and adaptation options. **Sustainability in Debate,** v. 11, n. 3, SE-Dossier, p. 157–196, 4 Jan 2021. Available at: https://periodicos.unb.br/index.php/sust/article/view/33838.

ZHAO, D.; LI, Y.-R. Climate Change and Sugarcane Production: potential impact and mitigation strategies. **International Journal of Agronomy**, v. 2015, p. 547386, 2015. Available at: https://doi.org/10.1155/2015/547386.

The socio-environmental aftermath of gold mining in the Amazon: the case of Yutzupino in Napo, Ecuador

As consequências socioambientais da mineração de ouro na Amazônia: o caso de Yutzupino em Napo, Equador

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ABSTRACT

This study addresses the social and environmental repercussions on Amazonian communities due to gold mining following the conclusion of official concessions. Framed within the literature on natural resource extraction, sustainability, and social impacts in developing countries, the work employs qualitative methods, including interviews with residents and field observations in the community of Yutzupino in the Ecuadorian Amazon. It reveals that post-concession mining, often informal and illegal, sharply triggers social and environmental degradation. The research emphasises the need to incorporate sustainability principles into mining concessions to prevent such effects. This analysis enhances understanding of the complex socio-ecological aftermath of mining in vulnerable environments. It proposes recommendations for mitigation, underlining the importance of dialogue between communities, governments, and mining companies.

Keywords: Amazon. Gold mining. Socio-environmental impacts. Sustainability.

RESUMO

Este estudo aborda as repercussões sociais e ambientais em comunidades amazônicas decorrentes da mineração de ouro após o término das concessões oficiais. Enquadrado na literatura sobre extração de recursos naturais, sustentabilidade e impactos sociais em países em desenvolvimento, o trabalho utiliza métodos qualitativos, incluindo entrevistas com moradores e observações em campo, na comunidade de Yutzupino, na Amazônia equatoriana. Revela que a mineração pós-concessão, frequentemente informal e ilegal, desencadeia uma acentuada degradação social e ambiental. A pesquisa enfatiza a necessidade de incorporar princípios de sustentabilidade nas concessões de mineração para prevenir tais efeitos. Essa análise enriquece a compreensão sobre as complexas sequelas socioecológicas da

mineração em ambientes vulneráveis e propõe recomendações para sua mitigação, ressaltando a relevância do diálogo entre comunidades, governos e empresas mineradoras.

Palavras-chave: Amazônia. Mineração de ouro. Impactos socioambientais. Sustentabilidade.

1 INTRODUCTION

The Amazon Rainforest, colloquially called "the lungs of the Earth," is an ecosystem of incalculable global ecological value. This unique ecosystem is threatened by various human activities, most notably traditional and industrial mining, both legal and illegal. The growing mining expansion in the Amazon region is of grave concern, mainly due to the potential harm to surrounding communities and the sustainability of this fragile ecosystem. This situation mirrors critical challenges in sustainable development and environmental justice.

When attempting to implement land-use change policies, the inherent ecological fragility of the Amazon region poses significant challenges. Historically, land use planning and zoning decisions have favoured economic gains over environmental and social welfare in these delicate ecosystems. While industrialisation may spur economic development, it also carries severe environmental and social repercussions that must be understood from various perspectives.

This study aims to explore and understand the ramifications of gold mining on communities near extraction sites. Specifically, it focuses on the daily life of communities near areas where illegal gold mining is practised, following years of legal exploitation with government permits. Within the framework of sustainable development, anticipating the legacy that mining will leave in communities after its closure is vital as it constitutes a crucial element of its planning (Mancini; Sala, 2018; Veiga *et al.*, 2001). The goal is to provide key insights that aid in planning land transformation and crafting policies for sustainable land use.

The community of Yutzupino, in the Napo province of Ecuador, serves as the focal point of this research. Through exploring the experiences of this community, we aspire to amplify our comprehension of the socio-economic interplay and challenges they face in the aftermath of official mining activities. Notably, this study posits the creation of a new category within spatial planning explicitly tailored for territories previously subjected to mining. A qualitative methodology encompassing comprehensive interviews and observational studies was employed to fulfil this objective.

The findings of this article contribute theoretical, empirical, and practical insights relevant to territorial planners, policymakers, and local communities. In addition, the study provides an essential understanding of the needs, challenges, and goals of the communities impacted by mining, which can inform and steer both sustainable development strategies and initiatives led by the community itself. The article's structure unfolds as follows: Section 2 provides the study's theoretical framework, focusing on the aftermath of mining following the termination of concession contracts. Section 3 outlines the methodology and approaches used in the research. The results and their corresponding analysis are presented in Section 4, divided into five subsections. The paper ends with a set of concluding remarks derived from the study.

2 THEORETICAL BACKGROUND

One of the main threats facing the Amazonian ecosystem is industrial and traditional mining activities. The expansion of mining poses concerns about the potential destruction of surrounding communities and the sustainability of particularly fragile ecosystems worldwide (Syahrir *et al.*, 2021). This

theoretical review explores the socio-environmental implications of gold mining in the Amazon and its consequences for local communities.

Land use zoning is a tool for regulating activities in a specific geographical area. It allows authorities to categorise lands for various purposes, such as agriculture, conservation, infrastructure, and industrial development (Sagala *et al.*, 2022). In the Amazon case, zoning favouring industrial mining has prioritised economic gains over environmental and social welfare (Araújo *et al.*, 2022). The expansion of industrial mining brings with it the destruction of forests and loss of habitats, impacting communities that depend on these resources for their livelihood and cultural identity, thereby exacerbating inequality and social conflicts (Degele, 2023).

Concurrently, the release of toxic chemicals into water bodies, such as mercury and cyanide, threatens biological diversity and disrupts the natural cycles of the ecosystem (Júnior; Carvalho, 2023; Mestanza-Ramón *et al.*, 2022). This negatively affects flora, fauna, and vital ecosystem services such as climate regulation, water purification, and food provision. The interconnection of the different ecosystem components like rivers, forests, and soils requires a holistic approach to land use management.

Deforestation, frequently spanning across borders (Andrews, 2018), often results from clearing forests to accommodate mining activities. This leads directly to extensive habitat loss and biodiversity displacement (Salisbury *et al.*, 2023). Also, the extraction of minerals and the associated infrastructure construction disrupt natural hydrological cycles, resulting in notable changes in water availability, heightened incidence of flooding, and exacerbated soil erosion (Brandão *et al.*, 2022).

Much like other mining activities, gold mining plays a substantial role in the Amazon's environmental degradation. Celi Sangurima (2005) and Velastegui-Montoya *et al.* (2022) underscore the connection between gold mining and forest loss, changes in land cover and use patterns, and decreasing biodiversity. Also, Pérez *et al.* (2021) scrutinise the detrimental effects on water quality and likewise link gold mining with long-term biodiversity loss.

Furthermore, by its very nature, gold mining requires substantial displacement of soil and rock, a factor that invariably instigates soil erosion. This erosion affects slope stability, undermines soil fertility, and hinders the ecosystem's innate regenerative abilities (Vráblík *et al.*, 2020). Comprehensive research, such as the study conducted by Balaka Opiyo *et al.* (2022) in Kenya, demonstrates that gold mining precipitates the degradation of vegetation cover and the depletion of fertile soil, posing substantial threats to agricultural productivity.

2.1 THE IMPACT ON SURROUNDING COMMUNITIES

Driven by the rising global demand (World Gold Council, 2023), the Amazon has seen a surge in gold mining, leading to significant land cover changes. Swenson *et al.* (2011) highlighted how this increased gold demand, local resource utilisation, and growing populations in communities around the mines have reshaped the Peruvian Amazon's environment. This demographic growth in mining areas pushes forests to be converted into agricultural land. López and Maldonado (2023) emphasise that while this land cover transition does not always spike overall deforestation rates, it notably diminishes successional forests and exacerbates water quality issues.

The health consequences of gold mining for Amazonian communities are notably alarming. The employment of hazardous substances like mercury and cyanide in gold extraction processes severely threatens human well-being (Keane *et al.*, 2023). Specifically, mercury contamination of fish and water sources has been associated with neurological and developmental disorders among communities along the Brazilian Amazon's riverbanks (Fillion *et al.*, 2011; Webb *et al.*, 2004).

Social disruptions are also of primary concern (Garvey *et al.*, 2022). The social impact of mining projects in Amazon communities is complex, marked by anticipation and conflict during various stages of mining operations (Arellano-Yanguas; Bernal-Gómez, 2022). In early phases, companies must obtain social consent to operate, leading to high expectations and sometimes resistance or division within communities. Attempts to secure local consent may involve harmful practices such as co-opting leaders and corruption. Once mining is underway, challenges include mismatches between expectations and reality, inequalities, dependency on the company, social changes, and erosion of trust in public institutions. These dynamics, along with land rights conflicts (Mestanza-Ramón *et al.*, 2022), underscore the multifaceted social impacts of mining in the region.

The literature has broadly examined the environmental and health consequences faced by communities surrounding gold mining territories in the Amazon. Much of this focus has been directed towards concession contracts for industrial exploitation, particularly emphasising the stages prior to and during the concession phases. However, a noticeable gap persists in understanding the social conflicts that arise post-concession. This underexplored area highlights a need for further investigation to comprehensively address the full spectrum of social impacts associated with gold mining in the region.

2.2 EMERGING APPROACHES TO MINING CONCESSIONS

Addressing the destructive consequences of mining in the Amazon requires a fundamental shift in land use zoning and resource management strategies. This includes encouraging responsible mining practices, utilising cleaner technologies, and enforcing stringent environmental regulations to reduce the ecological footprint of mining operations (Nii Ayi Aryee *et al.*, 2023). Moreover, facilitating the temporal coexistence of legally concessioned mining by industrial means with traditional mining practices has been identified as an approach to decrease social conflict between concessioned firms and local communities. This idea, supported by Loor and Evans (2021) and Roy (2005), illustrates the ongoing interaction between formal and informal spheres in the Global South, highlighting the potential for sustainable solutions that balance ecological integrity and social harmony.

Managing the challenges of mining concessions in the Amazon may also be addressed through strategic incentives. Barroso and Campos (2021) emphasise the crucial role of economic incentives, such as certification schemes and fair-trade initiatives, in promoting responsible gold mining practices. By offering financial rewards tied to sustainability, these incentives not only encourage miners to employ environmentally friendly techniques but also actively promote the restoration of areas that have been degraded.

Land tenure regularisation is another approach to tackle the challenge. According to Bernal Dávalos (2021), unrestrained mining exploitation in Bolivia has been driven by the separation of indigenous communities from their ancestral territories, leading to new mining settlements and consequent land ownership disputes. For indigenous peoples, land is more than a physical entity; it is a vital part of their cultural identity, providing wealth, comfort, security, and stability. Regularising land tenure and establishing clear ownership and rights can be a protective measure (Hänggli *et al.*, 2023). This approach could help prevent illegal mining activities, create a legal framework for sustainable land use, and preserve the delicate balance between economic growth and the conservation of culture and the environment.

Recognising and empowering indigenous communities in decision-making related to mining is also crucial. Indigenous territorial organisation and self-management play a vital role in conserving Amazonian ecosystems and protecting indigenous rights. Martin *et al.* (2022) emphasise the importance of land rights and indigenous management practices for achieving conservation and social goals. Indigenous communities possess traditional knowledge associated with sustainable practices that can help mitigate the negative impacts of gold mining and promote alternative livelihoods based on traditional resource use and cultural preservation.

Based on the literature review, a discernible gap in research has been identified in understanding the social conflicts that arise post-concession of gold mines. This unexplored aspect necessitates further investigation to provide a comprehensive understanding of the impacts of gold mining in the region. Moreover, little attention has been paid to understanding what it is like to live and subsist daily while economically depending on nearby gold mining. A comprehensive insight into these subtleties can pave the way for targeted solutions that balance economic growth with environmental stewardship.

3 METHODOLOGY AND METHODS

What is the social context of communities proximal to gold deposits, which are still subject to traditional and illegal mining operations in the Amazon after the end of official concessions? To tackle this research question, this study employs a qualitative and descriptive case study approach (Hollweck, 2015). The study aims for evidence-based insights into how the transition of gold mining concessions unfolds, emphasising the complex interplay between traditional mining practices and illegal operations.

The community of Yutzupino, located near Tena City in Napo Province within the Ecuadorian Amazon region, is the case selected for this study. Yutzupino is of interest because it encompasses various intersecting factors. Within this community, the interplay between traditional mining practices, industrial mining companies, and indigenous land connections forms a complex landscape. This combination yields unique challenges and insights into how mining influences the inhabitants, their lifestyles, and the surrounding environment. The specific circumstances in Yutzupino contribute to a broader understanding of the complex issues related to mining in the Amazon, marking it as an invaluable area for exploration. As part of this research, primary data were collected through detailed interviews and on-site observations, while secondary data were derived from recent censuses conducted by the Risk Secretariat of Ecuador and relevant media content. The subsequent sections delineate the case's characteristics and the data collection and analysis methods.

3.1 THE CASE

The community of Yutzupino, situated 14 Kilometers away from the parish of Puerto Napo and nestled in the heart of the Ecuadorian Amazon in Napo Province, is today home to 327 Kichwa-speaking residents living in 65 dwellings and families. Despite its modest size, the community showcases a substantial demographic variety, with pregnant women, persons with disabilities, and older adults. The houses are entwined with this biodiverse region's vibrant flora and fauna. At first glance, it may seem idyllic, yet Yutzupino faces a series of challenges threatening the life and safety of its inhabitants.

Homes in Yutzupino, traditionally constructed, are perpetually endangered due to their proximity to the Jatunyacu River, a tributary of the Napo River, meaning "big river". These houses are in a high flood-risk area, constantly threatening the safety and lives of their inhabitants. Land tenure issues and the scarcity of relocation alternatives limit residents' options to move away from this hazard zone.

The community's economy is rooted in agriculture, with crops like cassava, banana, and cacao as staples. However, the people have also turned to traditional mining as a vital supplement to their income, supporting their local economy. The simple yet effective act of miners shaking pans in the water to extract gold has become a symbol of daily life in Yutzupino, reflecting both their ingenuity and their connection to the land.

Over the last two decades, the landscape of Yutzupino has been profoundly transformed by the concession of mining rights to private firms for industrial gold extraction. The Ecuadorian government

has issued 153 concessions that cover an expansive area of 32,277 hectares in Napo Province alone (Ecuador. Unidad Judicial Especializada de Violencia contra la Mujer o Miembros del Núcleo Familiar e Infracciones contra la Integridad Sexual y Reproductiva de Tena, Napo, 2022, p. 64). International companies, including Canada's Hampton Court Resources and Merendon and China's Terraearth Resources, have been beneficiaries of these concessions, shaping the mining activities and interactions within this territory during this period.

These concessions have transformed the everyday life of local miners, who perform the extraction while dodging heavy machinery and excavators, a perilous reality that has woven itself into their routine. As the situation moved into the post-concession phase, it has further deteriorated. The blend of illegal industrial extraction, outsider traditional miners, and local traditional miners has ignited tensions and social conflicts. This mix has accelerated environmental degradation, heightened community vulnerability, and added complexity and risk to the mining practice.

3.2 DATA COLLECTION AND ANALYSIS

The primary data collection process unfolded as follows. Between April and May 2023, in-depth interviews were conducted with 18 heads of households, focusing on those involved in traditional gold mining. These hour-long interviews took place in the participants' homes, detailing their everyday lives, challenges, and relationships with illegal mining. Ethical considerations were paramount, with informed consent sought for all interviews and observations.

The selection of participants was carried out randomly during on-site observations between November 2022 and May 2023. Initially triggered by the interest of the Municipality of Tena, the capital city of Napo Province, to address the presence of illegal miners—a situation that escalated to become the subject of a hearing in the Ecuadorian National Assembly—the observations evolved in scope and focus. The research began with unsystematic observations to map the area and the communities affected by mining, later moving to a more structured approach. This focused on the houses, materials that sustain everyday life, and travel patterns to everyday places. Photographs were taken, and a diary was maintained to capture these observations.

Analysing the data involved content analysis and hand-coding. In-depth interviews were transcribed and organised by key themes and categories, forming the backbone for a narrative description of the community's daily experiences. This qualitative data was then linked to observations and secondary sources, allowing for triangulation and a more nuanced understanding of the area's complex, often tense, social dynamics. The researchers were mindful of the dangers and tensions in this area arising from the intersecting interests of locals, outsiders, and newcomers involved with illegal mining.

4 FINDINGS AND DISCUSSION

The findings unfold an unsettling reality faced by the Indigenous Amazonian community of Yutzupino. Historically engaged in rudimentary practices of gold mining as one of their diverse sources of income, these inhabitants now find themselves at a complex intersection of challenges. Their struggle to preserve their traditional way of life increasingly clashes with the need for conservation and personal safety. The current context presents a web of socio-economic, environmental, and security challenges that weave together, demanding immediate and effective intervention to untangle and resolve.

The following paragraphs are organised into five subsections. The end of mining concessions affecting the study area is reported in the first subsection, revealing their impact on the local community. The second subsection delves into traditional gold mining, elucidating its practices and significance within the community. Next, the focus shifts to the living conditions in the third subsection, where a portrayal

of the houses and limited access to essential services is given. The fourth subsection uncovers the physical vulnerabilities of Yutzupino's inhabitants, highlighting the prominent risks and challenges. The fifth section identifies governmental initiatives aiming to address the main issues.

4.1 THE END OF MINING CONCESSIONS

During the mining concession's active period, a balance of exploitation was forged between the concession beneficiary, particularly Terraearth Resources, and Yutzupino's local traditional miners. The community members coincide that this balance allowed a harmonious coexistence, with the company often employing local miners on a daily wage basis for various gold extraction tasks, including machinery maintenance. However, this cooperative relationship abruptly ended with the concession's suspension in October 2020 (Ministerio del Ambiente, Agua y Transición Ecológica, 2020).

In the aftermath of the suspension, illegal miners unfamiliar with the community rapidly invaded the area, wielding heavy machinery and aggressively competing with local miners. This dramatic shift has disrupted the previously established dynamics, creating tensions for Yutzupino's mining practices.

Yutzupino is now among the areas most severely impacted by rampant illegal gold mining. As reported in May 2021 by a technical analyst from the Ecuadorian Institute of Geological and Energy Research, citizen groups "Napo Loves Life" and "Napo Resists" exposed unlicensed gold extraction by four backhoes on the Jatunyacu river's beaches in November 2021. This illegal mining has been conducted using industrial machinery and without compliance with basic environmental standards. A report from the Andean Amazon Monitoring Project (Maap) further confirmed this, highlighting the illegal miners' swift takeover of the area.

Maap issued its initial alarm report in October 2021, identifying less than one hectare of affected land. Shockingly, by December, this damage had ballooned to 61 hectares. According to a journalism report, EcoCiencia spokespersons who participated in Maap's analysis pointed out that "87.5% of the illegal mining expansion occurred in December." By January 2022, the devastated area had expanded another six hectares (Alvarado, 2022). This alarming rate of mining activity expansion underscores the urgent need for intervention.

4.2 TRADITIONAL MINING

In the community of Yutzupino, traditional mining is viewed as a secondary activity, supplemental to their primary occupation of farming and selling local products like cassava, banana, and cocoa. In interviews, Yutzupino miners explained that gold mining typically occurs at night, continuing until about 3 in the morning. Community members, including men, women, and young people, embark on a 30-minute walk along a gravel road to reach the gold extraction area. There, heavy machinery is observed excavating and forming embankments.

Describing their hands-on process, miners shared how they collect material from the base of the embankment using shovels. After removing larger rocks, they wash the material with gentle pan movements, leaving only small sediments at the pan's bottom. These sediments may or may not contain gold. They emphasised that the success of this endeavour depends on the miner's skill, with each load taking approximately 5 minutes to process.

The miners also described an adaptation of traditional gold mining techniques through a less conventional tool: a homemade version of a washing machine commonly used in small-scale mining. As explained by the miners, the device consists of a wooden ramp covered with a piece of cloth and a metal grid. The process begins with the miners pouring material onto the ramp with a shovel and then

adding water to filter the material through the cloth and grid. After all the material has been filtered, they remove the cloth, and in the centre, sediments remain where gold may be present.

These descriptions vividly show how traditional methods are being fused with innovative techniques to maximise their gold extraction efforts. Figure 1 offers a visual representation of a miner using the pan.

Figure 1 | Panhandler in Misahuallí Rio Napo Ecuador.

Source: Peter van Evert / Alamy Stock: April 17, 2018.

In Yutzupino, traditional mining practices occur in dark and hazardous areas where machinery operators dig. The poor visibility increases the risk of traditional miners being struck by excavators. Furthermore, the community's digging activities at the base of the embankment undermine its stability, leading to frequent collapses that pose serious dangers to those working below.

Yutzupino miners have also voiced concerns about pollution and the authorities' responses to gold mining in the area. Recent military operations to combat illegal mining have led to the confiscation of their traditional mining tools and gold, further igniting dissatisfaction within the community. One resident emotionally reflected, "At least the Chinese miners gave us work; we had breakfast, lunch, and dinner for our children," recalling a time when the concession was still active.

Concerning pollution, they describe the pollutants in nearby bodies of water. They often find deposits of oils, fats, and metallic waste, formerly components of the mining machinery. They have observed that the bodies of water near the community are contaminated with sediments, which decreases water quality, exterminates aquatic life, and affects people's health. These issues, aligning with Martin *et al.* (2022), are viewed as an affront to indigenous land rights.

However, the impact of gold mining in Yutzupino extends beyond environmental degradation. The lure of gold has attracted outside miners, leading to clandestine businesses and tolerance zones. This influx has fostered an environment marked by excessive alcohol consumption and occasional aggression, disrupting community peace. Additionally, reports of prostitution and violence during protests further underline the negative social consequences of mining within the community.

The problems the Yutzupino community is facing are complex, involving their traditional way of living, taking care of the environment, and getting along with each other. What is happening in Yutzupino might not be unique to just their community. The experiences and concerns shared by the people there show that we must look deeper into these issues. More research is needed to see if similar things are happening in other places where gold mining occurs, especially after the official permissions for mining end. This will help us understand the broader effects of mining on local communities and their environment.

4.3 HOUSING

Houses of Yutzupino, erected on wooden pillars and chains without formal technical design, also symbolise the precarious living conditions and the ongoing struggle for survival faced by their inhabitants. The durability of the wood elements is particularly poor, making them highly vulnerable to the extreme weather conditions common to the Amazon region. The walls of these houses are made of vertically arranged wooden planks. Occasionally, cement blocks can be observed, denoting an attempt to incorporate more durable materials, but it also highlights inequality in resource access. As a result, the structures require frequent maintenance and reinforcement to ensure their integrity and to provide enough protection for those who live within them.

The roofs of the houses are made of zinc sheets. While these roofs are lightweight and resistant to heavy rain, they create a hot and overwhelming internal environment that is hardly conducive to the well-being of its inhabitants. Often covered with plastic sheets, windows provide an ephemeral barrier against the exterior environment and lack the security and durability of a conventional window. Figure 2 displays two houses with typical features of the community.

Figure 2 | Houses of the Yutzupino community.

Source: Photos by the authors, 2023.

The poverty situation in Yutzupino is further reflected in the shortcomings of its essential public services and facilities. Access to clean water is persistently challenging, largely due to the complexities of land subdivision, an administrative and legal process that divides properties into smaller lots with individual registration. This practice, vital for clarifying land use rights and maximising property value, is hampered by the need for proper land tenure regularisation to prevent misuses such as illegal mining, as Hänggli *et al.* (2023) emphasised. In addition to water issues, the community faces problems with electricity access. Though available throughout Yutzupino, the electricity supply is often unreliable and insufficient to meet everyday needs.

Education in Yutzupino is limited to a basic level. The daily commute to Puerto Napo, necessary for young people aspiring to obtain a high school education, is emblematic of the broader challenges faced by the community. This burden not only hinders their academic development but is a manifestation of the systemic weaknesses in the area, which adds to the unreliable utilities and the need for frequent housing maintenance. Figure 3 illustrates the daily route students use between Yutzupino and Puerto Napo, a visual representation of the interconnected challenges that obstruct educational advancement and overall progress within the community.

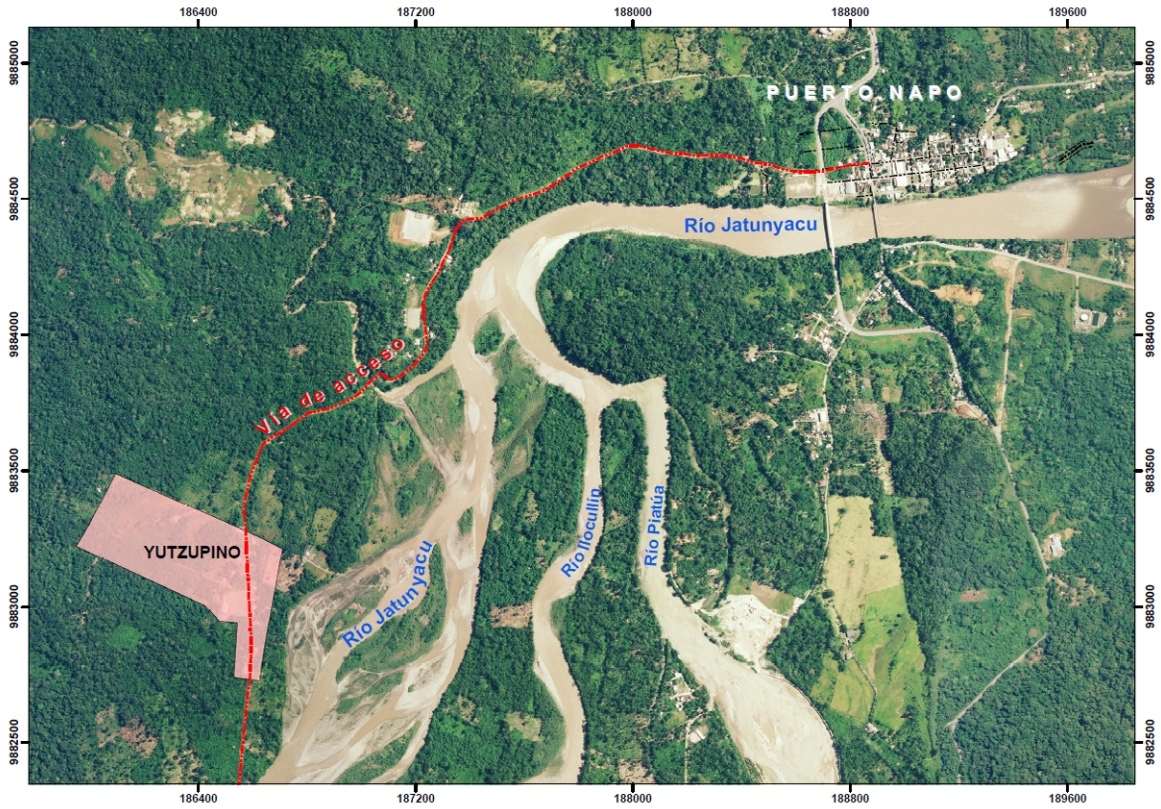

Figure 3 | Map of communication routes of the Yutzupino community.

Source: Maps by the authors, 2022.

In Yutzupino, the precarious state of housing, coupled with the lack of dependable utilities and constrained access to education, creates a vivid portrait of the challenges endemic to this Amazonian community. This complex situation does not merely reflect material hardship; it underscores a broader narrative of poverty and vulnerability. It is a call to action, emphasising the need for thoughtful intervention and support to address these multifaceted issues and empower the community.

4.4 THE PHYSICAL VULNERABILITIES OF YUTZUPINO INHABITANTS

Yutzupino is close to the river, which defines the area's appearance but also makes it vulnerable. The people there enjoy the rich natural resources but face constant threats to their safety because of the location. Flooding is common, especially when it rains heavily. The residents recall times when the floods were so strong that they washed away weak homes on the riverbanks, destroying important belongings and crops. The people believe that gold mining is making things worse, changing the river's flow and washing away the banks. This makes flooding more likely and puts the homes near the river in danger.

In addition to flooding, residents of Yutzupino mention feeling small earthquakes at least once a month. While they have become accustomed to these low-magnitude tremors, the experience is always unsettling and scary. These regular quakes have revealed cracks in the houses and throughout the community, adding to ongoing concerns for the inhabitants' safety. The inability of the structures to withstand even these minor quakes underscores the precariousness of living conditions in the area and keeps the fear of a more significant disaster.

Yutzupino susceptibility to house fires also stands out as a critical concern. The residents identify poor electrical installations and the use of highly flammable construction materials like wood as the primary causes. Such conditions allow fires to ignite and spread rapidly, posing an ever-present danger to both life and property.

The community also fears the force of strong winds, a common occurrence in the area. These windstorms have the power to tear off roofs and damage crops, causing chaos in the population's livelihoods and essential infrastructure.

In the face of these environmental challenges, Yutzupino finds itself in a ceaseless battle with nature. The combined threats of flooding, earthquakes, fires, and windstorms weave a tapestry of physical vulnerability exacerbated by a lack of resources and proper planning. This precarious situation perpetuates a cycle of poverty and exposure to environmental risks, underscoring the imperative need to mitigate these threats.

4.5 GOVERNMENT INTERVENTIONS

In addition to the vulnerabilities mentioned above, Yutzupino faces land regularisation and tenure security challenges. Here, 89 plots are dangerously located within the risk zone of the Jatunyacu River and do not qualify for regularisation. The Tena municipal government has played a crucial role in responding to these challenges. It has been confirmed that the lands belong to the heirs or relatives of the original owners, recognised by regulatory institutions such as the National Institute of Agrarian Development (Inda) and the Ecuadorian Institute of Agrarian Reform and Colonization (Ierac). However, instability persists due to the environmental risk that constantly imposes the threat of relocation.

To counteract these challenges, the municipality has acquired 2.35 hectares of land in the upper part of the community to relocate the endangered residents. The area was subsequently parcelled, and the parcel plan was approved and legalised. It fell to the community to take the final step to secure ownership of the individualised lands: registering them in their name at the Tena Property Registry. However, a lack of management and resources has thwarted this process, leaving the residents in an even deeper situation of vulnerability and uncertainty.

Besides interventions to resolve land tenure issues, the government has also implemented zoning plans. The annexes of the Ordinance updating the Tena Canton Development and Territorial Ordering Plan for the period 2021-2023, the Tena Canton Urban and Rural Land Use and Management Plan

2021-2023, and the Sustainable Comprehensive Urban Planning Plan of the city of Tena 2021-2023, include rural Land use plans for the canton.

In these plans, Yutzupino is categorised as a forest conservation area with minimal agricultural uses destined for sustainable forest utilisation. However, according to the map of conservation areas of the Tena canton, Yutzupino is not classified under any conservation category. On the contrary, it is identified as a metal extraction zone on the Mining Types – Mining Concessions map, which aligns with the mining concession granted to Terraearth Resources S.A. Company to explore and exploit a vast territory, including the community area. This evidences a conflict in the classification of land use in the canton.

5 CONCLUSION

This research sought to investigate the socio-environmental consequences of gold mining in Amazonian communities, particularly after the ending of official mining concessions. The core question revolved around the effects of mining activities, specifically how the cessation of formal concessions gave rise to an upsurge in illicit mining activities and its impact on local communities and their environment.

This study's theoretical contribution lies in a nuanced understanding of the dynamics of mining exploitation in Amazonian communities. During the active lifespan of a mining concession, a delicate equilibrium is observed to coexist between traditional and industrial exploitation, where environmental degradation occurs gradually. However, this equilibrium can be disrupted at the end of the official mining concession, marking a shift towards an anarchic state. In this phase, illegal exploitation, encompassing both traditional means and heavy machinery, overexploits resources, leading to exponential degradation. This understanding constitutes significant insights into the transitional phases of mining activity and their impact on social and environmental stability, providing a theoretical foundation for future territorial planning and industrial policy implementation.

In terms of empirical and practical implications, the study offers a rich exploration of overexploitation in mining. Empirically, it paints a vivid picture of how illegal mining practices can dramatically alter the socio-environmental context of local communities. Practically, these insights shed light on better land use planning in Amazonian mining sites. The research delivers tangible elements for developing sustainable mining policies, particularly on avoiding undesirable aftermaths of gold mining. By analysing the specific impacts and complex dynamics at play, the study equips policymakers and planners with the evidence-based understanding needed to navigate the challenges of post-concession mining activities, thus offering a robust foundation for planning and policy.

Future research in this field should focus on exploring potential measures to prevent overexploitation post the lifespan of mining concessions. A promising avenue of investigation is to evaluate the efficacy of various zoning policies that act as mitigating strategies against rampant exploitation. Furthermore, studies examining successful interventions in other regions could provide valuable insights and potential frameworks to guide policies and practices. The findings of such research would contribute significantly to devising and implementing sustainable mining policies that prioritise not just economic gain but also social welfare and environmental protection.

REFERENCES

ALVARADO, A. C. **Ecuador**: la minería ilegal está acabando con dos ríos de la provincia de Napo. 17 Feb. 2022. Available from: https://es.mongabay.com/2022/02/ecuador-la-mineria-ilegal-esta-acabando-con-dos-rios-de--napo/. Accessed: 11 aug. 2023.

ANDREWS, N. Land versus livelihoods: community perspectives on dispossession and marginalisation in Ghana's mining sector. **Resources Policy**, v. 58, p. 240-249, Oct. 2018. Available from: https://doi.org/10.1016/j.resourpol.2018.05.011. Accessed: 14 july 2023.

ARELLANO YANGUAS, J.; BERNAL-GÓMEZ, M. **Energy transition, mining expansion and eco-social conflicts in the Amazon**. Bilbao: Publicaciones de la Universidad de Deusto, 2022. E-book (88 p.). ISBN 978-84-1325-188-2. Available from: https://www.somos-amazonia.org/wp-content/uploads/2023/04/Conflictos-ecosociales-ENGL-DIG.pdf. Accessed: 7 aug. 2023.

BALAKA OPIYO, S.; OPINDE, G.; LETEMA, S. Dynamics and Drivers of Land Use and Land Cover Changes in Migori River Watershed, Western Kenya Region. **Watershed Ecology and the Environment**, Nov. 2022. Available from: https://doi.org/10.1016/j.wsee.2022.11.008. Accessed: 14 july 2023.

BARROSO, L.; MELLO, P. **How To Save The Amazon**: the reasons why a living forest is worth more than a cut down one. 26 Apr. 2021. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3830872. Accessed: 14 july 2023.

BERNAL DÁVALOS, N. E. Consecuencias de la explotación amazónica. In: SABLICH, L.; VICTORY, S.; STICOTTI, N. (ed.). **Amazonía y Expansión Mercantil Capitalista**. Buenos Aires, Argentina: Consejo Latinoamericano de Ciencias Sociales. Clacso, 2021. p. 595-644. ISBN 978-987-722-948-6. Available from: https://doi.org/10.2307/j.ctv2v88d7q.14. Accessed: 12 aug. 2023.

BRANDÃO, D. O.; BARATA, L. E. S.; NOBRE, C. A. The Effects of Environmental Changes on Plant Species and Forest Dependent Communities in the Amazon Region. **Forests**, v. 13, no. 3, p. 466, 16 Mar. 2022. Available from: https://doi.org/10.3390/f13030466. Accessed: 14 july 2023.

CELI-SANGURIMA, J. E. **The vulnerability of aquatic systems of the Upper Napo River Basin (Ecuadorian Amazon) to human activities**. 2005. FIU Digital Commons, [s. l.], 2005. Available from: http://digitalcommons.fiu.edu/etd/2095. Accessed: 14 july 2023.

DE ARAÚJO, S. N. *et al.* Copper mining in the eastern Amazon: an environmental perspective on potentially toxic elements. **Environmental Geochemistry and Health**, 21 Oct. 2021. Available from: https://doi.org/10.1007/s10653-021-01051-5. Accessed: 14 july 2023.

DEGELE, P. E. Protected areas in land use planning policies: key articulation for territorial justice. **Environmental Science & Policy**, v. 140, p. 189-201, Feb. 2023. Available from: https://doi.org/10.1016/j.envsci.2022.11.020. Accessed: 14 july 2023.

ECUADOR. Unidad Judicial Especializada de Violencia contra la Mujer o Miembros del Núcleo Familiar e Infracciones contra la Integridad Sexual y Reproductiva de Tena, Napo. Sentence 15571-2021-00685. Vallejo Real y otros contra Ministerio del Ambiente. 5 Oct. 2022. **Función Judicial**, p. 64. Available from: https://www.recursosyenergia.gob.ec/wp-content/uploads/2022/10/sentencia-Napo.pdf. Accessed: 8 aug. 2023.

FILLION, M. *et al.* Neurotoxic Sequelae of Mercury Exposure: an intervention and follow-up study in the Brazilian Amazon. **EcoHealth**, v. 8, no. 2, p. 210-222, June 2011. Available from: https://doi.org/10.1007/s10393-011-0710-1. Accessed: 7 aug. 2023.

GARVEY, B. *et al.* Green crime, territorial resistance and the metabolic rift in Brazil's Amazon and Cerrado biomes. **Criminological Encounters**, v. 5, no. 1, p. 166-182, 2022. Available from: https://doi.org/10.26395/CE22050111. Accessed: 7 aug. 2023.

HÄNGGLI, A. *et al.* A systematic comparison of deforestation drivers and policy effectiveness across the Amazon biome. **Environmental Research Letters**, 10 May 2023. Available from: https://doi.org/10.1088/1748-9326/acd408. Accessed: 14 july 2023.

HOLLWECK, T. YIN, R. K. Case Study Research Design and Methods (5th ed.). Thousand Oaks, CA: Sage. 282 pages. 2014. **The Canadian Journal of Program Evaluation**, 1 Mar. 2016. Available from: https://doi.org/10.3138/cjpe.30.1.108. Accessed: 14 july 2023.

JÚNIOR, C. de M. B.; CARVALHO, L. G. de. Transformations in artisanal and small-scale gold mining work and production structures in the tapajós region of Brazil's amazon. **Resources Policy**, v. 83, p. 103597, June 2023. Available from: https://doi.org/10.1016/j.resourpol.2023.103597. Accessed: 14 july 2023.

KEANE, S. *et al.* Mercury and artisanal and small-scale golding mining: review of global use estimates and considerations for promoting mercury-free alternatives. **Ambio**, 10 Mar. 2023. Available from: https://doi.org/10.1007/s13280-023-01843-2. Accessed: 14 july 2023.

LOOR, I.; EVANS, J. Understanding the value and vulnerability of informal infrastructures: footpaths in Quito. **Journal of Transport Geography**, v. 94, p. 103112, June 2021. Available from: https://doi.org/10.1016/j.jtrangeo.2021.103112. Accessed: 14 july 2023.

LÓPEZ, S.; MALDONADO, A. New Insights on Water Quality and Land Use Dynamics in the Napo Region of Western Amazonia. In: LÓPEZ, S.; MALDONADO, A. **The Latin American Studies Book Series.** Cham: Springer International Publishing, 2023. p. 81-115. ISBN 9783031226793. Available from: https://doi.org/10.1007/978-3-031-22680-9_5. Accessed: 7 aug. 2023.

MANCINI, L.; SALA, S. Social impact assessment in the mining sector: review and comparison of indicators frameworks. **Resources Policy**, v. 57, p. 98-111, Aug. 2018. Available from: https://doi.org/10.1016/j.resourpol.2018.02.002. Accessed: 14 july 2023.

MARTIN, P. *et al.* Governance and metagovernance systems for the Amazon. **Review of European, Comparative & International Environmental Law**, v. 31, no. 1, p. 126-139, 10 Dec. 2021. Available from: https://doi.org/10.1111/reel.12425. Accessed: 14 july 2023.

MESTANZA-RAMÓN, C. *et al.* Artisanal and Small-Scale Gold Mining (ASGM): management and socioenvironmental impacts in the northern Amazon of Ecuador. **Sustainability**, v. 14, no. 11, p. 6854, 3 June 2022. Available from: https://doi.org/10.3390/su14116854. Accessed: 14 july 2023.

MESTANZA-RAMÓN, C. *et al.* History, Socio-economic Problems and Environmental Impacts of Gold Mining in the Andean Region of Ecuador. **International Journal of Environmental Research and Public Health**, v. 19, no. 3, p. 1190, 21 Jan. 2022. Available from: https://doi.org/10.3390/ijerph19031190. Accessed: 14 july 2023.

MINISTERIO DEL AMBIENTE, AGUA Y TRANSICIÓN ECOLÓGICA. **Se suspende actividades mineras a empresa Terraerth por incumplimiento a normativa ambiental**. Ministerio del Ambiente, Agua y Transición Ecológica. 26 Oct. 2020. Available from: https://www.ambiente.gob.ec/se-suspende-actividades-mineras-a-empresa-terraerth-por-incumplimiento-a-normativa-ambiental/. Accessed: 8 aug. 2023.

NII AYI ARYEE, B.; MTEGHA, H.; SANDOW ALI, M. Sustainable and responsible mining investment in developing economies. In: NII AYI ARYEE, B.; MTEGHA, H.; SANDOW ALI, M. **Sustainable and Responsible Investment in Developing Markets**. [S. l.]: Edward Elgar Publishing, 2023. p. 305-321. ISBN 9781803927060. Available from: https://doi.org/10.4337/9781803927060.00029. Accessed: 14 july 2023.

PÉREZ, Á. J. *et al.* Myrcia machinazana (Myrtaceae), a new Amazonian species from southern Ecuador. **Neotropical Biodiversity**, v. 7, no. 1, p. 415-420, 1 Jan. 2021. Available from: https://doi.org/10.1080/23766808.2021.1964914. Accessed: 14 july 2023.

ROY, A. Urban Informality: toward an epistemology of planning. **Journal of the American Planning Association**, v. 71, no. 2, p. 147-158, 30 June 2005. Available from: https://doi.org/10.1080/01944360508976689. Accessed: 14 july 2023.

SAGALA, S. *et al.* Sustainable Urban Drainage System (Suds) as Nature Based Solutions Approach for Flood Risk Management in High-Density Urban Settlement. **IOP Conference Series**: earth and environmental science, v. 986, no. 1, p. 012055, 1 Feb. 2022. Available from: https://doi.org/10.1088/1755-1315/986/1/012055. Accessed: 14 july 2023.

SALISBURY, D. S. *et al.* Crossing Boundaries: transboundary geographic information in the Amazon borderlands of Peru and Brazil. In: SALISBURY, D. S. *et al.* **The Latin American Studies Book Series**. Cham: Springer International Publishing, 2023. p. 33-55. ISBN 9783031226793. Available from: https://doi.org/10.1007/978-3-031-22680-9_3. Accessed: 14 july 2023.

SWENSON, J. J. *et al.* Gold Mining in the Peruvian Amazon: global prices, deforestation, and mercury imports. **PLoS ONE**, v. 6, no. 4, p. e18875, 19 Apr. 2011. Available from: https://doi.org/10.1371/journal.pone.0018875. Accessed: 7 aug. 2023.

SYAHRIR, R.; WALL, F.; DIALLO, P. Coping with sudden mine closure: the importance of resilient communities and good governance. **The Extractive Industries and Society**, v. 8, no. 4, p. 101009, Dec. 2021. Available from: https://doi.org/10.1016/j.exis.2021.101009. Accessed: 14 july 2023.

VEIGA, M. M.; SCOBLE, M.; MCALLISTER, M. L. Mining with communities. **Natural Resources Forum**, v. 25, no. 3, p. 191-202, Aug. 2001. Available from: https://doi.org/10.1111/j.1477-8947.2001.tb00761.x. Accessed: 14 july 2023.

VELASTEGUI-MONTOYA, A. *et al.* Land Use and Land Cover in Tropical Forest: global research. **Forests**, v. 13, no. 10, p. 1709, 17 Oct. 2022. Available from: https://doi.org/10.3390/f13101709. Accessed: 14 july 2023.

VRÁBLÍK, P.; VRÁBLÍKOVÁ, J.; WILDOVÁ, E. Hydrological Mine Reclamations in the Anthropogenically Affected Landscape of North Bohemia. In: VRÁBLÍK, P.; VRÁBLÍKOVÁ, J.; WILDOVÁ, E. **Springer Water**. Cham: Springer International Publishing, 2019. p. 203-223. ISBN 9783030183622. Available from: https://doi.org/10.1007/978-3-030-18363-9_9. Accessed: 14 july 2023.

WEBB, J. *et al.* Mercury in Fish-eating Communities of the Andean Amazon, Napo River Valley, Ecuador. **EcoHealth**, v. 1, S2, p. SU59—SU71, Nov. 2004. Available from: https://doi.org/10.1007/s10393-004-0063-0. Accessed: 11 aug. 2023.

WORLD GOLD COUNCIL. **Gold Demand Trends Q2 2023**. 1 Aug. 2023. Available from: https://www.gold.org/goldhub/research/gold-demand-trends/gold-demand-trends-q2-2023. Accessed: 7 aug. 2023.

Comparison of air quality standards between Brazil and countries from the five continents

Comparação dos padrões de qualidade do ar entre o Brasil e países dos cinco continentes

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ARTICLE-VARIA

ABSTRACT

This article presents a comparative study of air quality regulations. The main objective was to compare Brazil's current technical air quality standards with international standards. The air quality standards defined by Brazil for $PM_{2.5}$, PM_{10}, lead, SO_2, NO_2, and O_3 have higher values than international norms, and Brazil lacks standards for important pollutants like mercury, cadmium, nickel, toluene, and PAHs. The use of more permissive air quality standards significantly distorts the perception of potential exposure for the population, downplaying the actual impact on public health, leading to inadequate public health planning, and resulting in avoidable hospitalisations, premature deaths, and other intangible costs like reduced quality of life for the population.

Keywords: Environmental pollution. Atmospheric emissions. Air quality standards.

RESUMO

Este artigo trata de um estudo comparativo entre legislações de qualidade do ar. O principal objetivo foi comparar as normas técnicas vigentes sobre qualidade do ar no Brasil, em relação a normas internacionais. Foram comparados os padrões de qualidade do ar definidos pelo Brasil com os padrões adotados em países dos cinco continentes. O Brasil apresentou padrões para o $MP_{2,5}$, MP_{10}, chumbo, SO_2, NO_2 e O_3 com valores maiores que outras normativas internacionais, além de não apresentar padrões para poluentes importantes como mercúrio, cádmio, níquel, tolueno e HPAs. A utilização de padrões de qualidade do ar mais permissivos deturpa severamente a percepção da exposição potencial da população,

minimizando o real impacto na saúde da população exposta, contribuindo para a falta de planejamento adequado de saúde pública e ocasionando desperdício do dinheiro público com internações evitáveis, mortes prematuras e outros custos intangíveis como qualidade de vida da população.

Palavras-chave: Poluição ambiental. Emissões atmosféricas. Padrões de qualidade do ar.

1 INTRODUCTION

Air pollution, which can be defined as the presence of foreign substances in the atmospheric air, ranks among the top 10 risk factors contributing to the total number of years of life lost due to disability-adjusted life years across all age groups (GBD, 2019). Numerous epidemiological studies demonstrate that air pollution can lead to chronic diseases, exacerbation of related conditions, such as cardiovascular and respiratory morbidity and mortality, as well as premature deaths, thereby impacting the health of populations and contributing to increased public expenditure on medical care provided to the affected population (Aguilera *et al.*, 2021; Burnett *et al.*, 2018; Rajagopalan, 2018).

In Brazil, Abe and Miraglia (2016) estimated that the cost of premature deaths caused by air pollution in 29 Brazilian capitals results in an annual loss of approximately $1.7 billion. The sheer magnitude of this figure alone underscores its significance. However, it is believed that this estimate may still be underestimated, considering that the potential savings for public funds could be even higher when takinginto account other events besides premature death, such as hospitalisations due to respiratory causes, workplace absenteeism, and intangible costs like quality of life and life expectancy. This highlights that air pollution is a critical public health and economic concern.

One of the ways to control the emission of pollutants into the environment as a whole, including the atmosphere, and thereby mitigate the harmful health effects caused by pollution is the implementation of strict regulations on the subject. Setting emission limits for specific substances can improve air quality to protect human health and the environment (Vormittag *et al.*, 2021).

The World Health Organization - WHO establishes recommended limits for the concentrations of key atmospheric pollutants based on a global synthesis of scientific evidence. These recommended limits are intended to address the anticipated adverse health effects occurring in a significant portion of the population, both outdoors and indoors. While these recommendations are guidelines for countries, they do not have regulatory authority. The WHO guidelines cover annual and daily concentrations of fine particulate matter, nitrogen dioxide, sulfur dioxide, carbon monoxide, and ozone (WHO, 2021).

In Brazil, the National Environmental Council (Conama) Resolution No. 03, dated June 28, 1990, used to be the technical regulation establishing air quality standards. It has been replaced by Conama Resolution No. 491, dated November 19, 2018. In Article 2, section II of the latter, it defines:

> Article 2 - II - Air quality standard: one of the instruments for managing air quality, determined as a concentration value of a specific pollutant in the atmosphere, associated with a time exposure interval, in order to preserve the environment and the health of the population from the risks of damage caused by air pollution.

Therefore, an air quality standard is a technical instrument that legally defines a maximum limit for the concentration of a pollutant. It aims to control emissions of pollutants to protect human health and the well-being of people and the environment. (Brazil, 1990, 2018).

Vormittag *et al.* (2021) explain that the air quality standards currently in place in Brazil are not only outdated but are often violated due to the government's lack of commitment to established policies. The use of outdated air quality standards, especially when they are higher compared to international

recommendations and therefore more lenient, can severely distort the potential exposure of the population to harmful levels of air pollution (Chiquetto *et al.*, 2019; Valdambrini; Ribeiro, 2021).

The primary objective of this study is to compare the current technical standards for air quality in Brazil with the international standards in effect in other countries around the world.

2 METHODOLOGICAL PROCEDURES

This is a comparative study of air quality standards among national technical regulations in different countries worldwide. Air quality standards are defined considering two parameters: the maximum acceptable concentration value in the environment for each pollutant, typically in micrograms per cubic meter (µg/m³) or parts per million (ppm), and the sampling period, which is the defined time for pollutant collection and evaluation.

The research was conducted by considering the current air quality standardisation technical regulations in each selected country during the period from November 2018 to January 2022. Air quality standards from at least one country in each continent were chosen, in addition to the air quality guidelines from the World Health Organization (WHO). Even though the WHO guidelines do not have regulatory authority, they serve as guidelines for developing and revising technical air quality standards in all countries worldwide.

Thus, the following standards were selected for comparison:

1. Conama Resolution No. 03, 1990 - Brazil's former air quality standards regulation.
2. Conama Resolution No. 491, 2018 - The current technical standard in effect in Brazil.
3. Directive 2008/50/CE - A reference standard for European Union countries, 2008.
4. Canadian Environmental Protection Act, 1999 - The technical standard for Canada, representing North America.
5. Environmental Quality Standards in Japan Air Quality, 2009 - The standard for Japan, representing Asia.
6. Resolución 2254, 2017 - Colombia, representing another South American country in addition to Brazil.
7. Air Quality Act 39: National Ambient Air Quality Standards, 2004 - The standard for South Africa, representing Africa.
8. National Clean Air Agreement, 2015 - Australia, representing Oceania.
9. WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide, 2021 - The reference guide from the World Health Organization.

This comprehensive selection allows for a comparative analysis of air quality standards from various continents and regions worldwide.

To perform the comparisons, it was necessary to convert all pollutant concentration limit values to a single unit of measurement. This was required because the values could be presented in milligrams per cubic meter (mg/m³), micrograms per cubic meter (µg/m³), parts per million (ppm), or parts per

billion (ppb), depending on the specific standard and pollutant. Standardising the units allows a more meaningful and straightforward comparison of air quality standards.

The data was organised in spreadsheets, and an attempt was made to compare the limit values for each pollutant with the same sampling time in each standard.

3 RESULTS AND DISCUSSION

Conama Resolution 491 of November 19, 2018, is the result of the revision process of Conama Resolution 03 of June 28, 1990, which established national air quality standards in that year and was in effect for 28 years without updates to incorporate new scientific knowledge on the subject. The revision process began in 2014 within the Technical Chamber for Environmental Quality and Waste Management of Conama. The beginning of the revision process was considerably delayed, and its approval, on the contrary, was rushed, without adequate discussion with the public and experts to ensure that real progress was made in meeting air quality standards in Brazil (Siciliano *et al.*, 2020).

Conama Resolution 491 (2018) established 14 air quality standards for 9 pollutants, whereas Conama Resolution 03 (1990) defined 13 standards for 7 pollutants. The maximum pollutant concentration values in the air, as well as the defined sampling times, are summarised in Table 1 below:

Table 1 | Air quality standards for Brazil defined by Conama Resolutions.

BRAZIL			
	Conama 03 (1990)	*Conama 491 (2018)*	
Pollutant	Concentration (µg/m3)	Concentration (µg/m3)	Sampling time
$MP_{2,5}$	-	25	24 hours
	-	10	1 year
MP_{10}	150	50	24 hours
	50	20	1 year
Total Suspended Particles	240	240	24 hours
	80	80	1 year
Smoke	150	50	24 hours
	60	20	24 hours
SO_2	365	20	24 hours
	80	-	1 year
NO_2	320	200	1 hour
	100	40	1 year
CO	40.000	10.310	1 hour
	10.000	-	8 hours
O_3	160	-	1 hour
	-	100	8 hours
Lead	-	0,5	1 year

Source: Resolutions Conama 03/1990 e 491/2018. Adapted by the author.

This study analysed eight technical standards for standardising air quality parameters and one international reference guide, the WHO Guideline (2021).

Regarding the number of standards defined by each regulation, the one with the fewest air quality standards defined was the Canadian standard, with 7 standards, while the technical standard from Colombia defined the highest number of standards, with 19 standards. The quantity of standards defined by each regulation is summarised in Figure 1.

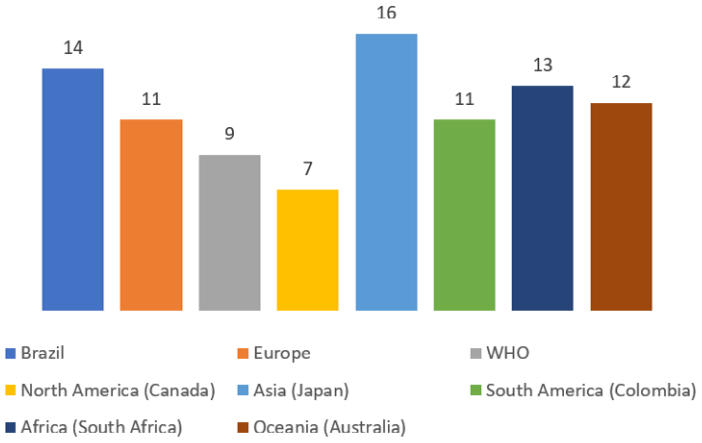

Figure 1 | Number of standards defined per country regulation

Source: Compiled by the author

The Japanese technical standard was the only one to define primary standards for the pollutants trichloroethylene, tetrachloroethylene, dichloromethane, dioxins, and photochemical oxidants. The air quality standards that are unique to Japanese standards are summarised in Table 2.

Table 2 | Air quality standards only found in the Japanese standard.

Environmental Quality Standards in Japan Air Quality		
Pollutant	Maximum concentration	Sampling Time
Trichloroethylene	0,2 mg/m³	1 year
Tetrachloroethylene	0,2 mg/m³	1 year
Dichloromethane	0,15 mg/m³	1 year
Dioxins	0.6 pg-TEQ/m³	1 year
Photochemical oxidants	0,06 ppm	1 hour

Source: Japanese Ministry of the Environment. Adapted by the author.
(Available at: https://www.env.go.jp/en/air/aq/aq.html)

Information from the Japanese Embassy in Brazil indicates that in the mid-1960s through the 1970s, Japan experienced various severe forms of environmental pollution. In addition to Minamata disease, several other pollution-related illnesses were discovered, including itai-itai disease, respiratory disorders in industrial areas of Tokyo-Yokohama, Nagoya, and Osaka-Kobe, and chronic arsenic poisoning in the Toroku region, Miyazaki Prefecture. These forms of pollution resulted from prioritising rapid economic growth at the expense of standards for protecting the health and safety of the population. These consequences prompted Japan to establish strict regulations to protect the environment starting in the 1960s.

Similar to the Japanese standard, some pollutants were only identified in the Colombian technical standard. These were referred to in the standard as “toxic air pollutants,” including cadmium, inorganic mercury, toluene, nickel (and its compounds), and Polycyclic Aromatic Hydrocarbons (PAHs). The air quality standards unique to the Colombian standard are summarised in Table 3.

Table 3 | Air quality standards found exclusively in the Colombian standard.

Toxic contaminants		
Pollutant	Maximum concentration (µg/m³)	Sampling Time
Cadmium	0,005	1 year
Inorganic Mercury (vapors)	1	1 year
Toluene	260	1 week
	1.000	30 minutes
Nickel (and its compounds)	0,18	1 hour
PAH	0,001	1 year

Source: Colombia. Ministry of Environment and Sustainable Development - Resolution 2254. Adapted by the author.

A study conducted by the World Health Organization's International Program on Chemical Safety (IPCS) reveals that, in addition to the more common or "traditional" atmospheric pollutants, a significant number of toxic and carcinogenic chemicals are increasingly being found in urban air, albeit at low concentrations. Examples include metals (beryllium, cadmium, and mercury), trace-level organic substances (benzene, polychlorinated dibenzo-dioxins and dibenzo-furans, formaldehyde, vinyl chloride, and PAHs), and fibres (asbestos). These substances are emitted from various sources, including waste incinerators, sewage treatment plants, industrial processes, solvent use, construction materials, and motor vehicles (WHO, 2000).

Excluding the pollutants only mentioned in Japan and Colombia's technical standards, Table 4 was created with the standards for the remaining pollutants, organised by sampling time and referencing each regulation.

Table 4 | Comparative study between air quality standards found in the study.

		Brazil			*WHO*		*Europe*	*North America*	*Asia*	*South America*	*Africa*	*Oceania*
		Resolution CONAMA 03/1990	Resolution CONAMA 491/2018		WHO Global Air Quality (2021)		Directive 2008/50/EC	Canadian Environmental Protection Act, 1999 (Canada)	Environmental Quality Standards in Japan Air Quality (Japan)	Resolución 2.254 (Colombia)	National Ambient Air Quality Standards (South Africa)	National Clean Air Agreement (Australia)
			(PI-1)	(PF)	(IT-1)	(AQG)						
	Sampling time	Concentration (µg/m³)										
$MP_{2,5}$	24 hours	-	60	25	75	15	-	27	35	50	-	25
	1 year	-	20	10	35	5	25	8,8	15	25	-	8
MP 10	1 hour	-	-		-	-	-	-	200	-	-	-
	24 hours	150	120	50	150	45	50	-	100	100	75	50
	1 year	50	40	20	70	15	40	-	-	50	40	-
Lead	1 year	-	0,5	0,5	-	-	0,5	-	-	-	0,5	0,5
Total Suspended Particles	24 hours	240	240	240	-	-	-	-	-	-	-	-
	1 year	80	80	80	-	-	-	-	-	-	-	-
Smoke	24 hours	150	120	50	-	-	-	-	-	-	-	-
	1 year	60	40	20	-	-	-	-	-	-	-	-
Benzene	1 year	-	-	-	-	-	5	-	3	-	5	-

		Brazil			WHO		Europe	North America	Asia	South America	Africa	Oceania
		Resolution CONAMA 03/1990	Resolution CONAMA 491/2018		WHO Global Air Quality (2021)		Directive 2008/50/EC	Canadian Environmental Protection Act, 1999 (Canada)	Environmental Quality Standards in Japan Air Quality (Japan)	Resolución 2.254 (Colombia)	National Ambient Air Quality Standards (South Africa)	National Clean Air Agreement (Australia)
			(PI-1)	(PF)	(IT-1)	(AQG)						
	Sampling time	Concentration (µg/m³)										
SO_2	10 min	-	-	-	-	-	-	-	-	-	500	-
	1 hour	-	-	-	-	-	350	180	260	100	350	520
	24 hours	365	125	20	125	40	125	-	100	50	125	210
	1 year	80	40	-	-	-	-	13,09	-	-	50	52,35
NO_2	1 hour	320	260	200	-	-	200	110	-	200	200	230
	24 hours	-	-	-	120	25	-	-	75,26-110	-	-	-
	1 year	100	60	40	40	10	40	32	-	60	40	56,44
CO	1 hour	40.000	-	-	-	-	-	-	22.900	35.000	30.000	-
	8 hours	10.000	10.310	10.310	-	-	-	-	-	5.000	10.000	10.310
	24 hours	-	-	-	7	4	10	-	11.450	-	-	-
O_3	1 hour	160	-	-	-	-	-	-	120	-	-	200
	4 hours	-	-	-	-	-	-	-	-	-	-	160
	8 hours	-	140	100	160	100	120	120	-	100	120	-

Source: The author's own work.

As you can see, until 2018, Brazil did not define standards for fine particulate matter $PM_{2.5}$. According to the WHO guidelines, the evidence regarding the public health impact of this material is consistent and demonstrates adverse health effects from exposures that are currently experienced by urban populations in both developed and developing countries (WHO, 2015).

Due to their extremely small size (aerodynamic diameter less than 2.5 micrometers), these particles can penetrate the upper respiratory tract, depositing in the bronchioles and alveoli, causing a range of cardiovascular and respiratory problems in humans. The entire exposed population is affected, but susceptibility to pollution can vary based on health status and age. Epidemiological evidence shows adverse effects of fine particulate matter following short-term and long-term exposures (Santos *et al.*, 2021).

A study conducted by Abe and Miraglia (2016) showed that in the state of São Paulo alone, reducing $PM_{2.5}$ pollution levels to the WHO-recommended levels of 10 µg/m³ (annual average) would add 15.8 months to life expectancy in the population, corresponding to a delay in 5,012 deaths and an annual gain of $15.1 billion, saving healthcare expenses (this value is actually even higher if we consider costs related to absenteeism and intangible costs like quality of life and life expectancy).

The establishment of Conama Resolution 491 in 2018 introduced air quality standards for this pollutant in Brazil. However, it is important to clarify that this resolution set Intermediate Air Quality Standards (PI-1, PI-2, and PI-3) that precede the Final Air Quality Standards (PF). Therefore, the air quality standards currently in effect are the PI-1 standards. Thus, the initial standard for $PM_{2.5}$ is 60 µg/m³, a value that is still 140% higher than the one recommended by the WHO (2021).

According to the regulation, the intermediate standards will be adopted one after another, taking into account the Air Emission Control Plans ("PCEA") and the Air Quality Assessment Reports ("RAQA"), which should be prepared by the state and Federal District environmental agencies. It is also worth noting that the regulation stipulates that if the migration to the subsequent standard is not possible, the current standard prevails.

The regulation also establishes that the Air Emission Control Plans (PCEA) will be defined according to their own regulations and must be prepared within 3 years from the effective date of the regulatory act. On the other hand, the Air Quality Assessment Reports (RAQA) must be prepared annually and should contain monitoring data and the evolution of air quality. These reports must include a minimum content that requires information such as: a description of the characteristics of the state (or Federal District) region where the environmental quality assessment is being conducted, a description of the monitoring network, identification of the monitored air pollutants, types of networks used (whether automatic or manual) and parameters monitored; as well as other aspects related to monitoring methodology and management measures that are being applied.

As a result, it can be observed that under the terms of the new Resolution, each federative unit is responsible for reporting to the federal government whether or not it has achieved the concentration limits of pollutants after a certain time interval. In the event of non-compliance, the period is simply extended for the state to meet the standards (meanwhile, the population continues to suffer from high levels of air pollution).

While there are no sanctions provided in case of an inability to progress to the subsequent standard, and consequently the risk of not reaching the Final Air Quality Standards, which the WHO recommends, it can be considered an advancement to reduce the acceptable concentration values of pollutants when compared to Conama Resolution 03/90 and the inclusion of standards for important pollutants like PM2.5 and lead. However, establishing standards alone does not solve the problem; it is essential to enforce deadlines, implement mechanisms, and establish penalties for those who do not adhere to the stricter standards (Fernandes *et al.*, 2021).

In fact, the experience of not advancing the evolution of established intermediate air quality standards is a known practice in Brazil. In the state of São Paulo, the Environmental Company of the State of São Paulo (Cetesb), which is the state agency responsible for controlling, monitoring, licensing, and supervising activities that generate pollution, established a similar structure as early as 2013 and did not advance in its intermediate goals, remaining stagnant in standards that had been defined as temporary, even to this day in 2022.

This is an example of the difficulty in making progress on this issue, even starting from the state of São Paulo, theoretically the most advanced air quality legislation in Brazil. It is a very complex matter as it involves, on the one hand, the protection of health and the environment and, on the other, a wide range of interests from productive sectors that are also essential to the economy of the states and the country.

Therefore, Brazilian legislation should have been developed interdisciplinary, with mechanisms that could support productive sectors to help them reach the new standards. After all, a plume of pollutants located in one state can easily be transported to a neighbouring state, depending on the wind direction and atmospheric conditions. Thus, this progress must be achieved not only in an interdisciplinary manner but also on a regional scale to obtain tangible results in this matter.

In the case of particulate matter with particles of aerodynamic diameter up to 10 micrometres, PM_{10}, it can be observed that Brazil defines standards for the 24-hour and 1-year periods. Despite the establishment of the new air quality resolution, when compared to other regulations, it is evident that currently, for the 24-hour period, the Brazilian standard is more permissive than all the assessed technical regulations, with its value (120 µg/m³) being 1.4 times higher than the limit recommended by the WHO and the limit adopted by the European regulation (50 µg/m³). For the 1-year sampling period, the current Brazilian standard is now equal to the value defined by the European and South African regulations, better than the one adopted by Colombia, but still 2 times more permissive than the WHO recommendation.

Abe and Miraglia (2016) also assessed the impacts on morbidity due to short-term exposure to PM_{10} in São Paulo from 2009 to 2011. They found that if the WHO-recommended level of PM_{10} (20 µg/m³) had been achieved, São Paulo would have prevented more than 1500 cardiovascular and respiratory hospitalisations annually. An additional 5 µg/m³ reduction would have prevented over 500 more hospitalisations.

Conama Resolution No. 003/1990 did not define standards for lead (Brazil, 1990; Brazil, 2018). This pollutant can be released into the environment through industrial processes, especially in the chemical, automotive, construction and mining industries, and can be transported for kilometres and, when sedimented, can contaminate soil and water (Reis *et al.*, 2019). Furthermore, lead was once a component of gasoline, and the partial or complete ban on the addition of tetraethyl lead to gasoline in some countries reduced the concentration of this element in the air, especially in urban areas, but did not eliminate the problem of lead pollution entirely. (Vanz *et al.*, 2003).

Lead affects all organs and systems of the human body, and it can cause adverse effects on the neurological, haematological, endocrinological, growth, renal, reproductive, and developmental aspects, as well as being associated with carcinogenic, cardiovascular, and gastrointestinal effects (Vargas *et al.*, 2019).

Currently, although the air quality standard for lead is defined as a final air quality standard, the legislation took steps to institute this standard immediately upon the publication of the regulatory act. However, it is a parameter to be monitored in specific areas, depending on the type of atmospheric emission sources and at the discretion of the competent environmental agency (Brazil, 2018).

Among the standards evaluated, only Brazil has established standards for Total Suspended Particles (PTS) and smoke. According to Cetesb, PTS can be simplistically defined as those with an aerodynamic diameter of less than or equal to 50 micrograms. Some of these particles are inhalable and can cause health problems, while others can adversely affect the population's quality of life, interfering with the aesthetic conditions of the environment and hindering normal community activities. Smoke, on the other hand, is associated with particulate matter suspended in the atmosphere from combustion processes (Cetesb, 2016).

Benzene, which is classified as a Group 1 substance by the International Agency for Research on Cancer (IARC/WHO), meaning it is a chemical substance with sufficient evidence of its carcinogenicity in humans (IARC, 1987), did not have a standard defined in the Brazilian technical regulation. Among the regulations evaluated, only the regulations from Europe, Japan, and South Africa established standards for this pollutant, with the Japanese standard being the strictest, setting the lowest maximum annual average concentration allowed at 3 µg/m³.

Regarding sulfur dioxide (SO_2), the Conama Resolution 491 defines standards for sampling periods of 24 hours and 1 year. Once again, despite the reduction in the maximum acceptable concentration value, the current Brazilian standard still performs poorly when compared to other selected standards. For the 24-hour sampling period, it is only equivalent to the South African standard. It is worth noting that, for this same sampling period, the current Brazilian standard is more than 6 times the value of the standard recommended by the WHO.

For the pollutant nitrogen dioxide (NO_2), the Brazilian technical standard defines primary standards for 1-hour and 1-year periods. The maximum acceptable value for the annual average concentration of 60 µg/m³ is the same as that of the Colombian standard, but it is higher and, therefore, more permissive than the others that set standards for this period. As for the 1-hour period (60 µg/m³), it is more permissive than all the others.

Regarding carbon monoxide (CO), Resolution Conama 03/1990 set standards for 1 hour and 8 hours for sampling periods. The new regulation removed the standard for the 1-hour period, maintaining it

only for the 8-hour sampling period. This pollutant does not have a standard defined by the WHO, but the standard adopted by Brazil was the same as Australia's and higher than the standards adopted by Colombia and South Africa.

Regarding ozone (O_3), the Brazilian standard previously set a standard for a 1-hour sampling period but changed it to an 8-hour period with a maximum acceptable concentration of 140 µg/m³. Once again, the Brazilian regulation proved to be worse than all the other standards that established standards for this pollutant in the same sampling period.

The study by Chiquetto *et al.* (2019) in the São Paulo metropolitan region in 2017 demonstrated that the number of people affected by exceeding the WHO's attention levels for ozone was almost ten times higher when compared to the current attention levels. This indicates that the attention levels determined by the current air quality standard clearly underestimate the number of vulnerable people in areas susceptible to high ozone levels and other pollutants.

It is clear from the study that the Conama Resolution 491/18 does not provide a clear timeline for compliance with the outdated national standards, let alone the international standards recommended by the WHO or other agencies.

The current air quality standards used by Brazil severely distort the potential exposure of the population to harmful levels of air pollution, as they underestimate the actual impact on public health. This leads to inadequate planning of public health costs and results in a significant waste of public funds on preventable hospitalisations, premature deaths, and other intangible costs, such as the population's quality of life.

4 CONCLUSIONS

It is clear that Resolution Conama 491/2018, the current Brazilian legislation, is still outdated compared to the air quality standards in force in other countries, particularly concerning acceptable concentration limits for air quality standards.

Brazil has set standards for $PM_{2.5}$, PM_{10}, lead, sulfur dioxide, nitrogen dioxide, and ozone with values higher than those in other international regulations. Additionally, it does not establish standards for important pollutants such as mercury, cadmium, nickel, toluene, and PAHs.

There are certain aspects to commend in the new resolution, such as the reduction of the permissible concentration levels for PM_{10}, smoke, sulfur dioxide, and nitrogen dioxide. Additionally, the introduction of standards for significant pollutants like lead and $PM_{2.5}$, representing a greater health risk than PM_{10}, is noteworthy. The provision for the progression of standards within the regulation is also a positive feature.

However, it is of utmost importance to establish strict timeframes for the transitions between the current intermediate standards, and these should be as short as possible to prevent them from remaining stagnant indefinitely.

It is important to emphasise the need for the inclusion of certain significant air pollutants that already have standards defined in other regulations, such as benzene, PAHs, mercury, cadmium, and nickel, among others.

Environmental legislation should continue to evolve in line with the advancements in production processes and modern lifestyles as new substances are created and released into the atmosphere every day. Therefore, it is essential to remain vigilant. Equally important to the existence and evolution of environmental legislation is its enforcement.

REFERENCES

ABE, K.; MIRAGLIA, S. Health impact assessment of air pollution in São Paulo, Brazil. **International Journal of Environmental Research and Public Health**, v. 13, n. 7, p. 694, 11 Jul. 2016. DOI: 10.3390/ijerph13070694.

AGUILERA, R. *et al.* Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California. **Nature Communications**, v. 12, n. 1, p. 1493, 5 Mar. 2021. DOI: 10.1038/s41467-021-21708-0.

AUSTRALIA. 2004. Available at: https://webarchive.nla.gov.au/awa/20200609071618/ https://www.environment.gov.au/resource/state-air-national-ambient-air-quality-status-and-trends-report-1991-2001. Accessed on: May 02, 2020.

BRAZIL. National Council for the Environment. Resolution Conama nº. 003, de 15 de junho de 1989. Establishes the National Program for Air Pollution Control – Pronar. Ministry of the Environment: Conama. **Diário Oficial da União**. Brasília, DF.

BRAZIL. National Council for the Environment. Resolution Conama nº. 491, de 19 de novembro de 2018. Provides for air quality standards. Ministry of the Environment: Conama, 2018. **Diário Oficial da União**. Brasília, DF.

BURNETT, R. *et al.* Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. **Proceedings of the National Academy of Sciences**, Estados Unidos, v. 115, n. 38, p. 9592-9597, 18 Set. 2018. DOI: 10.1073/pnas.1803222115.

CANADA. 2012. Available at: https://ccme.ca/en/air-quality-report. Accessed on: Jan. 16, 2020.

CHIQUETTO, J. B. *et al.* Air quality standards and extreme ozone events in the São Paulo megacity. **Sustainability**, v. 11, n. 13, p. 3725, 2019.

COLOMBIA. 2017. Available at: http://www.ideam.gov.co/documents/51310/527391/2 .+Resoluci%C3%B3n+2254+de+2017+-+Niveles+Calidad+del+Aire..pdf/c22a285e-058e-42b6-aa88-2745fafad39f. Accessed on: Jan. 16, 2020.

EC. **Directive 2008/50/EC of May 21**, 2008. Available at: https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:02008L0050-20080611&from=NL. Accessed on: Jan. 10, 2020.

EMBASSY OF JAPAN IN BRAZIL. **Environmental issues**, 2012. Available at: https://www.br.emb-japan.go.jp/cultura/ambiente.html. Accessed on: Jun. 02, 2019.

ENVIRONMENTAL COMPANY OF THE STATE OF SÃO PAULO. **Air Quality Report in the State of São Paulo**, São Paulo: Cetesb, p. 340, 2009. Available at: https://cetesb.sp.gov.br/wp-content/uploads/2017/09/relatorio-ar-2016.pdf. Accessed on: Jan. 16, 2020.

FERNANDES, M. A. O. *et al.* Avoiding hospital admissions for respiratory system diseases by complying to the final Brazilian air quality standard: an estimate for Brazilian southeast capitals. **Environmental Science and Pollution Research**, v. 27, n. 29, p. 35889-35907, Oct. 2020. DOI: 10.1007/s11356-020-07772-x.

GBD 2019. Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. **Lancet**, Londres, v. 396, n. 10258, p. 1223–1249, 2020. DOI: 10.1016/S0140-6736(20)30752-2.

JAPAN. 2009. Available at: https://www.env.go.jp/en/air/aq/aq.html. Accessed on: Jan. 20, 2019.

RAJAGOPALAN, S.; AL-KINDI, S. G.; BROOK, R. D. Air Pollution and Cardiovascular Disease: JACC State-of-the-Art Review. **Journals of the American College of Cardiology**, v. 72, n. 17, p. 2054-2070, 23 oct. 2018. DOI: 10.1016/j.jacc.2018.07.099.

REIS, R. A. *et al.* Air pollution related to port activities in Paranaguá: impacts on the protected natural areas of the Paraná Atlantic Forest. 2019. Available at: http://www.iat.pr.gov.br/sites/agua-terra/arquivos_restritos/files/documento/2020-12/projeto_39_2019.pdf. Accessed on: May 19, 2021.

SANTOS, C. **Pollution prevention in industry**: identification of opportunities, analysis of benefits and barriers. 2005. Thesis (Ph.D. in Environmental Engineering) – School of Engineering, São Carlos. University of São Paulo, São Carlos, 2005. Available at: https://www.teses.usp.br/teses/disponiveis/18/18139/tde-08042008-150419/publico/ TeseCarmenluciaSantos.pdf. Accessed on: May 19, 2021.

SANTOS, U. P. *et al.* Environmental air pollution: respiratory effects. **Jornal Brasileiro de Pneumologia**, São Paulo, v. 47, n. 1, e20200267, 2021. DOI: 10.36416/1806-3756/e20200267.

SICILIANO, B. *et al.* The Updated Brazilian National Air Quality Standards: a critical review. **Journal of the Brazilian Chemical Society**, v. 31, n. 3, mar. 2020. Available at: https://www.scielo.br/j/jbchs/a/PfgQRYrhznqJ6P7NHpjSkgG/abstract/?lang=em. Accessed on: Feb. 14, 2022.

SOUTH AFRICA. 2009. Available at: https://www.dffe.gov.za/sites/default/files/ legislations/ nemaqa_airquality_g32816gon1210_0.pdf. Accessed on: Feb. 05, 2020.

VALDAMBRINI, N. M.; RIBEIRO, F. N. D. Avaliação das Ultrapassagens dos Padrões de Ozônio Troposférico no Estado de São Paulo de 2014 a 2019. **Revista Brasileira de Meteorologia**, v. 36, n. 4, oct-dec 2021. DOI: 10.1590/0102-7786360046.

VANZ, A.; MIRLEAN, N.; BAISCH, P. Avaliação de poluição do ar por chumbo particulado: uma abordagem geoquímica. **Química Nova**, São Paulo, v. 26, n. 1, p. 25-29, jan. 2003. DOI: 10.1590/S0100-40422003000100006.

VARGAS, P. I. R.; HUSSEN, M.; BARBOSA, G. Intoxicação por Chumbo: uma revisão sistemática. **Revista Brasileira de Ciências Médicas e da Saúde**, v. 7, 2019.

VORMITTAG, E. M. P. A. *et al.* Análise do monitoramento da qualidade do ar no Brasil. **Energia e Ambiente**, v. 35, n. 102, May.-Aug. 2021. Available at: https://www.scielo.br/j/ea/a/fbCFjRbBRhf4M5F6xQVrbfR/?format=pdf&lang=pt. Accessed on: Feb. 14, 2022.

WORLD HEALTH ORGANIZATION. **WHO Hazardous chemicals to human health and the environment**. International Program on Chemical Safety. São Paulo: Academic culture; 2008. Available at: https://www2.unesp.br/Home/costsa_ses/20110610_084213.PDF. Accessed on: Oct. 02, 2023.

WORLD HEALTH ORGANIZATION. **WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide**. World Health Organization, Geneva, 2005. Available at: https://apps.who.int/iris/handle/10665/69477. Accessed on: Jul. 02, 2019.

WORLD HEALTH ORGANIZATION. **WHO Ambient air pollution**: a global assessment of exposure and burden of disease. World Health Organization, Geneva, 2016. Available at: http://who.int/phe/publications/air-pollution-global-assessment/en/. Accessed on: Jul. 02, 2019.

WORLD HEALTH ORGANIZATION. **Evolution of WHO air quality guidelines**: past, present and future. WHO Regional Office for Europe, Copenhagen, 2017. Available at: https://www.euro.who.int/__data/assets/pdf_file/0019/331660/Evolution-air-quality.pdf. Accessed on: Feb. 14, 2022.

WORLD HEALTH ORGANIZATION. **WHO Air quality guidelines** – Update 2021. Copenhagen, Denmark: WHO Regional Office for Europe (2021). Available at: https://www.who.int/news/item/22-09-2021-new-who-global-air-quality-guidelines-aim-to-save-millions-of-lives-from-air-pollution. Accessed on: Sept. 26, 2023.

Comparação dos padrões de qualidade do ar entre o Brasil e países dos cinco continents

Comparison of air quality standards between Brazil and countries from the five continents

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ARTICLE-VARIA

RESUMO

Este artigo trata de um estudo comparativo entre legislações de qualidade do ar. O principal objetivo foi comparar as normas técnicas vigentes sobre qualidade do ar no Brasil, em relação a normas internacionais. Foram comparados os padrões de qualidade do ar definidos pelo Brasil com os padrões adotados em países dos cinco continentes. O Brasil apresentou padrões para o $MP_{2,5}$, MP_{10}, chumbo, SO_2, NO_2 e O_3 com valores maiores que outras normativas internacionais, além de não apresentar padrões para poluentes importantes como mercúrio, cádmio, níquel, tolueno e HPAs. A utilização de padrões de qualidade do ar mais permissivos deturpa severamente a percepção da exposição potencial da população, minimizando o real impacto na saúde da população exposta, contribuindo para a falta de planejamento adequado de saúde pública e ocasionando desperdício do dinheiro público com internações evitáveis, mortes prematuras e outros custos intangíveis como qualidade de vida da população.

Palavras-chave: Poluição ambiental. Emissões atmosféricas. Padrões de qualidade do ar.

ABSTRACT

This article presents a comparative study of air quality regulations. The main objective was to compare Brazil's current technical air quality standards with international standards. The air quality standards defined by Brazil for $PM_{2.5}$, PM_{10}, lead, SO_2, NO_2, and O_3 have higher values than international norms, and

Brazil lacks standards for important pollutants like mercury, cadmium, nickel, toluene, and PAHs. The use of more permissive air quality standards significantly distorts the perception of potential exposure for the population, downplaying the actual impact on public health, leading to inadequate public health planning, and resulting in avoidable hospitalisations, premature deaths, and other intangible costs like reduced quality of life for the population.

Keywords: Environment pollution. Atmospheric emissions. Air quality standards.

1 INTRODUÇÃO

A poluição atmosférica, que pode ser definida como a presença de substâncias estranhas no ar atmosférico, está entre os 10 principais fatores de risco que contribuem para o número total de anos de vida perdidos ajustados por incapacidade em todas as idades combinadas (GBD, 2019). Diversos estudos epidemiológicos mostram que a poluição do ar pode causar doenças crônicas, agravamento de patologias relacionadas, como morbidade e mortalidade cardiovascular e respiratória, além de mortes prematuras, afetando assim a saúde de populações e contribuindo para o aumento de gastos públicos com atendimentos médicos prestados à população afetada (Aguilera *et al.*, 2021; Burnett *et al.*, 2018; Rajagopalan, 2018).

No Brasil, Abe e Miraglia (2016) estimaram que o custo das mortes prematuras causadas devido à poluição do ar em 29 capitais brasileiras ocasiona uma perda de cerca de US$ 1,7 bilhão anualmente. A magnitude do dado por si só já demonstra a sua relevância, mas acredita-se ainda que ele está subestimado, visto que o valor que poderia deixar de ser gasto pelos cofres públicos pode ainda ser maior se levarmos em consideração outros eventos, além da morte prematura, como internações por causas respiratórias, absenteísmo no trabalho e custos intangíveis, como qualidade e expectativa de vida, o que mostra que a poluição do ar, além de ser uma questão importante de saúde pública, é também uma questão de ordem econômica.

Uma das formas de controlar a emissão de poluentes no meio ambiente como um todo, inclusive na atmosfera e consequentemente mitigar os efeitos danosos à saúde provocados pela poluição, é a instituição de regulamentações rígidas sobre o tema. O estabelecimento de limites de emissões de determinadas substâncias pode ajudar a melhorar a qualidade do ar para proteger a saúde humana e o meio ambiente (Vormittag *et al.*, 2021).

A Organização Mundial da Saúde – OMS estabelece limites recomendados de concentrações de importantes poluentes atmosféricos, baseados na síntese global de evidências científicas, para os quais espera-se que efeitos adversos à saúde ocorram em uma parcela significativa da população, tanto ao ar livre quanto dentro de edifícios e casas. Essas recomendações são diretrizes a serem seguidas pelos países, mas não possuem caráter normativo. As diretrizes da OMS cobrem as concentrações anuais e diárias de partículas finas, dióxido de nitrogênio, dióxido de enxofre, monóxido de carbono e ozônio (OMS, 2021).

No Brasil a Resolução do Conselho Nacional do Meio Ambiente (Conama) Nº 03, de 28 de junho de 1990, era o regulamento técnico que estabelecia os padrões de qualidade do ar tendo sido substituída pela Resolução Conama Nº 491, de 19 de novembro de 2018, que em seu artigo 2º, inciso II define:

> Art. 2º - II - Padrão de qualidade do ar: um dos instrumentos de gestão da qualidade do ar, determinado como valor de concentração de um poluente específico na atmosfera, associado a um intervalo de tempo de exposição, para que o meio ambiente e a saúde da população sejam preservados em relação aos riscos de danos causados pela poluição atmosférica.

Um padrão de qualidade do ar, portanto, é um instrumento técnico que define legalmente um limite máximo para a concentração de um poluente, visando controlar as emissões dos poluentes com o intuito de garantir a proteção da saúde e do bem-estar das pessoas e do meio ambiente (Brasil, 1990, 2018).

Vormittag *et al.* (2021) explicam que os padrões de qualidade do ar vigentes no Brasil, além de estarem defasados, muitas vezes são descumpridos em função da falta de compromisso do governo com as políticas estabelecidas. A utilização de padrões de qualidade do ar desatualizados, sobretudo mais elevados quando comparados com as recomendações internacionais, e, portanto, mais permissivos, pode deturpar severamente a exposição potencial da população a níveis prejudiciais de poluição do ar (Chiquetto *et al.*, 2019; Valdambrini; Ribeiro, 2021).

O principal objetivo deste estudo é comparar as normas técnicas vigentes sobre qualidade do ar no Brasil com as normas internacionais vigentes em outros países pelo mundo.

2 MÉTODO

Trata-se de um estudo comparativo sobre padrões de qualidade do ar entre normas técnicas nacionais de diferentes países do mundo. Os padrões de qualidade do ar são definidos levando-se em consideração dois parâmetros: o valor limite de concentração aceitável no ambiente para cada poluente, geralmente em micrograma por metro cúbico (µg/m³) ou partes por milhão (ppm), e o período de amostragem, que é o tempo definido para coleta e avaliação do poluente.

A pesquisa foi realizada levando-se em consideração as normas técnicas de padronização de qualidade do ar vigentes em cada país selecionado, durante o período de novembro 2018 até janeiro de 2022. Foram escolhidos padrões de qualidade do ar de normas técnicas de pelo menos um país de cada continente do mundo, além das diretrizes sobre qualidade do ar da Organização Mundial da Saúde – OMS, que apesar de não possuir caráter normativo, serve como diretriz para a elaboração e revisão das demais normas técnicas de qualidade do ar em todos os países do mundo.

Dessa forma, foram selecionadas para comparação a Resolução Conama Nº 03, de 1990, antiga regulamentação de padrões de qualidade do ar no Brasil; a Resolução Conama Nº 491 (2018), norma técnica atualmente em vigência no Brasil; a Diretiva 2008/50/CE, norma que serve de referência para os países da União Europeia (2008); a *Canadian Environmental Protection Act* (1999), norma técnica do Canadá, país escolhido da América do Norte; a *Environmental Quality Standards in Japan Air Quality* (2009), norma do Japão, representando o continente asiático; *Resolución* 2.254 (2017) da Colômbia, para se ter mais um país da América do Sul, além do Brasil; a *Air Quality Act* 39: *National Ambient Air Quality Standards* (2004), norma da África do Sul, representando o continente africano; *National Clean Air Agreement* (2015) da Austrália, representando a Oceania; além do *WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide* (2021), guia de referência da Organização Mundial da Saúde.

Para realizar as comparações, foi necessário converter todos os valores limites de concentração dos poluentes para uma única unidade de mensuração, pois tais valores, a depender da norma e do poluente, se apresentavam em miligrama por metro cúbico (mg/m³), micrograma por metro cúbico (µg/m³), partes por milhão (ppm) ou partes por bilhão (ppb).

Os dados foram organizados em forma de planilhas e buscou-se realizar a comparação dos valores limites de cada poluente relativo ao mesmo tempo de amostragem em cada norma.

3 RESULTADOS E DISCUSSÃO

A Resolução Conama Nº 491, de 19 de novembro de 2018, é resultado do processo de revisão da Resolução Conama Nº 03, de 28 de junho de 1990, que estabeleceu os padrões de qualidade do ar nacionais naquele ano, e esteve em vigor durante 28 anos, sem atualização dos novos conhecimentos científicos sobre o tema. Somente em 2014, foi iniciada sua revisão na Câmara Técnica de Qualidade Ambiental e Gestão de Resíduos do Conama. Então, o processo de início da revisão foi tomado de forma demasiadamente atrasada e a sua aprovação, ao contrário, foi realizada de forma precipitada, sem se discutir com a sociedade e com os especialistas as melhores formas de se garantir que houvesse, de fato, avanços no atendimento aos padrões de qualidade do ar no Brasil (Siciliano *et al.*, 2020).

A Resolução Conama Nº 491 (2018) definiu 14 padrões de qualidade do ar para nove poluentes, enquanto a Resolução Conama Nº 03 (1990) definia 13 padrões para sete poluentes. Os valores das concentrações máximas de poluentes no ar, assim como os tempos de amostragem definidos, estão sintetizados na Tabela 1 a seguir:

Tabela 1 | Padrões de qualidade do ar do Brasil definidos pelas Resoluções Conama.

BRASIL			
	Conama 03 (1990)	*Conama 491 (2018)*	
Poluente	Concentração (µg/m3)	Concentração (µg/m3)	Tempo de amostragem
$MP_{2,5}$	-	25	24 horas
	-	10	1 ano
MP_{10}	150	50	24 horas
	50	20	1 ano
Partículas Totais em Suspensão	240	240	24 horas
	80	80	1 ano
Fumaça	150	50	24 horas
	60	20	24 horas
SO_2	365	20	24 horas
	80	-	1 ano
NO_2	320	200	1 hora
	100	40	1 ano
CO	40.000	10.310	1 hora
	10.000	-	8 horas
O_3	160	-	1 hora
	-	100	8 horas
Chumbo	-	0,5	1 ano

Fonte: Resoluções Conama 03/1990 e 491/2018. Adaptada pelo autor.

Neste trabalho foram analisadas oito normas técnicas de padronização de parâmetros de qualidade do ar e um guia de referência internacional, que foi o *Guideline* da OMS (2021).

No que diz respeito à quantidade de padrões definidos por cada norma, a que apresentou a menor quantidade de padrões de qualidade do ar definidos foi a do Canadá, com a definição de sete padrões, e a que apresentou a maior quantidade de padrões foi a norma técnica da Colômbia, com 19 padrões definidos. O quantitativo de padrões definido por norma encontra-se sintetizado na Figura 1.

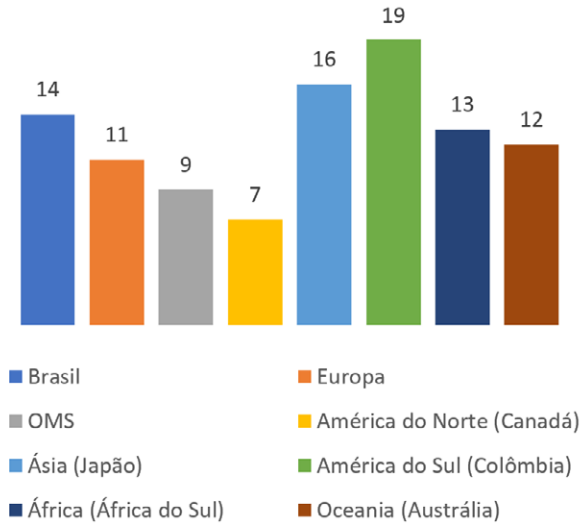

Figura 1 | Quantitativo de padrões definido por norma

Fonte: Elaborado pelo autor

A norma técnica do Japão foi a única a definir padrões primários para os poluentes tricloroetileno, tetracloroetileno, diclorometano, dioxinas e oxidantes fotoquímicos. Os padrões de qualidade do ar só encontrados na norma japonesa encontram-se sintetizados na Tabela 2.

Tabela 2 | Padrões de qualidade do ar só encontrados na norma japonesa.

Environmental Quality Standards in Japan Air Quality		
Poluente	Concentração máxima	Tempo de amostragem
Tricloroetileno	0,2 mg/m³	1 ano
Tetracloroetileno	0,2 mg/m³	1 ano
Diclorometano	0,15 mg/m³	1 ano
Dioxinas	0.6 pg-TEQ/m³	1 ano
Oxidantes fotoquímicos	0,06 ppm	1 hora

Fonte: Ministério do Meio Ambiente japonês. Adaptada pelo autor.
(Disponível em: https://www.env.go.jp/en/air/aq/aq.html)

Segundo informações da embaixada japonesa no Brasil, em meados da década de 1960 até a década de 1970, o Japão vivenciou diversas formas graves de poluição ambiental. Além da doença de Minamata, uma série de outras doenças relacionadas à poluição foram descobertas, como a doença de itai-itai, transtornos respiratórios nos bolsões industriais de Tóquio-Yokohama, Nagoya e Osaka-Kobe e intoxicação crônica por arsênico na região de Toroku, na Província de Miyazaki. Essas formas de poluição ocorreram como resultado da priorização do rápido crescimento econômico em detrimento de padrões para proteger a saúde e a segurança das pessoas. Essas consequências levaram o Japão a estabelecer regulamentações rígidas para proteger o meio ambiente a partir da década de 1960.

Da mesma forma que ocorreu com a norma japonesa, alguns poluentes também só foram identificados na norma técnica colombiana. Trata-se do que a própria norma chamou de "contaminantes tóxicos do ar": cádmio, mercúrio inorgânico, tolueno, níquel (e seus compostos) e os Hidrocarbonetos Policíclicos Aromáticos – HPA. Os padrões de qualidade do ar só encontrados na norma colombiana encontram-se sintetizados na Tabela 3.

Tabela 3 | Padrões de qualidade do ar só encontrados na norma colombiana.

Contaminantes tóxicos		
Poluente	Concentração máxima (µg/m³)	Tempo de amostragem
Cádmio	0,005	1 ano
Mercúrio inorgânico (vapores)	1	1 ano
Tolueno	260	1 semana
	1.000	30 minutos
Níquel (e seus compostos)	0,18	1 hora
HPA	0,001	1 ano

Fonte: Colômbia. Ministério de Ambiente y Desarrolo Sostenible - Resolución 2.254. Adaptada pelo autor.

Um estudo realizado pelo Programa Internacional sobre Segurança Química (IPCS) da OMS mostra que, além dos mais comuns ou "tradicionais" poluentes atmosféricos, um grande número de substâncias químicas tóxicas e carcinogênicas vem sendo cada vez mais encontrado na atmosfera urbana, embora em baixas concentrações. Exemplos incluem metais (berílio, cádmio e mercúrio), substâncias orgânicas em nível de traços (benzeno, dibenzo-dioxinas policloradas e dibenzo-furanos, fomaldeído, cloreto de vinila e os HPAs) e fibras (asbesto). Tais substâncias são emitidas por diversas fontes, incluindo incineradores de resíduos, estações de tratamento de esgoto, processos industriais, uso de solventes, materiais de construção e veículos automotores (OMS, 2000).

Retirados os poluentes que só são mencionados nas normas técnicas do Japão e da Colômbia, foi montada a Tabela 4 com os padrões dos demais poluentes distribuídos por tempo de amostragem e referentes a cada norma.

Tabela 4 | Comparativo entre padrões de qualidade do ar encontrados no estudo.

		Brasil			*OMS*		*Europa*	*América do Norte*	*Ásia*	*América do Sul*	*África*	*Oceania*
		Resolução Conama 03/1990	Resolução Conama 491/2018		WHO Global Air Quality (2021)		Diretiva 2008/50/CE	Canadian Environmental Protection Act, 1999 (Canadá)	Environmental Quality Standards in Japan Air Quality (Japão)	Resolución 2.254 (Colômbia)	National Ambient Air Quality Standards (África do Sul)	National Clean Air Agreement (Austrália)
			(PI-1)	(PF)	(IT-1)	(AQG)						
	Tempo de amostragem	Concentração (µg/m³)										
$MP_{2,5}$	24 horas	-	60	25	75	15	-	27	35	50	-	25
	1 ano	-	20	10	35	5	25	8,8	15	25	-	8
MP 10	1 hora	-	-		-	-	-	-	200	-	-	-
	24 horas	150	120	50	150	45	50	-	100	100	75	50
	1 ano	50	40	20	70	15	40	-	-	50	40	-
Chumbo	1 ano	-	0,5	0,5	-	-	0,5	-	-	-	0,5	0,5
Partículas totais em suspensão	24 horas	240	240	240	-	-	-	-	-	-	-	-
	1 ano	80	80	80	-	-	-	-	-	-	-	-
Fumaça	24 horas	150	120	50	-	-	-	-	-	-	-	-
	1 ano	60	40	20	-	-	-	-	-	-	-	-

		Brasil			OMS		Europa	América do Norte	Ásia	América do Sul	África	Oceania
		Resolução Conama 03/1990	Resolução Conama 491/2018		WHO Global Air Quality (2021)		Diretiva 2008/50/CE	Canadian Environmental Protection Act, 1999 (Canadá)	Environmental Quality Standards in Japan Air Quality (Japão)	Resolución 2.254 (Colômbia)	National Ambient Air Quality Standards (África do Sul)	National Clean Air Agreement (Austrália)
			(PI-1)	(PF)	(IT-1)	(AQG)						
	Tempo de amostragem	Concentração (µg/m³)										
Benzeno	1 ano	-	-	-	-	-	5	-	3	-	5	-
SO_2	10 min	-	-	-	-	-	-	-	-	-	500	-
	1 hora	-	-	-	-	-	350	180	260	100	350	520
	24 horas	365	125	20	125	40	125	-	100	50	125	210
	1 ano	80	40	-	-	-	-	13,09	-	-	50	52,35
NO_2	1 hora	320	260	200	-	-	200	110	-	200	200	230
	24 horas	-	-	-	120	25	-	-	75,26-110	-	-	-
	1 ano	100	60	40	40	10	40	32	-	60	40	56,44
CO	1 hora	40.000	-	-	-	-	-	-	22.900	35.000	30.000	-
	8 horas	10.000	10.310	10.310	-	-	-	-	-	5.000	10.000	10.310
	24 horas	-	-	-	7	4	10	-	11.450	-	-	-
O_3	1 hora	160	-	-	-	-	-	-	120	-	-	200
	4 horas	-	-	-	-	-	-	-	-	-	-	160
	8 horas	-	140	100	160	100	120	120	-	100	120	-

Fonte: Elaboração própria.

Como pode-se perceber, até 2018 o Brasil não definia padrões para o material particulado fino $PM_{2,5}$. De acordo com as diretrizes da OMS, as evidências sobre o impacto na saúde pública provocado por esse material são consistentes e mostram efeitos adversos à saúde em exposições que são atualmente experimentadas por populações urbanas em países desenvolvidos e em desenvolvimento (OMS, 2015).

Essas partículas, por possuírem um tamanho demasiadamente reduzido (diâmetro aerodinâmico menor que 2,5 micrômetros), atravessam as vias respiratórias superiores, depositando-se nos bronquíolos e alvéolos, sendo fonte de uma série de problemas cardiorrespiratórios aos seres humanos. Toda a população exposta é afetada, mas a suscetibilidade à poluição pode variar com o estado de saúde ou com a idade. Evidências epidemiológicas mostram efeitos adversos ao material particulado fino após exposições de curto e de longo prazo (Santos *et al.*, 2021).

Um estudo conduzido por Abe e Miraglia (2016) mostrou que, só no estado de São Paulo, uma redução dos níveis de poluição do $MP_{2,5}$ aos níveis recomendados pela OMS de 10 µg/m³ (em média anual) acrescentaria 15,8 meses de expectativa de vida na população, correspondendo a um adiamento de 5.012 óbitos e um ganho anual de US$ 15,1 bilhões, com economia de recursos despendidos com saúde (esse valor na verdade é ainda maior se considerássemos os gastos com absenteísmo e custos intangíveis, como qualidade de vida e expectativa de vida).

A instituição da Resolução Conama 491 em 2018, no entanto, inseriu padrões de qualidade do ar no Brasil para esse poluente, porém é preciso esclarecer que a referida resolução estabeleceu padrões de Qualidade do Ar Intermediários (PI-1, PI-2 e PI-3) que vão anteceder os Padrões de Qualidade do Ar Final – PF. Assim, os padrões de qualidade do ar atualmente em vigência tratam-se dos PI-1. Dessa forma, o padrão adotado inicialmente para o $MP_{2,5}$ é de 60 µg/m³, um valor ainda 140% maior que o recomendado pela OMS (2021).

De acordo com a norma, os padrões intermediários serão adotados, cada um, subsequentemente, levando em consideração os Planos de Controle de Emissões Atmosféricas (“PCEA”) e os Relatórios de

Avaliação de Qualidade do Ar ("RAQA"), que deverão ser elaborados pelos órgãos de meio ambiente estaduais e do Distrito Federal. Cabe ainda destacar que a norma previu que caso não seja possível a migração para o padrão subsequente, prevalece o padrão já adotado.

A norma também estabelece que os PCEA serão definidos de acordo com regulamentação própria e elaborados em até três anos a partir da entrada em vigor do ato normativo, enquanto que os RAQA deverão ser elaborados anualmente e conter os dados de monitoramento e a evolução da qualidade do ar com um conteúdo mínimo que exige que os relatórios contenham informações tais como: descrição das características da região do estado (ou Distrito Federal) onde estiver sendo realizada a avaliação da qualidade ambiental; descrição da rede de monitoramento; determinação dos poluentes atmosféricos monitorados; tipos de rede utilizados (se automática ou manual) e parâmetros monitorados; além de outros aspectos relativos à metodologia do monitoramento e medidas de gestão que estão sendo aplicadas.

Assim, é possível perceber que nos termos da nova Resolução cabe a cada Unidade Federativa reportar à União se atingiu ou não os limites de concentração dos poluentes após o intervalo de tempo de alguns anos e, no caso do não atendimento, simplesmente prorroga-se o período para que o estado possa atingir os padrões (enquanto isso, a população continua sofrendo com altos níveis de poluição do ar).

Em que pese não haver sanções previstas no caso de incapacidade de progressão para o padrão subsequente, e consequentemente incorrer no risco de não se conseguir chegar aos Padrões de Qualidade do Ar Final, que são aqueles recomendados pela OMS, pode ser considerado um avanço a redução dos valores das concentrações aceitáveis dos poluentes, quando comparados com a Resolução Conama 03/90, e a inserção de padrões para poluentes importantes como o MP2,5 e chumbo. Mas o estabelecimento de padrões por si só não resolve o problema, é preciso se fazer cumprir um prazo, implementar mecanismos e estabelecer punições para quem não implementar os padrões mais rigorosos (Fernandes *et al.*, 2021).

Aliás, essa experiência de não evoluir para os padrões intermediários de qualidade do ar estabelecidos já é uma prática conhecida no Brasil. No estado de São Paulo, a Companhia Ambiental do Estado de São Paulo – Cetesb, que é a agência estadual do governo responsável pelo controle, fiscalização, monitoramento e licenciamento de atividades geradoras de poluição, instituiu estrutura semelhante já em 2013, e não avançou em suas metas intermediárias, continuando estagnada nos padrões que haviam sido definidos como temporários, ainda hoje em dia, em 2022.

Dessa forma, temos um exemplo da dificuldade que é avançar nessa questão (partindo do estado de São Paulo, teoricamente o mais avançado na legislação de qualidade do ar), que é muito complexa ao envolver, de um lado, a proteção da saúde e do meio ambiente, e, de outro, interesses dos mais variados setores produtivos que também são necessários à economia dos estados e do país.

Assim, a legislação brasileira precisaria ter sido elaborada de forma intersetorial, com mecanismos que pudessem dar subsídios aos setores produtivos para que atingissem os novos padrões. Mesmo porque uma pluma de poluentes localizada em um estado pode facilmente ser transportada para um estado vizinho, a depender da direção do vento e das condições atmosféricas, assim, é fundamental que esse avanço seja realizado de forma integrada não só intersetorialmente, mas em escala regional, para que se obtenham resultados concretos nessa questão.

No caso do material particulado, com partículas de diâmetro aerodinâmico de até 10 micrômetros, o MP_{10}, pode-se perceber que o Brasil define padrões para os períodos de 24 horas e 1 ano. Apesar da instituição da nova resolução sobre qualidade do ar, quando comparado às demais legislações evidencia-se que atualmente para o período de 24 horas o padrão brasileiro se mostra superior, e, portanto, mais permissivo que todas as normas técnicas avaliadas, sendo o seu valor (120 $\mu g/m^3$) 1,4

vezes superior ao limite recomendado pela OMS e o limite adotado pela norma Europeia (50 µg/m³). Para o período de amostragem de 1 ano, o padrão brasileiro, em vigência atual, se igualou ao valor definido pela norma da Europa e da África do Sul, sendo melhor até que o adotado pela Colômbia, mas se apresentava duas vezes mais permissivo que a recomendação da OMS.

Abe e Miraglia (2016) também avaliaram os impactos na morbidade devido à exposição de curto prazo ao MP_{10}, em São Paulo, no período compreendido entre 2009 e 2011, e verificaram que se o nível recomendado pela OMS (de 20 µg/m³) de MP_{10} tivesse sido atingido, São Paulo teria evitado mais de 1.500 internações cardiovasculares e respiratórias anualmente. Uma redução adicional de 5 µg/m³ teria evitado mais de 500 internações.

A Resolução Conama Nº 003/1990 não definia padrões para o chumbo (Brasil, 1990; Brasil, 2018). Esse poluente pode ser liberado no meio ambiente por meio de processos industriais, principalmente das indústrias químicas, automotiva e atividades de construção e mineração, que pode ser transportado por quilômetros e, ao se sedimentar, pode contaminar o solo e a água (Reis *et al.*, 2019). Além disso, o chumbo já foi um componente da gasolina, a proibição parcial ou total da adição do chumbo tetraetil na gasolina de alguns países, diminuiu a concentração desse elemento no ar, sobretudo em zonas urbanas, mas não determinou o desaparecimento do problema da poluição por esse metal (Vanz *et al.*, 2003).

O chumbo afeta todos os órgãos e sistema do corpo humano, ele pode causar efeitos adversos neurológicos, hematológicos, endocrinológicos, sobre o crescimento, renais, sobre a reprodução e o desenvolvimento, carcinogênicos, cardiovasculares e gastrointestinais (Vargas *et al.*, 2019).

Atualmente, apesar de o padrão de qualidade do ar para o chumbo estar definido somente como padrão de qualidade do ar final, a legislação se preocupou em tornar imediata a instituição desse padrão a partir do momento da publicação do ato normativo, porém é um parâmetro a ser monitorado em áreas específicas, em função da tipologia das fontes de emissões atmosféricas e do critério do órgão ambiental competente (Brasil, 2018).

Das normas avaliadas, somente o Brasil apresentou padrões para as Partículas Totais em Suspensão – PTS e para fumaça. De acordo com a Cetesb, as PTS podem ser definidas de maneira simplificada como aquelas cujo diâmetro aerodinâmico é menor ou igual a 50 microgramas. Uma parte dessas partículas é inalável e pode causar problemas à saúde, outra parte pode afetar desfavoravelmente a qualidade de vida da população, interferindo nas condições estéticas do ambiente e prejudicando as atividades normais da comunidade. A fumaça, por sua vez, está associada ao material particulado suspenso na atmosfera proveniente dos processos de combustão (Cetesb, 2016).

O benzeno, que é uma substância classificada no Grupo 1 pela Agência Internacional de Pesquisa em Câncer (*International Agency for Research on Cancer* – IARC/OMS), ou seja, como uma substância química com evidências suficientes de sua carcinogenicidade em seres humanos (IARC, 1987), não teve padrão definido na norma técnica brasileira. Das normas avaliadas, apenas as regulamentações da Europa, Japão e África do Sul apresentaram padrões para esse poluente, sendo que a norma japonesa foi a mais rigorosa, apresentando a menor concentração média anual máxima permitida com o valor de 3 µg/m³.

Com relação à substância dióxido de enxofre (SO_2), a Resolução Conama Nº 491 define padrões para os períodos de amostragem de 24 horas e 1 ano. Novamente, apesar da redução do valor da concentração máxima aceitável, a norma brasileira, atualmente, ainda experimenta os piores resultados quando comparada às demais normas selecionadas, para o período de amostragem de 24 horas, se igualando apenas à norma da África do Sul. Chama atenção que para esse mesmo período de amostragem, atualmente, o padrão brasileiro é mais de seis vezes o valor do padrão recomendado pela OMS.

Para o poluente dióxido de nitrogênio (NO_2), a norma técnica do Brasil define padrões primários para os períodos de 1 hora e 1 ano. O valor máximo aceitável da média das concentrações anuais de 60 µg/m³ foi igual ao da norma da Colômbia, porém superior, e, portanto, mais permissiva que as demais que definiram padrões para esse período. E para o período de 1 hora (60 µg/m³), foi mais permissiva que todas as demais.

Com relação ao monóxido de carbono (CO), a Resolução Conama 03/1990 definia padrões para os períodos de amostragem de 1 hora e 8 horas. A nova regulamentação retirou o padrão para o período de 1 hora, mantendo apenas para o período de amostragem de 8 horas. Esse poluente não tem padrão definido pela OMS, mas o padrão adotado pelo Brasil foi igual ao da Austrália e superior aos padrões adotados pela Colômbia e África do Sul.

Em relação ao ozônio (O_3), a norma brasileira definia padrão apenas para o período de amostragem de 1 hora, mudou para o período de 8 horas e possui valor máximo de concentração aceitável de 140 µg/m³. Mais uma vez a normativa brasileira se mostrou pior que todas as outras normas que instituíram padrão para esse poluente no mesmo período de amostragem.

Um estudo realizado por Chiquetto *et al.* (2019), em 2017, na região metropolitana de São Paulo, mostrou que o número de pessoas afetadas pela superação dos níveis de atenção da OMS para o ozônio foi quase dez vezes maior do que quando em comparação com os níveis de atenção atualmente vigentes. Isso nos mostra que os níveis de atenção determinados pelo padrão de qualidade do ar atual claramente subestimam o número de pessoas vulneráveis em áreas suscetíveis a altos níveis de ozônio, assim como para outros poluentes.

Dessa forma, percebe-se que a Resolução Conama 491/18 não fornece um horizonte claro de atendimento sequer dos atrasados padrões nacionais, quanto mais os recomendados internacionalmente pela OMS ou outras agências.

Os atuais padrões de qualidade do ar utilizados pelo Brasil deturpam severamente a exposição potencial da população a níveis prejudiciais de poluição do ar, visto que eles minimizam o real impacto na saúde da população, contribuindo para a falta de planejamento adequado de custos de saúde pública e ocasionando um desperdício imenso de dinheiro público com internações evitáveis, mortes prematuras, além de outros custos intangíveis como a qualidade de vida da população.

4 CONSIDERAÇÕES FINAIS

Fica evidente que a Resolução Conama 491/2018, que é a legislação brasileira atualmente vigente, ainda está defasada perante as legislações vigentes em outros países, no que se refere a valores limites aceitáveis de padrões de qualidade do ar.

O Brasil apresentou padrões para o $MP_{2,5}$, MP_{10}, chumbo, dióxido de enxofre, dióxido de nitrogênio e ozônio com valores maiores do que outras normativas internacionais, além de não apresentar padrões para poluentes importantes como mercúrio, cádmio, níquel, tolueno e HPAs.

Até existem pontos que podem ser exaltados com a instituição da nova Resolução, como a redução dos valores limites dos padrões de qualidade dos poluentes MP_{10}, fumaça, dióxido de enxofre e dióxido de nitrogênio, por exemplo, e a inserção de padrões para alguns poluentes importantes, como o chumbo e o $MP_{2,5}$, que é um poluente mais perigoso para a saúde que o MP_{10}, além da previsão da evolução dos padrões dentro da própria norma.

Porém, é de extrema importância que se adotem prazos limites para as mudanças entre os padrões intermediários vigentes e que sejam os mais breves possíveis para que eles não permaneçam estagnados indefinidamente.

Ressalta-se o apelo pela inserção de alguns poluentes atmosféricos importantes que já têm padrões definidos em outras normativas, como o benzeno, os HPAs, mercúrio, cádmio, níquel, entre outros.

A legislação ambiental deve continuar evoluindo da mesma forma que os processos produtivos e os modos de vida modernos o fazem, pois a cada dia milhares de substâncias novas são criadas e lançadas na atmosfera, portanto é necessário manter-se vigilante. Tão importante quanto a existência e evolução da legislação ambiental é o cumprimento dela.

REFERÊNCIAS

ABE, K.; MIRAGLIA, S. Health impact assessment of air pollution in São Paulo, Brazil. **International Journal of Environmental Research and Public Health**, v. 13, n. 7, p. 694, 11 jul. 2016. DOI: 10.3390/ijerph13070694.

ÁFRICA DO SUL. 2009. Disponível em: https://www.dffe.gov.za/sites/default/files/ legislations/ nemaqa_ airquality_g32816gon1210_0.pdf. Acesso em: 05 fev. 2020.

AGUILERA, R. *et al.* Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California. **Nature Communications**, v. 12, n. 1, p. 1493, 5 mar. 2021. DOI: 10.1038/s41467-021-21708-0.

AUSTRÁLIA. 2004. Disponível em: https://webarchive.nla.gov.au/awa/20200609071618/ https://www.environment.gov.au/resource/state-air-national-ambient-air-quality-status-and-trends-report-1991-2001. Acesso em: 05 fev. 2020.

BRASIL. Conselho Nacional de Meio Ambiente. Resolução Conama nº. 005, de 15 de junho de 1989. Dispõe sobre o Programa Nacional de Controle da Poluição do Ar – Pronar. Ministério do Meio Ambiente: Conama. **Diário Oficial da União**. Brasília, DF.

BRASIL. Conselho Nacional de Meio Ambiente. Resolução Conama nº. 491, de 19 de novembro de 2018. Dispõe sobre padrões de qualidade do ar. Ministério do Meio Ambiente: Conama, 2018. **Diário Oficial da União**. Brasília, DF.

BURNETT, R. *et al.* Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. **Proceedings of the National Academy of Sciences**, Estados Unidos, v. 115, n. 38, p. 9592-9597, 18 set. 2018. DOI: 10.1073/pnas.1803222115.

CANADÁ. 2012. Disponível em: https://ccme.ca/en/air-quality-report. Acesso em: 16 jan. 2020.

CHIQUETTO, J. B. *et al.* Air quality standards and extreme ozone events in the São Paulo megacity. **Sustainability**, v. 11, n. 13, p. 3725, 2019.

COLÔMBIA. 2017. Disponível em: http://www.ideam.gov.co/documents/51310/527391/2.+Resoluci%C3%B3n+2254+de+2017+-+Niveles+Calidad+del+Aire..pdf/c22a285e-058e-42b6-aa88-2745fafad39f. Acesso em: 16 jan. 2020.

COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO. **Relatório de Qualidade do Ar no Estado de São Paulo**, São Paulo: Cetesb, p. 340, 2009. Disponível em: https://cetesb.sp.gov.br/wp-content/uploads/2017/09/relatorio-ar-2016.pdf. Acesso em: 16 jan. 2020.

EC. **Diretiva 2008/50/CE, de 21 de maio de 2008**. Disponível em: https://eur-lex.europa.eu/legal-content/PT/TXT/ PDF/?uri=CELEX:02008L0050-20080611&from=NL. Acesso em: 10 jan. 2020.

EMBAIXADA DO JAPÃO NO BRASIL. **Questões ambientais**, 2012. Disponível em: https://www.br.emb-japan.go.jp/cultura/ambiente.html. Acesso em: 02 jul. 2019.

FERNANDES, M. A. O. *et al.* Avoiding hospital admissions for respiratory system diseases by complying to the final Brazilian air quality standard: an estimate for Brazilian southeast capitals. **Environmental Science and Pollution Research**, v. 27, n. 29, p. 35889-35907, out. 2020. DOI: 10.1007/s11356-020-07772-x.

GBD 2019. Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. **Lancet**, Londres, v. 396, n. 10258, p. 1223–1249, 2020. DOI: 10.1016/S0140-6736(20)30752-2.

JAPÃO. 2009. Disponível em: https://www.env.go.jp/en/air/aq/aq.html. Acesso em: 20 jan. 2019.

ORGANIZAÇÃO MUNDIAL DE SAÚDE. **Substâncias químicas perigosas à saúde e ao ambiente**. Programa Internacional de Segurança Química. São Paulo: Cultura Acadêmica. 2008. Disponível em: https://www2.unesp.br/Home/costsa_ses/20110610_084213.PDF. Acesso em: 02 out. 2023.

ORGANIZAÇÃO MUNDIAL DE SAÚDE. **WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide**. World Health Organization, Geneva, 2005. Disponível em: https://apps.who.int/iris/handle/10665/69477. Acesso em: 02 jul. 2019.

ORGANIZAÇÃO MUNDIAL DE SAÚDE. **WHO Ambient air pollution**: a global assessment of exposure and burden of disease. World Health Organization, Geneva, 2016. Disponível em: http://who.int/phe/publications/air-pollution-global-assessment/en/. Acesso em: 02 jul. 2019.

ORGANIZAÇÃO MUNDIAL DE SAÚDE. **Evolution of WHO air quality guidelines**: past, present and future. WHO Regional Office for Europe, Copenhagen, 2017. Disponível em: https://www.euro.who.int/__data/assets/pdf_file/0019/331660/Evolution-air-quality.pdf. Acesso em: 14 fev. 2022.

ORGANIZAÇÃO MUNDIAL DE SAÚDE. **WHO Air quality guidelines** – Update 2021. Copenhagen, Denmark: WHO Regional Office for Europe (2021). Disponível em: https://www.who.int/news/item/22-09-2021-new-who-global-air-quality-guidelines-aim-to-save-millions-of-lives-from-air-pollution]. Acesso em: 26 set. 2023.

RAJAGOPALAN, S.; AL-KINDI, S. G.; BROOK, R. D. Air Pollution and Cardiovascular Disease: JACC State-of-the-Art Review. **Journals of the American College of Cardiology**, v. 72, n. 17, p. 2054-2070, 23 oct. 2018. DOI: 10.1016/j.jacc.2018.07.099.

REIS, R. A. *et al.* **Poluição atmosférica relacionada às atividades portuárias em Paranaguá**: impactos nas áreas naturais protegidas da Mata Atlântica paranaense. 2019. Disponível em: http://www.iat.pr.gov.br/sites/agua-terra/arquivos_restritos/files/documento/2020-12/projeto_39_2019.pdf. Acesso em: 19 maio 2021.

SANTOS, C. **Prevenção à poluição industrial**: identificação de oportunidades, análise dos benefícios e barreiras. 2005. Tese (Doutorado em Ciências da Engenharia Ambiental) – Escola de Engenharia de São Carlos. Universidade de São Paulo, São Carlos, 2005. Disponível em: https://www.teses.usp.br/teses/disponiveis/18/18139/tde-08042008-150419/publico/ TeseCarmenluciaSantos.pdf. Acesso em: 19 maio 2021.

SANTOS, U. P. *et al.* Environmental air pollution: respiratory effects. **Jornal Brasileiro de Pneumologia**, São Paulo, v. 47, n. 1, e20200267, 2021. DOI: 10.36416/1806-3756/e20200267.

SICILIANO, B. *et al.* The Updated Brazilian National Air Quality Standards: a critical review. **Journal of the Brazilian Chemical Society**, v. 31, n. 3, mar. 2020. Disponível em: https://www.scielo.br/j/jbchs/a/PfgQRYrhznqJ6P7NHpjSkgG/abstract/?lang=em. Acesso em: 14 fev. 2022.

VALDAMBRINI, N. M.; RIBEIRO, F. N. D. Avaliação das Ultrapassagens dos Padrões de Ozônio Troposférico no Estado de São Paulo de 2014 a 2019. **Revista Brasileira de Meteorologia**, v. 36, n. 4, oct-dec 2021. DOI: 10.1590/0102-7786360046.

VANZ, A.; MIRLEAN, N.; BAISCH, P. Avaliação de poluição do ar por chumbo particulado: uma abordagem geoquímica. **Química Nova**, São Paulo, v. 26, n. 1, p. 25-29, jan. 2003. DOI: 10.1590/S0100-40422003000100006.

VARGAS, P. I. R.; HUSSEN, M.; BARBOSA, G. Intoxicação por Chumbo: uma revisão sistemática. **Revista Brasileira de Ciências Médicas e da Saúde**, v. 7, 2019.

VORMITTAG, E. M. P. A. *et al.* Análise do monitoramento da qualidade do ar no Brasil. **Energia e Ambiente**, v. 35, n. 102, mai./ago. 2021. Disponível em: https://www.scielo.br/j/ea/a/fbCFjRbBRhf4M5F6xQVrbfR/?format=pdf&lang=pt. Acesso em: 14 fev. 2022.

In this last issue of 2023, Sustainability in Debate, in its editorial, reflects on the concept of Sustainability and its evolution into a value that today concerns society as a whole.

Subsequently, SiD publishes ten articles, seven in the *Dossier* "Just Energy Transitions" and three in the *Varia* section. Firstly, Paulino *et al.* discuss the advances in wind energy in the Brazilian Northeast with a focus on socio-environmental conflicts, followed by Araújo and Gorayeb, who address the problem of social acceptance of wind generators and the perception of injustices from part of a community. González *et al.* discuss institutional arrangements related to the advancement of "energy communities", and Baigorrotegui *et al.* address energy network maintenance problems in Puerto Edén (Chile). Costa *et al.* discuss the role of transmission lines in promoting access to renewable sources. Araújo *et al.* debate the applicability of spatial modelling in the local planning of transmission projects, and Wolffenbüttel discusses how individuals mobilise certain values to acquire electric cars. In the *Varia* section, Zulkifli *et al.* present a financial viability study of a sugarcane company in Indonesia, while Canãr and Loor address the social and environmental effects of gold mining after the end of official concessions in the Amazon. Finally, Amaral *et al.* present a comparative study on air quality legislation between Brazil and other countries.

Nesse último número de 2023, Sustainability in Debate, *em seu editorial, faz uma reflexão sobre o* conceito *de Sustentabilidade, e a sua mudança para um valor que hoje diz respeito a toda a sociedade.*

Na sequência, SiD publica dez artigos, sete no Dossiê "Transições Energéticas Justas" e três na seção Varia. *Primeiramente, Paulino* et al. *discutem os avanços da energia eólica no Nordeste com foco nos conflitos socioambientais, seguido por Araújo e Gorayeb que abordam o problema da aceitação social dos geradores eólicos e a percepção sobre injustiças por parte de uma comunidade. González* et al. *discorrem sobre arranjos institucionais relacionados ao avanço das "comunidades energéticas", e Baigorrotegui* et al. *abordam os problemas de manutenção da rede de energia em Puerto Edén (Chile). Costa* et al. *dialogam sobre o papel das linhas de transmissão para a promoção do acesso às fontes renováveis, Araújo* et al. *debatem sobre a aplicabilidade da modelagem espacial no planejamento locacional de projetos de transmissão, e Wolffenbüttel discorre sobre como os indivíduos mobilizam certos valores para a aquisição de automóveis elétricos. Na seção* Varia, *Zulkifli* et al. *apresentam um estudo de viabilidade financeira de uma empresa de cana-de-açúcar na Indonésia, enquanto Canãr e Loor abordam as repercussões sociais e ambientais da mineração de ouro após o término de concessões oficiais na Amazônia. Por fim, Amaral* et al. *apresentam um estudo comparativo sobre as legislações de qualidade do ar do Brasil e outros países.*

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