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Original Research Article

Indigenous Adaptive Capacity Index to Climate Change: Brazilian Case Study

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ABSTRACT

This paper introduces an index to assess the adaptive capacity of Indigenous Lands in the context of climate change vulnerability. The index was developed considering two sub-indices, one to evaluate the indigenous autonomy and ability to self-organise and establish relationships with other groups and the surrounding society, and the other to assess the level of protection of the Indigenous Land surroundings. The aim is to guide integrated climate adaptation strategies for electricity companies operating near Indigenous Land. The paper also presents an application of the proposed index in the Belo Monte hydropower plant in the Amazon region, with a strong presence of Indigenous Lands and one of Brazil's most important hydropower plants. The results made it possible to compare the adaptive capacity of the Indigenous Lands and evaluate their different degrees of engagement and environmental protection, which can help in the proposition of adaptation actions.

KEYWORDS

Adaptive capacity, Climate change, Indigenous vulnerability, Belo Monte hydropower plant, Vulnerability index, Adaptation strategies.

INTRODUCTION

Traditionally, the debate on climate change has focused on scientific, environmental, or economic perspectives. Still, it has gradually expanded to include the social dimension [1], as it is necessary to face the unequal income distribution and benefits from the so-called development [2]. Promoting a fair and ethical development process is essential, as equality is a primary condition for sustainable development [3]. There is an increasing global concern for Indigenous Peoples who rely on the environment for their subsistence [4]. These communities may suffer direct impacts from the effects of climate change [5], such as loss of ecosystem functions, replacement of endemic species, and regime shifts across landscapes and seascapes [6], and even from the efforts to mitigate them, as outlined in the IPCC AR6 technical report [7]. Nevertheless, Indigenous Peoples offer valuable examples of sustainable adaptation strategies based on their traditional knowledge [8], which contains unique information sources about past changes [9] and potential solutions to current issues [10].

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Identifying and evaluating existing vulnerabilities in communities, as well as their current capacity for adaptation [11], are factors that contribute to the development of successful strategies for adapting to climate change [12]. In discussing the importance of adaptation, Ford and Smit [13] acknowledge that mitigation strategies alone will not be able to reduce or stop anthropogenic actions that cause climate change, negative impacts will inevitably occur, and many countries are already seeking support from the international community to establish and adopt adaptation measures. The authors point out the need to understand the nature of vulnerability in terms of who and what is vulnerable, what causes stress and how, and the existing capacity to adapt to risk changes. According to Preston *et al.* [14], early policy efforts to combat climate risks were more focused on mitigation, and more recently, these actions have included adaptation. In this sense, surveying the experiences of other countries can provide important elements for developing more proactive and anticipatory adaptation strategies. The authors of [14] evaluated 57 adaptation plans from different sectors and levels of planning in Australia, the United Kingdom, and the United States, and the results suggest that the plans are mostly superficial and are based on incomplete or biased risk perceptions as they do not consider other socioeconomic and biophysical factors. The impacts of climate change, the responses to these impacts, and the capacity for adaptation are local characteristics that further emphasise the importance of measures implemented at the local community level for the adaptation process. Therefore, although the problem is global, the action is local [15]. Promoting adaptation based on communities in developing countries presents many advantages. It can be considered a governance tool that helps manage the risks of climate change, empowering communities and creating synergies with other broader objectives focused on sustainable development and poverty reduction [15]. However, there are still many challenges to be overcome.

One challenge is having adequate methodologies and tools capable of mapping the most vulnerable areas to support the planning of adaptation actions. Most methodologies for calculating indigenous vulnerability to climate change recognise the importance of incorporating local knowledge [16] and community participation in the adaptation process [17]. These methodologies present different ways of assessing vulnerability, considering exposure, sensitivity, and adaptive capacity, according to the technical reports of IPCC AR3 [18] and AR4 [19], as well as information concerning access to resources, community perceptions, and institutional capacity.

Although various methodologies have been developed to assess the vulnerability of Brazilian protected areas [20] and Brazilian Amazon Indigenous Territories [21], none of them have been specifically designed to address the electric energy sector regarding companies operating near Indigenous Land. The electric energy sector has been a significant player in global climate change, and it must comprehend and map how its projects and installations can effectively contribute to achieving the goals established by countries in the Paris Agreement. An integrated approach to planning adaptation actions is necessary, and this gap is crucial to proposing adequate adaptation actions that must be implemented by these companies in nearby Indigenous Lands, aligned with the Brazilian Plan for Adaptation to Climate Change [22]. Moreover, sectoral evaluation can prioritise specific adaptation actions for each Indigenous Land, identifying the most vulnerable ones that require immediate adaptation measures. Furthermore, another significant gap that has been identified in the vulnerability indices found in the literature is the absence of consideration of climate vulnerability, which is associated with changes in climate variables over time. The changes in these variables, when combined with the specific vulnerabilities of indigenous communities, can exacerbate the fragility of these populations.

In this context, adaptive capacity is a fundamental aspect of discussions on climate change concerning Indigenous Peoples. Understanding how to increase local adaptive capacity is important as it helps communities deal with vulnerability and risk [23]. This paper analyses the specific aspects of the indigenous population's vulnerability to climate change by proposing an index to evaluate the adaptive capacity of Indigenous Land, which can guide integrated climate adaptation strategies for electricity companies operating near Indigenous Land.

This paper also presents an application of the proposed Adaptive Capacity Index at the Belo Monte hydropower plant [24], one of Brazil's most important hydropower plants located in the Xingu River Basin in the Amazon region. The Amazon region has a strong presence of Indigenous Land and one of the world's largest hydropower potentials [25]. It has been extensively studied by the Brazilian Energy Research Company (EPE, responsible for the energy expansion planning for the coming years), as more than half of Brazil's hydropower potential available for expansion is located in this region [26].

For example, the Long-Term Brazilian Energy Expansion Plan [27], with a horizon until 2030, was crucial in strengthening and prioritising the expansion of hydropower sources in Brazil. Moreover, the Brazilian Ten-Year Energy Expansion Plan [26] reveals that the participation of hydropower in the energy matrix for the next ten years will remain virtually unchanged. Several significant hydropower plants, such as Belo Monte, have been constructed since then [24]. Nowadays, Belo Monte is the largest 100% Brazilian hydropower plant, with an installed capacity of 11,233 MW and an average generation capacity of 4,571 MW. According to Panday *et al.* [28], the forested area of the Xingu basin decreased from 90% to 75% between 1970 and 2000. Furthermore, the construction of the Belo Monte dam led to a significant increase in water bodies upstream and decreased downstream of the plant [29]. Deforestation combined with changes in water bodies can significantly affect the hydroclimatic characteristics of the region and, consequently, the ecosystems, local communities, and electricity generation. Additionally, this basin has more than 30 Indigenous Lands in different degrees of regularisation.

Therefore, the proposed methodology aims to practically identify the most vulnerable areas of the river basin by systematising relevant information from recognised databases, facilitating the assessment of indigenous vulnerability to climate change. By identifying the areas and populations that are most vulnerable, as well as their most pressing needs, it is possible to clarify the adjustments that the electric energy sector must make to increase the resilience of these populations and reduce the potential impacts of climate risks on their business.

Furthermore, the assessment results will provide valuable insights into indigenous communities' complexities and conflicts in maintaining their territories and way of life. These insights will be crucial in developing effective policies and programs to support their resilience. Obtaining adequate information and knowledge of the specific realities of these populations is essential to efficiently rank the adaptation options. Thus, systematic collection and analysis of relevant data are crucial for informed decision-making and ensuring the long-term sustainability of these communities.

METHODS

The following key steps were undertaken to develop a comprehensive methodology for assessing indigenous vulnerability to climate change, as outlined in this paper, aligned with international standards and best practices in climate change adaptation research:

- Identification of most relevant issues − A thorough investigation was conducted to identify the most relevant issues that should be considered in the vulnerability assessment. It involved an extensive review of international literature on climate change adaptation in communities and an analysis of diverse National Adaptation Plans.
- Selection of appropriate indicators − A meticulous effort was made to identify and select suitable indicators that could effectively support the formulation of the proposed Indigenous Vulnerability Index, ensuring their relevance and reliability.
- Indigenous Vulnerability Index framework development − The formulation of the index framework was a pivotal stage in the methodology development. This step involved structuring the essential components and parameters of the entire Indigenous

Vulnerability Index in alignment with established definitions from IPCC AR3 and AR4 technical reports.

- Development of the Adaptive Capacity Index – This phase involved formulating the distinct component within the Indigenous Vulnerability Index related to adaptive capacity (Adaptive Capacity Index) and its corresponding subindices.

Identification of the most relevant issues

The discussion was conducted to identify the most relevant issues that should be considered, focused primarily on understanding the pressures and threats that already impact indigenous territories [30]. It involved a review of international literature on climate change adaptation in communities [31], providing valuable insights into the challenges and best practices in this area. An analysis of National Adaptation Plans from various countries, including Brazil [22], Chile [32], and Canada [33], which present similar characteristics in terms of energy generation and vulnerability to climate change, was carried out to identify common characteristics and vulnerabilities, to identify relevant issues, and approaches for adaptation actions aligned with environmental, climate policy, and multilateral agreements signed by the countries. The analysis led to the identification of adaptation options that focus on reducing vulnerability and social inequalities in the context of Community-Based Adaptation, which involves the development and execution of strategies at the community level through collective efforts based on traditional knowledge and community priorities, corroborating Klein *et al.* [1] and Reid [34].

The analysis also highlighted the importance of measuring vulnerability as a fundamental element for adaptation in terms of its three components: exposure, sensitivity, and adaptive capacity of the community under investigation. It is important to consider its social and biophysical vulnerabilities to understand what factors related to these components affect the community [35]. Comprehending these issues is critical for defining effective and adjusted adaptation actions for different populations.

As a result of this discussion, it is clear that the evaluation and monitoring of adaptation are crucial for managing climate risks. Despite the efforts to critically examine adaptation worldwide, such evaluation has yet to be fully implemented in practice. Hence, it is important to emphasise the necessity of bridging this gap. For more details of the discussion based on the proposed methodology, please refer to [36].

Selection of appropriate indicators

The second step refers to the analysis conducted to identify suitable vulnerability indicators to support the development of the proposed Indigenous Vulnerability Index. The "Social Vulnerability Index" created by IPEA [37] aims to provide organised information for public policy planning, considering factors such as urban infrastructure, human capital, income, and employment. The "Climate Vulnerability Index" [38], developed by James Cook University in Australia, was designed to evaluate the vulnerability of areas listed as World Heritage sites by UNESCO. This index considers exposure (temporal) and sensitivity (spatial) to climate change and assesses the level of economic, social, and cultural adaptive capacities. The "Municipal Index of Human Vulnerability to Climate Change" developed by FIOCRUZ [39] considers vulnerability in the three main axes defined by the IPCC: exposure, sensitivity, and adaptive capacity. Each of these dimensions is translated into an index contributing to the overall Vulnerability Index. In addition, the FIOCRUZ index also considers the Climate Scenario Index, which is based on two climate projection scenarios proposed by the IPCC, RCP 4.5 and RCP 8.5. Another study [40] developed the "Composite Drought Vulnerability Index" to map the 30 districts of Tamil Nadu and analyse the best mitigation measures to be implemented in each region. The authors also utilised the IPCC's definition of vulnerability (exposure, sensitivity, and adaptive capacity) to ensure an interdisciplinary and comprehensive analysis. The districts were categorised into three different levels of vulnerability according to their calculated index, enabling the mapping of the entire territory for visualisation and analysis of the most vulnerable portions. This approach can inform decision-making on the implementation of appropriate mitigation measures.

Rorato *et al.* [21] and Lapola *et al.* [20] stand out regarding methodologies for assessing indigenous vulnerability in the Brazilian Amazon. However, their studies were not developed to focus on the electric energy sector. Since the authors of [20] developed a framework for assessing the vulnerability of protected areas (conservation units and Indigenous Lands), the study does not consider specific information regarding Indigenous Lands to assess their adaptive capacity. The approach has some limitations, including a minimum area threshold (> 50 km²) that excludes over half of Brazil's protected areas, which could be considered more vulnerable due to their smaller size. The framework classified the protected areas into high, medium, or low vulnerability. Still, due to the significant number of protected areas categorised as "high vulnerability", the authors concluded that it would be financially and logistically unfeasible to apply complex adaptation actions to such a large number of protected areas. The authors also recognised that strategic planning and decision-making at the local level would undoubtedly play a role in determining best practices. Therefore, future initiatives should be tailored to each location and consider the local institutional, environmental, and social circumstances [41], particularly those close to protected areas [42]. The index proposed in this paper contributes to filling these identified gaps.

The methodology developed by Rorato *et al.* [21] went a step further by specifically calculating the vulnerability of Indigenous Lands in the Amazon. While there are similarities between the information used in their study and the vulnerability index proposed in this paper, there are also differences in the objectives and methodologies used. Specifically, the index proposed in this paper focuses on indigenous population information, whereas the authors of [21] primarily used some information based on statistics that are more suitable for non-indigenous municipal populations. However, for the proposed index of this paper, it is considered important to rely on information from sources with greater expertise on traditional indigenous populations, gathered through more detailed and up-to-date information, taking into account important aspects of their ways of life, to capture their specificity. These differences are particularly evident in the adaptive capacity component of the index proposed. Therefore, while the study from Rorato *et al.* [21] is an important contribution, the proposed index offers a more targeted approach to assessing the vulnerability of indigenous populations in the Amazon region.

Indigenous Vulnerability Index framework development

The proposed adaptive capacity index is part of the Indigenous Vulnerability Index (IVI), which aims to measure vulnerability to climate change by focusing on indigenous communities and lands. It is based on the definitions provided in the IPCC AR3 [18] and AR4 [19] technical reports, encompassing exposure, sensitivity, and adaptive capacity components. To better characterise indigenous vulnerability to climate change, it is crucial to understand the previous context of these communities, so the methodology of the present study considers that exposure refers to external stress factors (the pressures and threats of the many economic interests that affect indigenous territories and natural resources). The methodology also considers sensitivity, which refers to internal stress factors (such as the level of the legal protection of the IL, the existence of conflicts, etc.), and adaptive capacity related to structural stress factors, which is the focus of this paper. Although the IPCC AR6 technical report [7] has changed its approach, most vulnerability indices developed so far still measure vulnerability in terms of these three components. The next stage of this methodology is to adapt IVI to the new IPCC structure.

To narrow the identified gap of the absence of the consideration of climate vulnerability, in addition to the proposed IVI, the Climate Vulnerability Index (IVC) was developed and is considered as a second intermediate index when calculating the Final Vulnerability Index. The IVC aims to represent local vulnerability due to climate change, directly linked to analysing changes in extreme weather events, such as air temperature and precipitation, within the study area. Figure 1 illustrates the structure of the Final Vulnerability Index and its components, highlighting the Adaptive Capacity Index, the object of this study, in blue.

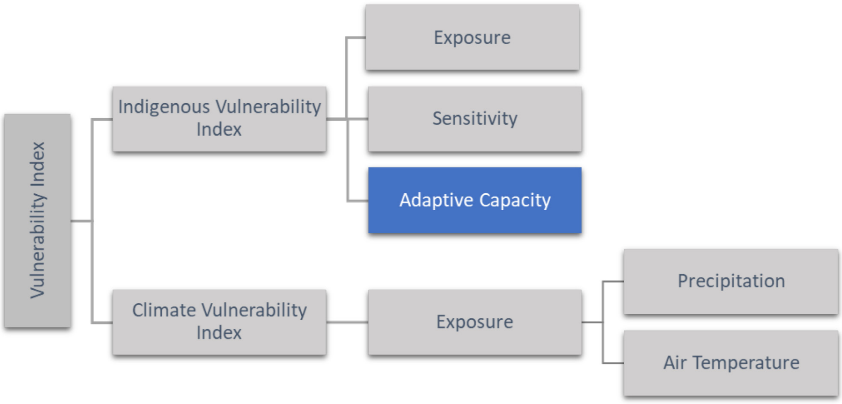


Figure 1. General structure of the Vulnerability Index

After specifying the index framework, it is important to define the study area that better represents the key aspects of the Electric Energy Sector. So, in the case of a hydropower project, to enable the analysis of socio-environmental processes intrinsic to the region considered, the entire river basin in which the project is located was chosen as the study area of the proposed index according to what is defined on the expansion planning of river basin hydropower, as stated in the methodology of the Hydropower Inventory Studies [43]. Considering the river basin as the study area allows for a more comprehensive understanding of human interactions and environmental processes. It is recommended to adopt the river basin for applying the proposed methodology, considering other sources of electric energy generation.

Adaptive Capacity Index

Adaptive capacity can be defined as the ability of a system to adjust to changes or threats to moderate potential harm [44], take advantage of opportunities, or deal with consequences [45]. According to Turner *et al.* [46], adaptive capacity can also be understood as the extent to which a system can react and change its circumstances to move towards a less vulnerable condition and, therefore, depends on the quantity and quality of resources the system possesses [47].

Within the context of indigenous vulnerability, adaptive capacity refers to the ability of indigenous people to cope with environmental degradation and the illegal occupation of their lands. Based on this premise, this paper proposes a methodology for an Adaptive Capacity Index to assess indigenous autonomy and their capacity to self-organise, establish relationships, engage with other groups, and interact with the surrounding society. Indigenous organisations play a crucial role in creating partnerships, projects, and programs that provide Indigenous peoples access to knowledge and information in different contexts. The index also measures the level of protection of the surrounding lands, reducing external pressures and preventing the entry of third parties that could negatively impact indigenous communities and territories. The quality of life and availability of resources are affected by the fragmentation of the vegetation around the Indigenous Lands, which affects their ability to deal with potential impacts on their lives.

In this sense, the Adaptive Capacity Index comprises two sub-indices: the Indigenous Land Engagement Index and the Surrounding Land Protection Index. The scores for each index are assigned by Indigenous Land based on available and recognised database information. The adaptive capacity component represents the structural stress factors associated with administrative, legal, and service-related issues that assist the community. Therefore, the methodology for assigning adaptive capacity values considers Indigenous Lands with greater engagement and protection in their surroundings as having a higher adaptive capacity and those with lower engagement and less protected areas in their surroundings as having lower adaptive capacity. The methodology aims to assign values to each sub-index, ranging from 0 (lower adaptive capacity) to 1 (maximum adaptive capacity). The adaptive capacity of each Indigenous Land is then obtained through the weighted sum of the Engagement and the Surrounding Land Protection indices. The weight assigned to each index should consider the specificity of the basin under study. However, it is recommended to use equal weights of 0.5 for both indices to give them the same relative importance and equal participation in differentiating Indigenous Lands regarding adaptive capacity.

Engagement Index

The objective of the Engagement Index is to assess the level of social and political organisation within indigenous groups, the existence of intra-group or inter-group political unity, and the interactions between indigenous peoples and society. Indigenous Lands with higher levels of engagement and stronger relationships with other indigenous groups and society, as well as a greater internal organisation, are considered to have greater adaptive capacity.

According to Rorato *et al.* **[21]**, Brazil's history of indigenous empowerment is closely linked to the creation of indigenous self-representation organisations. Since the 1980s, various indigenous groups have been fighting for their rights and articulating their demands for territory, health, and education through these organisations, which relate to different spheres of society, governmental sectors, non-governmental organisations, and private organisations. These indigenous organisations establish partnerships, projects, and programs for these peoples, providing access to knowledge and information and helping preserve their culture. As the IPCC technical report outlined, "cultural losses threaten adaptive capacity and may accumulate into intergenerational trauma, resulting in the irreparable loss of their sense of belonging, valued cultural practices, identity, and home" **[7]**.

The engagement evaluation can be carried out by considering various indicators, such as participation in indigenous associations and organisations, forms and nature of contact with the surrounding society and other groups, and axes of reciprocal solidarity and rivalry between indigenous groups. The calculation of this index must be based on available information from reliable sources such as the Socio-Environmental Institute (ISA) database **[48]**. ISA is a Brazilian civil society and public interest organisation that works to develop solutions to protect the territories of indigenous and other traditional peoples, strengthen their cultures and traditional knowledge, raise their political profiles, and develop sustainable economies. So, for the Engagement Index, two indicators were selected from the ISA database:

- Indigenous Organisations: whether the Indigenous Land has any organisation or association that represents the community to articulate the struggle of their people to defend their rights to land, education, and health;
- Projects with Indigenous Participation: projects that involve the participation of indigenous organisations to work on various areas such as biodiversity conservation, territorial protection, development of sustainable productive activities, and strengthening of political representation of leaders. Such projects are supported through donations.

The scores for these indicators are determined based on whether organisations and projects are present (higher engagement) or absent (lower engagement) within the Indigenous Land. The Engagement Index is calculated by multiplying the scores assigned to the two indicators. Initially, a value of 1 should be assigned for presence and 0.5 for absence for both indicators. Assigning a value of 0 for absence should be avoided, as it would result in a final score of 0 for an Indigenous Land with either an organisation or a project (but not both), equivalent to the score of an Indigenous Land with neither. **Table 1** presents the possible results of the Engagement Index assuming the suggested values.

Table 1. Possible results of the Engagement Index

Organisation	Project	Result
YES (= 1)	YES (= 1)	$1 \times 1 = 1$
YES (= 1)	NO (= 0.5)	$1 \times 0.5 = 0.5$
NO (= 0.5)	YES (=1)	$0.5 \times 1 = 0.5$
NO (= 0.5)	NO (= 0.5)	$0.5 \times 0.5 = 0.25$

Surrounding Land Protection Index

Fragmented landscapes tend to be more susceptible to fire, present lower provision of ecosystem services [49], have lower habitat quality for various species and have decreasing food availability [50]. Thus, the more fragmented the vegetation around the Indigenous Land, the lower the quality of life and the availability of resources for the indigenous population [51], and consequently, their ability to face potential impacts on their lives will be lower. In addition, the more protected the surrounding areas of the Indigenous Lands, the farther away the economic pressures that can negatively affect indigenous peoples will be. Therefore, for the calculation of the Surrounding Land Protection Index, it was considered that the more protected areas are in the surroundings of the Indigenous Land, the more protected it will be from external pressures.

The concept of a buffer zone of protected areas was utilised as a proxy variable to explain the component to evaluate the level of protection of the surroundings. The primary purpose of the buffer zone is to mitigate the adverse effects of activities outside the protected area, according to the Brazilian National System of Conservation Units (SNUC) Law. The perimeter of the protected areas is considered in this study as a vulnerable region that becomes even more fragile when exposed. The buffer zone aims to preserve the integrity of the protected area, thereby promoting the stability and balance of the ecosystem.

Thus, to calculate the proposed index, it is suggested to consider a 10 km buffer surrounding the Indigenous Land to determine what percentage of this area is protected, as shown in Figure 2. The selection of a 10 km buffer zone was based on Brazilian legislation[†]. Furthermore, previous studies conducted in the Brazilian Amazon explored the dynamics of deforestation patterns in protected areas using remote sensing data [52], the role of Brazilian protected areas in climate change mitigation [53], and environmental vulnerability assessment of protected areas [21] support the 10 km range. Nevertheless, this value can be adjusted to the particularities of each river basin and each case by seeking input from the specialists involved in the study.

When evaluating the protected areas surrounding Indigenous Lands and assigning scores based on their level of protection, it is important to consider the various classes of protection: conservation units of integral protection and sustainable use and Indigenous Lands with different stages of the regularisation process according to Brazilian legislation[‡]. Formally protected areas, such as conservation units or Indigenous Lands, should be mapped, and the typologies of protection should be identified. Since these areas have official legal protection, they are likelier to keep their territories free of invasions and will be assigned a Surrounding Land Protection Index closer to 1. In the case of conservation units, distinct values should be assigned according to each typology. The highest protection value for the surrounding area (equal to 1) will be assigned to conservation units of integral protection.

[†] National Environmental Council (CONAMA) Resolution nº13/1990; Decree nº 99274/1990; Brazilian Interministerial Ordinance nº 60/2015.

[‡] The regularisation procedures of the Brazilian Indigenous Lands are defined by Law n° 6,001/1973 and Decree n° 1,775/1996, and includes the stages of Identification (to propose the physical limits of the IL), Declaration (that officially states that the territory is an IL), Demarcation (the physical demarcation of the indigenous territory), Homologation (by Presidential Decree), Registration and Exclusion (that legally register the IL and remove illegal occupants) [52].

In contrast, for conservation units for sustainable use, high values can be assigned but not equal to 1. This is because conservation units of integral protection have more restrictions on the use of the territory than conservation units of sustainable use, as this includes extractive reserves, sustainable development reserves, etc. For Indigenous Lands, the assignment of values will be based on the degree of land regularisation of the area. Higher protection values will be assigned to regularised Indigenous Lands, and decreasing values will be declared, delimited and under regularisation as the degree of protection decreases without formal interlocutors defending the territories and communities. Thus, the Indigenous Lands under study will receive the lowest values among the protected areas. All other regions of the study area that are not protected will receive a low protection value for the surrounding area (close to 0).

The methodology does not intend to define specific values for each type of conservation unit and each stage of the Indigenous Land because they should be defined according to the specificities of each basin under study. It is important to emphasise that the purpose of defining these values is to differentiate the areas surrounding Indigenous Lands with different levels of protection. Therefore, using index values to compare regions in different basins is not recommended because these values are not comparable only for regions within the same basin.

Thus, the methodology for calculating the Surrounding Land Protection Index can be summarised in the following steps:

1. Using a georeferenced map, delimit a buffer area with a thickness of 10 km around the Indigenous Land, according to the scheme in **Figure 2b**;
2. Calculate the percentage of the level of protection of the area within the buffer, identifying which areas are protected and which are not (**Figure 2c**);
3. Assign a score for each typology of level of protection. The logic is that the higher the indicator value, the greater the protection of the surroundings and, thus, the greater the adaptive capacity.
4. Calculate the final score of the indicator for each Indigenous Land by the weighted sum of the different typologies of levels of protection found within the buffer area, using Equation 1. The weight of each typology refers to the percentage of the area that the typology occupies within the buffer area.

$$Iprot_i = \sum_{j=1}^{n} p_{j,i} \times PROT_j \quad (1)$$

Where: $Iprot_i$ – Indigenous Land "i"; $p_{j,i}$ – % of the buffer area surrounding the Indigenous Land "i" referring to typology "j"; $PROT_{j,i}$ – Score of typology "j".

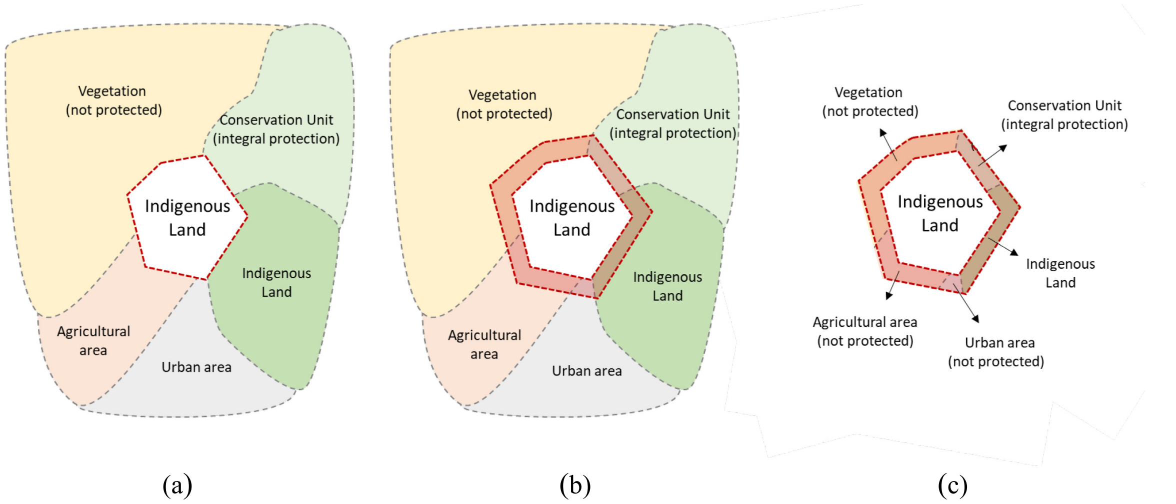


Figure 2. Scheme for calculating the degree of protection of the surroundings: identification of the Indigenous Land and its surrounding areas (a); Delimitation of the buffer area (b); and calculation of the percentage of area of each typology within the buffer (c)

RESULTS AND DISCUSSION

Based on the information presented in the Introduction section, the index proposed in this paper was applied to the Belo Monte Hydropower Plant, considering the entire Xingu River Basin, as shown in **Figure 3**. The choice of this basin as a case study was motivated by the desire to analyse all the socio-environmental processes intrinsic to the region that are considered in the proposed methodology.

Figure 3. Location of the study area

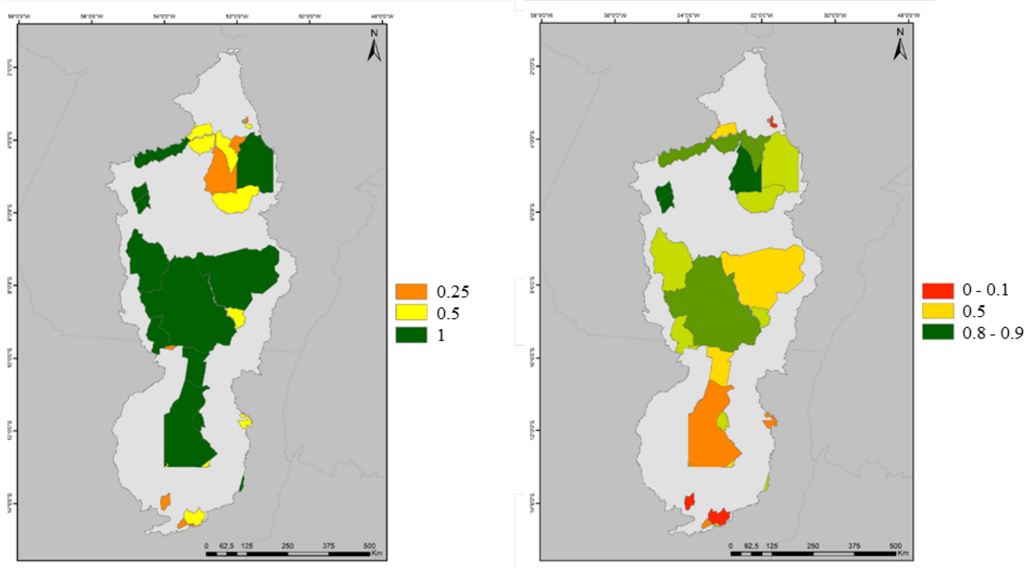
The index was applied in three steps comprising the calculation of Engagement Index, Surrounding Land Protection Index, and Adaptive Capacity Index.

Engagement Index Calculation

The data on Indigenous Lands within the Xingu River Basin and the presence of Indigenous organisations and projects in these Indigenous Lands were obtained from the ISA database **[48]**. **Figure 4a** shows the basin map indicating the final result of the Engagement Index for each Indigenous Land. The Indigenous Lands with a score of 1 (in green) have a higher Engagement Index, owing to the presence of both indigenous organisations that are already consolidated and projects with indigenous participation. The map reveals that most Indigenous Lands achieved the highest score for the index, with only a few Indigenous Lands scoring the lowest (due to the absence of organisations and projects), mostly located at the northern and southern extremes of the basin.

Surrounding Land Protection Index

The first step was to delineate a buffer area with a thickness of 10 km around each Indigenous Land, using a georeferenced map to compute the Surrounding Land Protection Index. Once the buffer was delineated, the percentages of each protected area and land use typology were calculated by considering the total area of the buffer. This application assigned scores between 0 (minimum) and 1 (maximum score) to each protection typology. For instance, areas without protection were assigned a score of 0. In contrast, regions with a high degree of protection, such as the conservation unit of integral protection, were assigned a score of 1. For other protection typologies, intermediate scores were assigned closer to 0 or 1, depending on the degree of protection compared to the extreme values. Once the weights and scores of each typology were obtained, Equation 1 was applied to compute the Surrounding Land Protection Index for each Indigenous Land. The computed values are presented in **Figure 4b**. Values closer to 0 (in red) indicate a lower Surrounding Land Protection Index of the Indigenous Land, while values closer to 1 (in green) indicate a higher Index.



(a) (b)

Figure 4. Maps of Engagement Index (a) and Surrounding Land Protection Index (b)

Adaptive Capacity Index

Based on the previously calculated indices of Engagement and Surrounding Land Protection, the adaptive capacity of the Indigenous Lands in the Xingu River Basin was determined using the weighted sum method with equal weights for both indices. **Figure 5** presents the resulting map of adaptive capacity: no region of the basin obtained the maximum possible value of 1 or the lowest possible value of 0. However, it is possible to differentiate Indigenous Lands based on their adaptive capacity. Generally, Indigenous Lands closer to other Indigenous Lands have values greater than 0.5, while isolated Indigenous Lands have values closer to 0. For example, the Menkragnoti Indigenous Land (the darkest green area in the map centre) has one of the highest values of adaptive capacity due to its high index of engagement and many protected areas in its surroundings.

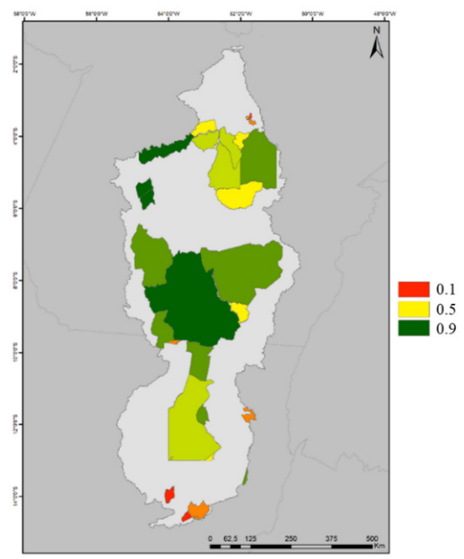


Figure 5. Map of Adaptive Capacity Index

CONCLUSION

Understanding the factors contributing to indigenous populations' vulnerability to climate change is crucial in developing anticipatory and proactive adaptation strategies. It is important to identify the pressures and threats posed by economic interests that impact these communities' territories, natural resources, and livelihoods, as well as the elements that influence their sensitivity to impacts and their adaptive capacity.

As previously discussed by some of the present authors (Paz *et al.* [36]), social and regional inequalities in Brazil pose an extra challenge, exacerbating vulnerability among different social groups. In the case of indigenous communities that rely on nature and biodiversity resources for survival, these vulnerabilities are further compounded by historical conflicts, economic interests, and pressures from non-indigenous people to possess their lands and natural resources. Additionally, deforestation and environmental degradation in surrounding territories contribute to the vulnerability of these communities. Therefore, it is crucial to narrow the gap between the historical increase in vulnerability of these specific groups and the factors that influence their ability to adapt. Mapping this vulnerability is essential in developing successful adaptation strategies to cope with the impacts of climate change.

The methodology presented by this paper contributes to showing how to systematise and evaluate the adaptive capacity of indigenous lands, which is a fundamental aspect of vulnerability analysis besides exposure and sensitivity. The main focus of the adaptive capacity index is to show the level of autonomy and ability to engage with other indigenous groups and the surrounding society. Moreover, the Index shows the importance of protected areas in the Indigenous Land surroundings to prevent external pressures and the entrance of non-indigenous people that can cause negative impacts in their communities and territories. These aspects can strengthen communities' capacity to deal with vulnerability and risk.

The proposed Indigenous Adaptive Capacity Index was applied in the Xingu River Basin case study, associated with the Belo Monte hydropower plant, in a region that includes Indigenous Lands, protected areas, rural settlements, conflicts, and economic pressures. From the results of the application, it was possible to compare the adaptive capacity of the Indigenous Lands and evaluate their different degrees of engagement and environmental protection, which can help in the proposition of adaptation actions. In general, Indigenous Lands adjacent to other Indigenous Lands have greater adaptive capacity than isolated ones. Moreover, indigenous organisations can be valuable partners to build more effective adaptation actions that rely on the community's participation and knowledge. Electricity companies operating in these areas can use this information along with the evaluation of existing adaptation strategies to include the proposed vulnerability analysis in their corporate climate strategies. Identifying the most vulnerable lands and indigenous groups and their most pressing needs should contribute to mapping which adjustments need to be made to increase the resilience of these populations and, at the same time, reduce climate, social, reputational, or legal risks of energy companies. Moreover, traditional knowledge and the participation of these populations are key points for proposing effective climate change adaptation measures.

One of this study's limitations is the concept of synthetic indices, which seek to represent a dynamic reality quantitatively and objectively. Therefore, an Indigenous Land with good indicators will not always be less vulnerable. A single pressure can be enough to cause severe negative impacts, even with a high engagement and a legally protected territory. One way to minimise this issue is to evaluate the components of the Indigenous Vulnerability Index separately, as they can be inputs for proposing specific adaptation actions according to the reality of each community. Indeed, the variables selected for the composition of the Indigenous Adaptive Capacity Index are aspects that can effectively promote the engagement of communities in different contexts, showing the capacity for self-organisation and the establishment of partnerships that can increase their resilience.

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