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Up close, it gets worse: Comparison of hydropower perceptions between impacted populations in the Amazon and those of the Brazilian population as a whole

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ABSTRACT

In the context of the Sustainable Development Goals, addressing the global demand for affordable and clean energy is paramount. While hydropower is often perceived as meeting both criteria, its true merits are subject to debate. This paper delves into energy preferences within Brazil, with a specific focus on hydropower, the nation's predominant energy source. It takes on a unique challenge previously unexplored in the literature by investigating how a population living near a major hydropower dam perceives this energy source in contrast to the broader national population. We conducted two comprehensive surveys, one covering the entire nation of Brazil and the other concentrated in Altamira, an urban area in the Amazon profoundly impacted by the construction of the Belo Monte dam, the second largest in the country. Our research findings indicate that people living near a large dam hold a less favorable view of hydropower's social and environmental impacts when compared to the national population. However, it is noteworthy that over 60 % of Altamira's residents still express support for hydropower, believing they are a "sacrifice zone" for the greater national good. We recommend that decision-making regarding energy investments in the Global South involve a dialogue with national preferences, particularly with directly impacted populations. This process should carefully consider the pros and cons of each energy source. For regions most affected by the construction of new energy plants, we advocate directing targeted benefits that address impacts and enhance energy affordability.

1. Introduction

Within the framework of the Sustainable Development Goals outlined in the 2030 Agenda, achieving affordable and clean energy has emerged as a universally agreed-upon objective [1]. Enhanced energy accessibility and sustainable electricity generation methods have become a priority. Nonetheless, the need to broaden energy access must be accompanied by efforts to evaluate the impacts of energy sources on populations. In doing so, impacted populations, in collaboration with stakeholders, can make well-informed decisions regarding the prioritization of energy sources. However, there is relatively little research about energy preferences in the Global South where hydropower has been experiencing a dramatic expansion. It is exemplified by the case of Brazil. Despite the fact that approximately 63 % of Brazil's energy mix relies on hydropower [2], a comprehensive evaluation of how populations both near and far from hydropower projects perceive this energy source has not been previously undertaken, either by academic researchers or stakeholders. This paper will bridge this gap in the existing literature.

The evolution of Brazil's hydropower industry has closely mirrored global trends, originating in the early 1900s with private initiatives to provide electricity to local urban centers. Foreign investment was instrumental during this phase, with foreign entities dominating 70 % of hydropower generation capacity by 1915 [3]. The introduction of the Water Codes in 1934 marked a transition towards government regulation and public ownership of hydropower development. This led to the rise of Federal and State-owned utilities after 1945, with Eletrobras, established in 1961, taking a pivotal role in studying, financing, constructing, and operating power projects [4]. As electricity demand surged, particularly in populated areas, Brazil invested significantly in large hydropower plants from the 1960s to 1980s, adding over 22,000 MW of capacity [3], especially in South-Central Brazil, aided by the

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World Bank in the advancement of the energy sector's expansion planning [5]. In more recent times, the expansion of hydropower production's frontier in the country is primarily situated within the Amazon region [6,7].

Brazil's geographical advantages, blessed with abundant precipitation and freshwater resources, justified heavy reliance on hydropower [3,6,8]. As previously mentioned, these plants contributed 63 % of the nation's installed capacity [9], notably higher than the global average of15% [10]. While hydropower persisted as a significant energy source, its share declined from 80 % in the past decade with the ascent of solar, wind, and biomass sources [11].

With some of the world's largest hydropower plants, like Itaipu (14 GW) and Belo Monte (11 GW), Brazil's distribution of such installations was concentrated in select regions where topography facilitated large storage reservoirs, mainly in the Midwest, South, and the Southeast of the country [12]. Conversely, the Amazon Basin built run-of-river projects, utilizing bulb turbines and smaller reservoirs to mitigate environmental and social repercussions [13]. However, environmental concerns and indigenous land rights have put a check on Amazonian hydropower's rapid expansion [14]. Additionally, despite Brazil's robust electricity grid, reliance on thermal power during low hydropower periods due to rainfall variability remains a necessity [15,16]. Balancing energy needs with environmental preservation in regions like the Amazon Basin poses a formidable challenge [17]. In this paper, we compare the attitudes of the residents of the city of Altamira—host to Belo Monte, one of the world's largest dams—with a national representative sample of the population of Brazil. We ask how proximity to this mega-dam has shaped attitudes, and the extent to which Altamira residents view their community as a "sacrifice zone" for the greater good of the nation. In this next section, we describe the relevant literature on hydropower impacts and energy attitudes.

2. Literature review

2.1. Hydropower social and environmental impacts

Hydropower has a variety of extensively documented adverse environmental and social consequences. Among the environmental impacts are the disturbance of riverine ecosystems and alterations to fish ecology [18,19], which subsequently complicate the livelihoods of fisherfolk reliant on fisheries [20,21] Additionally, the development of hydropower is linked to deforestation [22–24].

Large-scale hydropower projects bring about a myriad of impacts on the communities located nearby. Among these, displacement emerges as one of the most significant consequences, where the construction of a dam forces hundreds, and in some instances, even thousands of individuals to undergo relocation [25,26]. Scudder's study in 2005 estimated that between 1900 and 2000, between 40 and 80 million people were resettled to make way for dams, often receiving little to no compensation [27].

Construction also leads to "boomtown" effects, characterized by a sudden influx of workers that place immense stress on local infrastructure, such as housing, water, and sewage systems ill-equipped to handle a sudden population increase [28,29]. Communities experience adverse mental health impacts, safety concerns (e.g., increased crime and traffic), a loss of community cohesion, heightened disease prevalence, and runaway inflation, particularly during the construction phase of a large hydropower project [30–33].

In Europe there is still a discussion about whether hydropower could help to move away from fossil fuels to reduce emissions and avoid worsening the causes and consequences of climate change [34–38]. This is true especially for countries still heavily reliant on fossil fuels not foreseeing other more sustainable energy sources to replace those polluting power plants. However, this is not the case of Brazil, where other energy sources are widely available, such as solar and wind, which have grown rapidly in recent years [39].

While the effects of hydropower are widely acknowledged, there has been comparatively limited research assessing the perspectives of individuals residing in communities that host hydropower projects. In the following section, we delve into the matter of proximity to an energy project and its influence on attitudes.

2.2. Proximity and energy attitudes

We are not aware of any studies that compare the attitudes of populations at different distances from hydropower installations in the Brazilian context. Nevertheless, there exists a substantial body of literature on the relationship between proximity to energy infrastructure and attitudes in other countries, as well as with other technologies. This existing research can offer valuable insights into how proximity to energy sources influences attitudes.

People form deep attachments to the natural, cultural, and social attributes of their surroundings, and energy projects like wind farms, oil and gas drilling, and hydropower can disrupt these attachments [40–42]. However, many communities do not actively oppose energy development in their vicinity and may even welcome such projects due to their economic benefits, even though they have concerns about potential impacts [43–46]. Scholars employing an environmental justice perspective have observed that certain communities function as "sacrifice zones" or "internal colonies" for the broader nation, bearing the brunt of the environmental and social consequences of energy production while providing energy services to the rest of the country [47–49]. These sacrifice zones are often found in rural or sparsely populated areas, far removed from metropolitan centers.

People often express general support for energy development, but their attitudes tend to become more nuanced and qualified when the prospect of energy projects occurring in their immediate vicinity arises. Several studies have drawn inspiration from construal level theory, which emphasizes how attitudes evolve as a particular phenomenon becomes less distant in terms of social, geographic, or temporal proximity, transitioning from abstract to concrete [50]. In the United States, one of the most influential factors shaping energy-related attitudes is political partisanship. This effect operates as an information heuristic, with partisans striving to align their views with those of their political leaders or fellow party members [51,52]. However, the influence of political partisanship weakens as the distance to the issue in question diminishes. For instance, Gravelle and Lachapelle's research in 2015 focused on support for the Keystone XL pipeline and found that partisan differences in support for the pipeline decreased significantly as the distance to the proposed pipeline site decreased [53]. Similarly, Clarke et al. in 2016 discovered similar trends in attitudes towards oil and gas drilling—when drilling was distant, partisanship played a significant role, but its impact diminished considerably when drilling activities were nearby [54]. Furthermore, proximity to power lines is linked to heightened perceptions of risk [55].

Additionally, numerous studies have examined the relationship between proximity and attitudes across various topics beyond energy. For example, individuals who have firsthand experience with wildfires in their area tend to hold higher perceptions of wildfire risk [56]. There is also research suggesting that proximity to a coastline can elevate climate change risk perceptions [57,58] although these effects are not consistently observed and vary within the literature [59]. Living in close proximity to natural hazards may lead people to develop coping strategies, such as ignoring or compartmentalizing the threat, as the daily experience of risk can generate substantial levels of stress [60].

This research indicates that the viewpoints of communities residing in close proximity to an energy project are likely to diverge from those further away because the former have direct, personal experience with the said project. However, as far as our knowledge extends, the connection between proximity and attitudes has not been investigated within the context of hydropower in Brazil, with most of the pertinent literature concentrated in the Global North. In the following section, we

outline the research questions that drive our analysis.

2.2.1. Research questions

This paper aims to address two significant gaps in the existing literature. Firstly, it examines the energy preferences of the Brazilian population concerning various energy sources, including hydropower, which accounts for the largest share of electricity production in the country. Secondly, this study provides insights into how a population directly affected by the construction of a large hydropower dam may have differing perceptions compared to the overall national population. Consequently, our research questions (RQs) are as follows:

RQ1. How does proximity to a hydropower mega-project shape attitudes towards this energy source?

RQ2. Do people who live near hydropower, as compared to the national population at large, have more negative views of the social and environmental impacts of hydropower?

RQ3. Do populations affected by the construction of a large hydropower dam perceive their sacrifices as contributing to the greater good of the nation?

RQ4. What are the predictors associated with favorability towards hydropower?

To investigate these questions, we utilize both a nationally representative sample and a survey conducted among the urban population of Altamira, which recently experienced the construction of the Belo Monte hydropower dam, the second largest in Brazil. In the next section, we provide detailed descriptions of the study areas and the data used to assess the research questions.

3. Materials and methods

3.1. Study areas

Brazil, situated in South America, has a population of over 203,063 million in 2022 [61]. 63 % of the nation's electricity derives from hydropower, establishing it as the dominant energy source. Following far behind are wind power at 12.1 %, biomass at 7.7 %, natural gas at 6.2 %, and solar power at 4.4 %. Nonetheless, the utilization of electricity in the country varies across sectors and regions. Approximately 36.2 % is allocated to industrial consumption, 30 % dedicated to residential use, and 18.2 % directed towards commercial applications. Meanwhile, 9.9 % of industrial energy consumption is concentrated in the Northern region, which largely coincides with the geographical area of the Brazilian Amazon, while a substantial 78.4 % is attributed to the South, Southeast, and Midwest regions, known for their higher levels of industrialization [2].

Altamira, a municipality nestled within the Brazilian Amazon, has 126,276 inhabitants in 2022 [61]. Throughout its history, Altamira has been the recipient of two significant infrastructure projects. The first was the construction of the Transamazon Highway in the early 1970s, while the second was the Belo Monte hydropower dam, built between 2011 and 2016 [62]. Altamira is not only in close proximity to the dam, but it also served as the primary staging area for its construction. The arrival of Belo Monte ushered in substantial investments into the region, with an expenditure exceeding 31 billion reais (equivalent to 13 billion USD at that time) allocated to its construction. In Altamira, this massive infusion of capital led to a notable expansion in the commercial sector, driven by the necessity to accommodate the increasing population, employment opportunities, and businesses. Conversely, the city underwent a surge in criminal activities, drug-related issues, prostitution, significant spikes in dengue fever cases, heightened urban segregation and a prevailing sense of social ennui [63–66]. Besides, the rapid population and economic growth resulted in significant inflationary pressures during the initial three years, as the city was ill-prepared for the influx of inhabitants and economic activity [67].

Fig. 1 provides a visual representation of the study areas, encompassing Brazil as a whole and Altamira city.

3.2. Data sources

3.2.1. Brazilian national sample

The Brazilian national sample was acquired as part of a larger project, "Convergence for Innovative Energy Solutions," funded by the National Science Foundation and headquartered at Michigan State University (MSU), USA. It entailed gathering data from 2015 participants. We asked questions related to sentiments regarding various energy sources, diverse impacts of hydropower, and sociodemographic characteristics of the respondents.

The survey utilized an online questionnaire programmed on the Andia Integra platform, owned by the enterprise TESI Brasil. A link to the survey was distributed to a panel of respondents. Data collection occurred between February 17th and February 28th, 2022. Encompassing all regions of Brazil, data was collected using proportions of age, sex, and income strata with quotas to represent the population. The survey comprehensively represented the entire Brazilian population, offering a 95 % confidence interval for the sample.

3.2.2. Altamira sample

The survey in the urban area of Altamira is a pivotal component of a broader, long-term project that engages multiple researchers employing a diverse array of quantitative and qualitative methodologies. The project investigates the persistent social and environmental impacts stemming from the construction of large hydropower dams in the Brazilian Amazon a decade after their completion. The project is entitled "After hydropower dams: social and environmental processes that occur after the construction of Belo Monte, Jirau and Santo Antônio in Brazilian Amazon" and was funded by the São Paulo Research Foundation (FAPESP), being based at University of Campinas (UNICAMP), in Brazil. In this specific phase of the study, we utilized a probability sampling technique [68], selecting a random sample of households to represent various socioeconomic strata and geographic regions within the study area.

The sampling process began with the selection of 10 urban census tracts, from which 50 households were subsequently chosen at random within each tract. This procedure ensured that every household had an equal opportunity to be part of the sample. Our interviews were conducted with either the household head or another member aged 18 or older. To be eligible for the survey, participants needed to be residents of the urban area of Altamira during and after the dam construction.

Moreover, the survey questionnaire encompassed sociodemographic inquiries about household members. Data collection occurred between July 13th and July 30th, 2022, facilitated by eight interviewers who were either undergraduate or graduate students from local universities. Prior to the household visits, interviewers underwent comprehensive training. The data input process was conducted through tablets featuring questionnaires programmed within the ArcGIS Survey123 application. The online version of this platform was employed for daily systematization, verification, and resolution of any inconsistencies. Roughly 5 % of the sample was composed of cases where either the residents could not be located after 6 attempts or residents declined participation. In such cases, substitute residences within the same census tract were incorporated into the sample through a process of random selection, continuing until the target of successfully interviewing 500 households was achieved. Like the national sample, the Altamira survey also produced a 95 % confidence interval.

3.3. Data analysis

For RQ1, we ask how proximity to a hydropower mega-project shapes attitudes towards hydropower more generally. To evaluate this

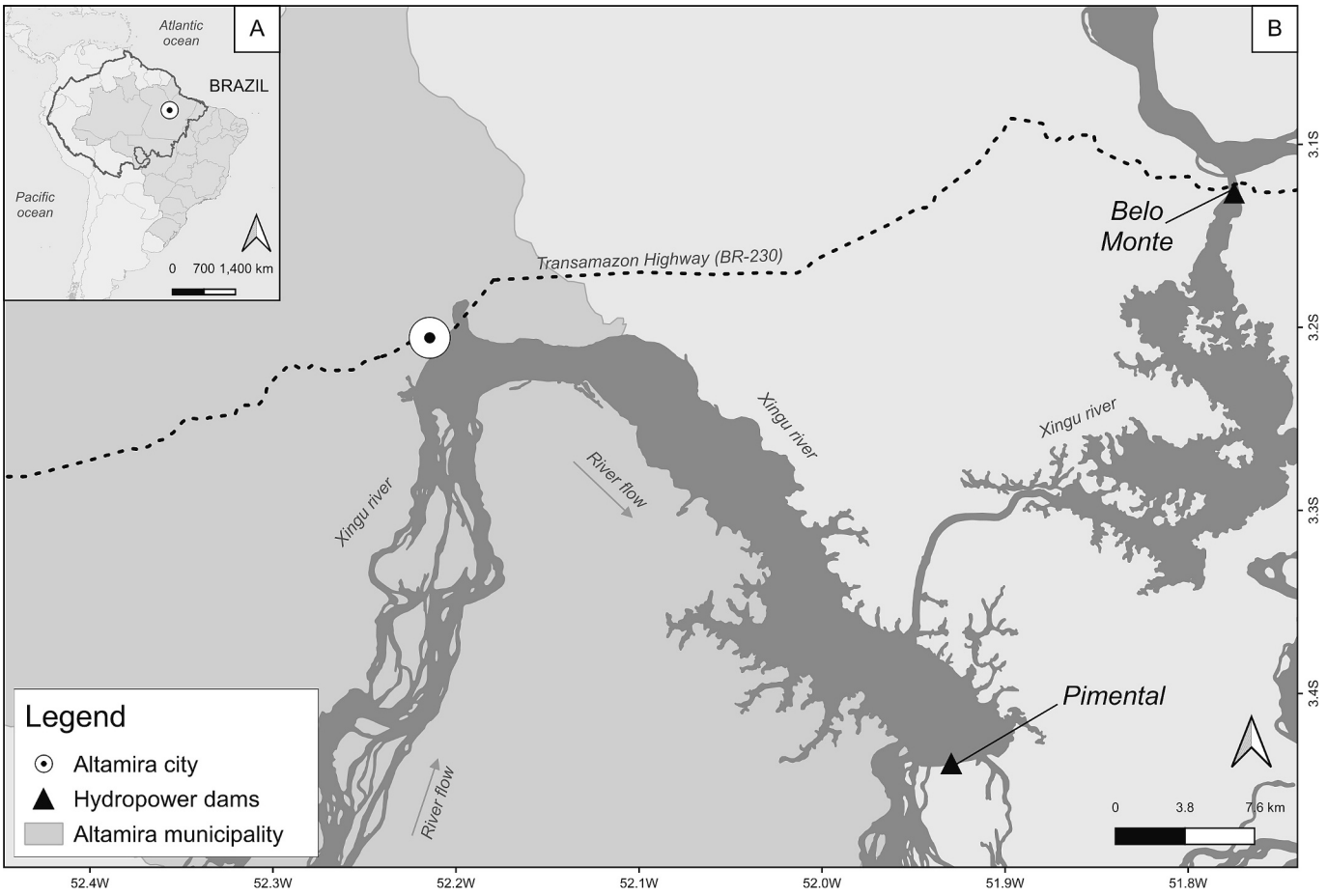

Fig. 1. Study Sites. A. Brazilian territory, the thick grey line represents the trans-national Amazon River basin. B. Altamira city, sided by the Transamazon Highway and the Belo Monte dam. Note: Pimental dam is an integral component of the Belo Monte hydropower project, designed to redirect the flow of the Xingu River towards the turbines of the Belo Monte facility.

question, we show responses to the degree of favorability that both the national and Altamira populations hold towards various energy sources. We apply chi-squared tests to ascertain the statistical significance of differences. Both national and local datasets gauge favorability towards the following energy sources: hydropower, thermal, wind, biofuel, solar and nuclear. Response choices encompass unfavorable; neither unfavorable nor favorable; or favorable.

To address RQ2–whether those who live near a hydropower dam, as compared to the national population, have more negative views of the social and environmental impacts of this energy source—we juxtapose responses between the national and Altamira samples with regards to hydropower impacts. Significance is determined via chi-squared tests. We used identical questions in the Altamira and national samples for the following impacts of hydropower: independence from foreign energy sources; independence from fossil fuels (e.g., coal, oil, natural gas); ecosystem health/quality; economic prosperity; societal well-being; biodiversity of plants and animals; indigenous territories; and energy affordability. Response options encompass negative, no impact or positive impact.

For RQ3 — do populations affected by a major hydropower dam construction view their sacrifices as contributing to the nation's greater good? — we use cross-tabulations. This involves evaluating how the Altamira population assess the impacts of Belo Monte on both Brazil as a whole and on the specific Altamira region regarding: fisherpeople; their own families; indigenous people; Altamira residents; Transamazon residents (Population residing in the vicinity of the Transamazon highway, which traverses through all the adjacent municipalities); and migrant workers. These questions were only used in the Altamira sample because the national population likely has little knowledge of the localized impacts of hydropower. Response options were negative, none or positive.

For addressing RQ4 we used an ordinal logistic regression model to investigate predictors of hydropower favorability. This accommodates the ordinal nature of the dependent variable (unfavorable; neither unfavorable nor favorable; or favorable). Prior to estimating the regression, a factor analysis was conducted on impact items utilized to address RQ2 (Appendix A). The resulting factor score was used as a predictor in the regression model, alongside sociodemographic variables, and Altamira residency. For all the research questions utilized in this study, responses such as “I don't know” or “I don't want to answer” were categorized as missing data and subsequently excluded from the analysis.

4. Results

4.1. RQ1: comparing the favorability of energy sources

Fig. 2 illustrates a general trend where the national population tends to hold more favorable perspectives towards various energy sources compared to the Altamira sample. Specifically, 73.1 % of the national respondents expressed favorability towards hydropower, whereas this percentage was lower at 60.7 % for Altamira residents. This difference holds statistical significance (Chi2 = 107.54, $p = 0.000$).

In terms of thermal power (i.e., fossil fuels), 45.7 % of the national sample regarded it as “favorable,” whereas only 22 % of Altamira residents shared the same view. The chi-squared test confirms that the distributions are notably dissimilar. Conversely, the distributions for

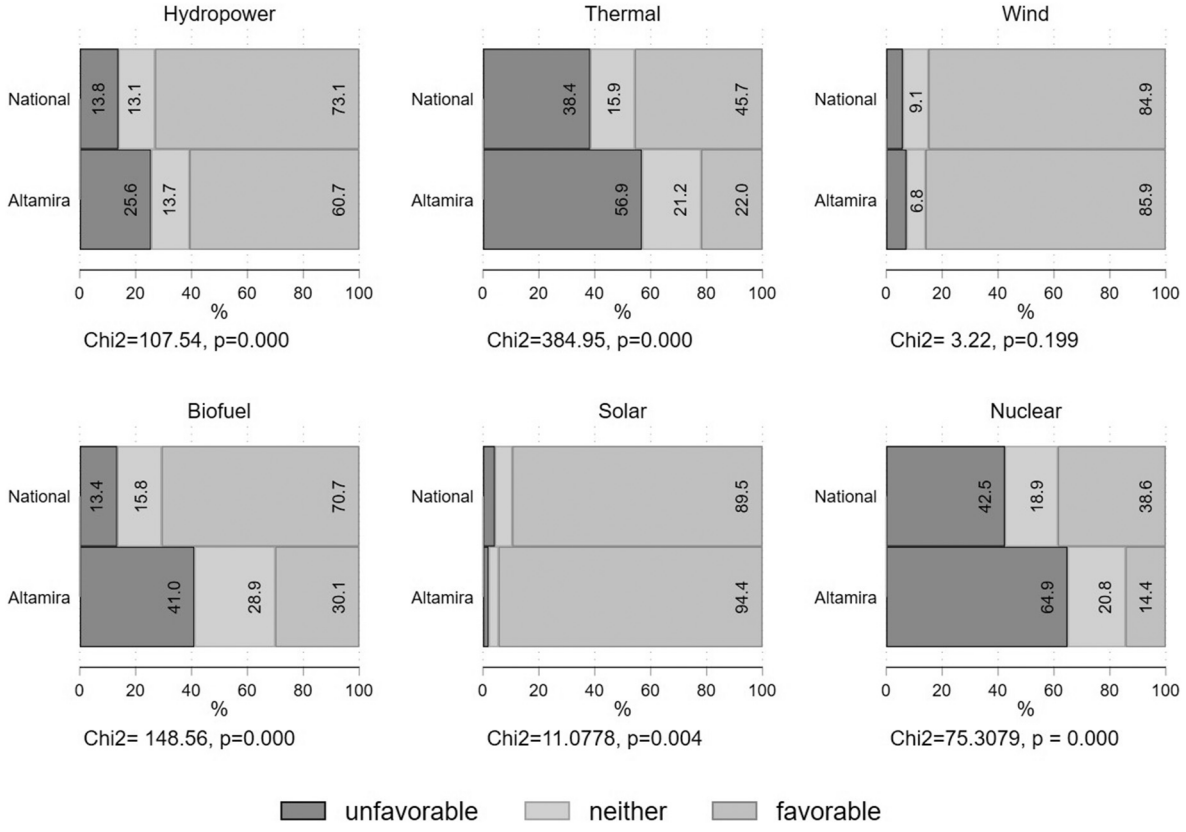

Fig. 2. Favorability of Energy Sources between the national and Altamira Sample.

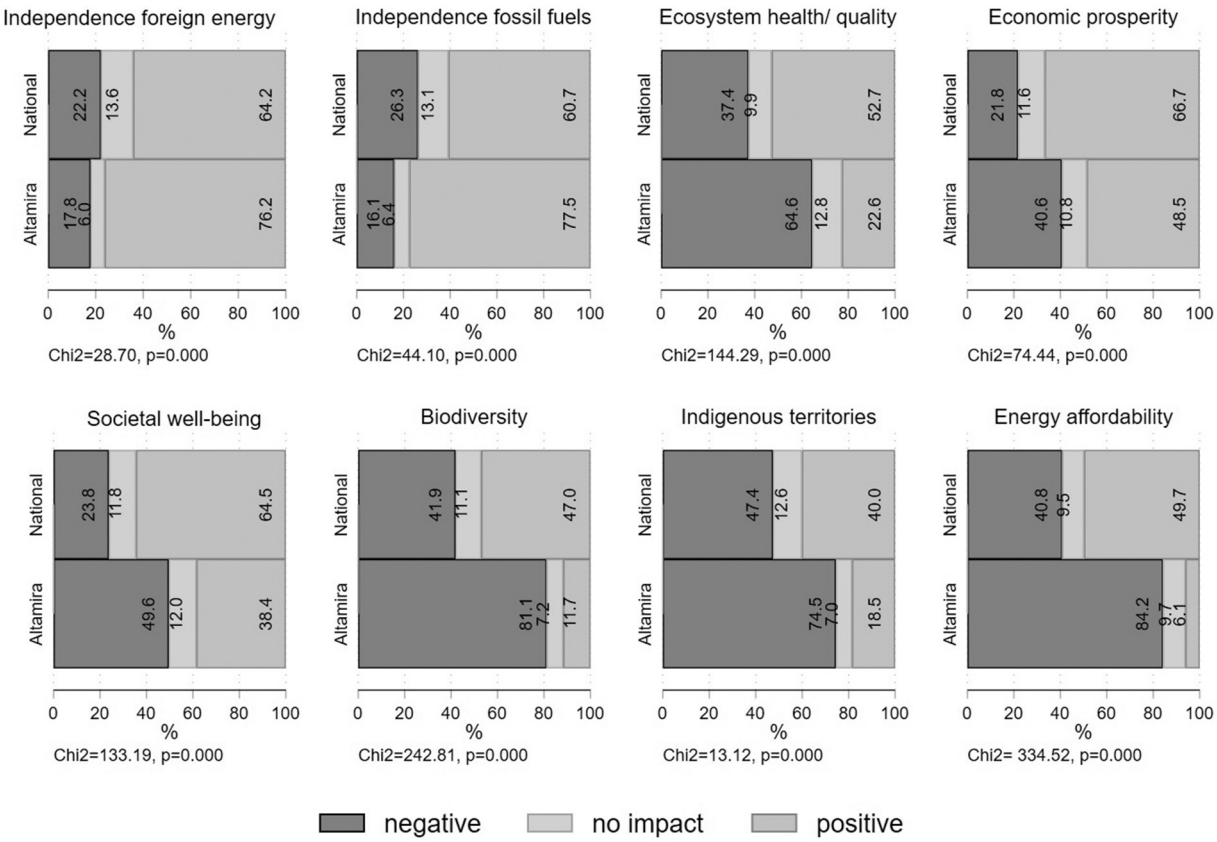

Fig. 3. Perceptions of Hydropower Impacts between Altamira and the National Sample.

wind power are strikingly alike, with a vast majority displaying favorability towards this energy source (~85 % in both samples). The corresponding chi-squared test yielded null results (Chi2 = 3.22, p = 0.199).

Examining biofuels, the national sample again exhibited higher "favorable" ratings (70.7 %), in contrast to Altamira where the percentage was less than half (30.1 %) (Chi2 = 148.56, $p = 0.00$). For solar energy, there were minor but statistically significant distinctions, with the national sample slightly more inclined to indicate "neither" or "unfavorable" stances. In any case, solar energy emerged as the most preferred option among all energy sources, with approximately 90 % favorability in both samples. Conversely, nuclear power garnered favorability from 38.6 % of the national population, whereas this figure dropped to 14.4 % within the Altamira sample.

4.2. RQ2: comparing perceived impacts of hydropower

Fig. 3 shows that Altamira residents have more positive perception regarding the effects of hydropower on independence from foreign energy and independence from fossil fuels in contrast to the national sample. However, when it comes to the remaining explored aspects, Altamira's viewpoint leans more negatively compared to the wider national population.

Notably, only 22.6 % of Altamira residents regarded the impact of hydropower on ecosystems as "positive", in contrast to 52.7 % of the national sample, marking a statistically significant difference (chi2 = 144.29, $p = 0.000$). Concerning economic prosperity, slightly less than half of Altamira residents (48.5 %) viewed it as "positive", whereas a substantial majority of national residents (66.7 %) perceived a positive impact (chi2 = 74.44, p = 0.000). "Societal well-being" registered as more negative in Altamira (49.6 % compared to 23.8 %), with a statistically significant gap (chi2 = 133.19, p = 0.000).

Similarly, significantly more Altamira residents expressed a "negative" impact on biodiversity, with 81.1 % compared to the national figure of 41.9 %. Altamira residents were also notably more inclined (by nearly 30 percentage points) to state that the impact on indigenous groups was negative. Lastly, a substantial 84.2 % of Altamira respondents, compared to 40.8 % of the national sample, indicated a negative impact on energy affordability (i.e., energy became less affordable) due to hydropower.

4.3. RQ3: comparing perceived impacts from the Altamira sample

Fig. 4 presents row percentages based on the variable represented on the vertical axis. To illustrate, panel 1 shows that 46.5 % of respondents who indicated a "negative" impact of Belo Monte on fisherpeople in the Xingu region also expressed a positive impact on the nation. This pattern remains notably consistent across all variables—remarkably, even among those who perceive adverse local impacts, there's a tendency to associate positive benefits with the nation as a whole.

For instance, in panel 4. 41.8 % of respondents who noted a negative impact of Belo Monte on Altamira residents also indicated a positive impact on Brazil. It's noteworthy that very few respondents observed a positive local impact of Belo Monte coupled with a negative impact on Brazil. For instance, a mere 5.4 % mentioned a "positive" local impact alongside a negative impact on Brazil (panel 5). This pattern is consistent across all variables. In summary, the cross-tabulations underscore that a considerable number of respondents perceive negative local consequences while simultaneously perceiving positive outcomes for the nation at large. This association is statistically significant across all variables.

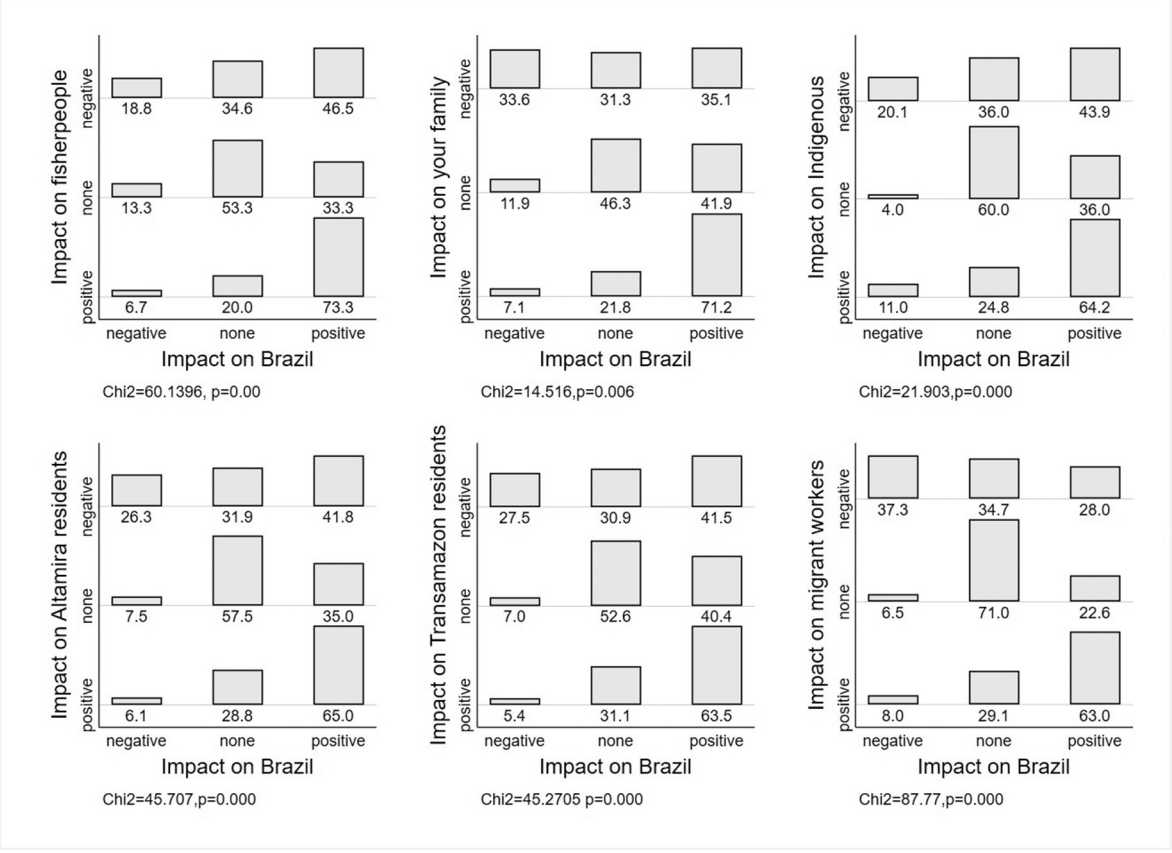

Fig. 4. Cross-tabulations of local impacts and impacts to Brazil from the Altamira Sample. Note: Graphic displays row percentages.

Table 1
Exploring predictors of hydropower favorability through ordinal logistic regression analysis (sample size: 2398).

	B	SE	p
Impacts	1.040***	0.066	0
Female	−0.128	0.099	0.196
Age (ref. 18–24)			
25–34	0.031	0.147	0.835
35–44	0.098	0.146	0.502
45–54	0.278	0.168	0.097
55–64	0.197	0.191	0.304
65 or older	0.703*	0.341	0.039
Education (ref. less than High School)			
High school	0.226	0.182	0.216
College or more	0.296	0.19	0.12
Altamira	−0.075	0.153	0.622

4.4. RQ4: predictors of hydropower favorability

The factor analysis conducted on the impact items robustly pointed towards a singular factor solution (refer to Appendix A). As illustrated in Table 1, it becomes apparent that perceived impacts bear a connection to hydropower favorability. Individuals who perceive more positive impacts tend to exhibit a greater inclination towards hydropower. Nevertheless, no discernible distinctions emerge based on gender or education but older persons (those 65 and older) view hydropower more favorably than the reference group (18–24 years old). Interestingly, residency in Altamira did not exhibit a statistically significant link with perceived favorability towards hydropower once adjustments were made for other covariates.

5. Discussion

This study represents the first comprehensive exploration of public perceptions regarding various energy sources in Brazil, including hydropower. Hydropower holds a significant historical significance in the country and presently constitutes the largest portion of its energy production. Moreover, to the best of our knowledge, this research represents the inaugural attempt to conduct a comparative analysis of perceptions regarding the impacts of hydropower between a region directly affected by a hydropower mega-project and the national population.

This paper demonstrates that the Altamira population, directly affected by the construction of a large hydropower dam, tends to view the social and environmental impacts of this energy source more negatively than the national population as a whole. Interestingly, despite this, a significant majority of its residents (over 60 %) still support hydropower. This finding is broadly consistent with other research that finds that people proximate to energy development have perspectives that differ from those farther from development, often more negative or complex views [53,54,69].

Moreover, this discovery also aligns with the concept that areas such as Altamira, along with its neighboring communities, function as designated “sacrifice zones” for the broader nation [43,47–49]. In essence, Altamira and its surrounding regions shoulder the direct and unfavorable consequences of extensive hydropower expansion while reaping only marginal rewards. Residents of these sacrifice zones might psychologically justify these impacts by convincing themselves that their hardships contribute to the greater welfare of the entire nation [47–49,70]. This finding is corroborated by the fact that, when analyzing Altamira with the national population, there is no strong sociodemographic predictor for preference regarding hydropower (solely the oldest age group more in favor of this energy source). This leads us to conclude that support for this hydropower project is widespread, extending not only across the nation and the directly affected area but also across various sociodemographic profiles.

Why does the population harbor these sentiments and appear willing to make sacrifices? To understand this, we must examine recent analyses that reveal how the media in Brazil has been actively advocating for hydropower as an essential component of the nation's development for decades. They have consistently echoed the government and energy sector's messages, both of which have been committed to hydropower since the 1970s [71]. Additionally, this research has uncovered that the media seldom highlighted criticisms of hydropower, except in cases where protests turned violent and became impossible to ignore. These media dynamics have undoubtedly influenced local perspectives and were further exacerbated during the construction phase of hydropower projects.

During fieldwork for data collection, it was common to hear from the local population a prevailing perception that the challenges arising from hydropower construction—such as elevated food prices and unmet demands for essential services like sanitation, security, and housing [29,63,72]—were viewed as a necessary sacrifice for the greater good of the nation. Additionally, negative repercussions post-construction, such as the impacts on resettled populations, manifested through changes in social capital and heightened socio-spatial segregation [64,66], were perceived as part of the region's toll for the benefit of the country. This sentiment is rooted in the belief that energy is indispensable for fostering economic development. Consequently, the augmentation of energy availability is seen as a catalyst for a new wave of economic growth for the entire Brazilian economy. Remarkably, the population's articulation of these viewpoints mirrors the promotional narratives crafted to legitimize the imperative for the construction of the dam.

Moreover, Brazil is renowned for its abundant natural beauty, including its vast river systems [73,74], particularly in the Amazon basin, the world's largest, the majority of which falls within Brazilian territory [75]. This wealth of water resources is often cited as a compelling argument for maintaining the country's commitment to hydropower [76]. Additionally, it's worth noting that alternative energy sources are relatively unfamiliar to the Brazilian population, with the exceptions of wind, biofuel, and solar power. However, biofuel is typically associated more with fueling vehicles than with generating energy per se [77].

A pressing question that arises is the extent of the public discourse regarding the merits and drawbacks of various energy sources and the path the country intends to follow in terms of future energy production. One plausible hypothesis is that such a debate is not widely accessible, as it remains confined to select research groups within academia, government officials and technicians, and private sector energy stakeholders [78].

In addition to perceiving themselves as a sacrifice zone and highlighting the adverse social and environmental consequences of hydropower, the Altamira population also raises concerns about the high cost of energy in their region. During the survey, this emerged as a major issue, with more than 84 % of the population expressing dissatisfaction with the affordability of hydropower. It is worth noting that all the energy generated by the Belo Monte dam is directed to remote areas in the Southeast region [79], where the majority of the country's economic activities occur and where the majority of its population resides [61]. It would seem logical to consider providing an affordability bonus to the populations most affected by these energy developments. However, as of now, no such benefit has been proposed, either for Altamira or any other affected area resulting from the construction of large hydropower dams in Brazil. Boudet (2019) argues for the importance of tailoring decision-making processes to the unique characteristics of each locality and its residents to foster a more positive public perception regarding the implementation of energy technologies [80]. For the local population, it seems counterintuitive that after the construction of one of the world's largest hydropower dams, the cost per kilowatt-hour (kw/h) for residents is higher than it was before the dam's construction. This situation has not only impacted the population residing near Belo Monte but has also extended to those living in the vicinity of Jirau and Santo Antonio, which are similarly large hydropower dams constructed recently in the

Brazilian Amazon.

Energy prices in Brazil have been steadily increasing, driven not only by anticipated corrections due to inflation but also by a complex equation that factors in energy production costs, transmission lines, investments made by energy distribution companies, and taxes. While this paper does not aim to delve deeper into the intricacies of electricity tariffs and their variations across the country, it is noteworthy that, in the current year of 2023, the state of Pará (the focus of our study) bears the highest electricity tariffs in the nation [81]. In the case of Pará, one argument used to rationalize these elevated prices is the difficulty of supplying remote areas with a low concentration of consumers. In essence, due to the sparse demographic density, providing electricity to these regions becomes costly and is shared among a limited number of residents, exacerbating the distribution expenses. Despite this, it would be reasonable to expect that the population directly affected by the Belo Monte project would have benefitted from targeted policies aimed at improving electricity affordability. It is also reasonable to suggest that the cost of hydropower infrastructure locally should be shared with the much larger beneficiaries outside the region, and not borne largely by the local population. Contrary to these expectations, the populations displaced from the Xingu riverbanks, now residing on the outskirts of Altamira city, face a paradox. While they now have access, albeit virtually, to electricity, the reality is that the associated bills are beyond their means. This situation starkly contrasts with the principles of energy justice, which advocate for providing all individuals with access to safe, affordable, and sustainable energy [82,83]. Belo Monte and other contemporary dams in the Brazilian Amazon have been criticized as examples of energy injustice, not only due to the environmental and social impacts they cause but also because they fail to ensure energy access for the local populations affected by these projects [67,84,85].

This paper contributes valuable insights about Brazil, aligning with existing literature that explores how proximity to energy sources can influence population attitudes towards them. Even when people are aware of the potential impacts, they may support energy plants in their vicinity due to the anticipated local economic benefits [43,46]. Notably, over 48 % of the Altamira population assesses the impact of the hydropower dam as positive. Indeed, a recent systematic literature review on hydropower projects revealed that positive perceptions of this energy source often center on its contributions to economic development, while the most frequently cited negative impacts in the literature are associated with social and environmental concerns [86]. Public support may also be linked to the promises of hydropower contributing to sustainability, particularly as a strategy to transition away from more polluting energy sources. It is asserted that the drawbacks associated with hydropower could be mitigated through enhanced governance, such as in the European Union countries [87–90]. Nevertheless, despite witnessing substantial improvements in hydropower governance over the decades, the adverse impacts on the environment and local populations persist, especially in countries of the Global South, like Brazil [7,13,21,29–31,62,64,67,84,91–94].

As our model demonstrates, public support is nuanced in Altamira. While perceived positive impacts of hydropower can bolster support for this energy source, the reverse is also true—more negative perceived impacts play a role in unfavorable evaluations. This finding aligns with a study conducted in China, which showed that perceptions of the negative impacts of hydropower can diminish support for this energy source. This was specifically investigated in the context of the Three Gorges Dam, the world's largest hydropower plant in terms of installed capacity [95]. The instances in both Brazil and China serve as emblematic examples of the growing hydropower industry in the Global South. These cases could serve as inspiration for new studies, shedding light on the unique characteristics and shared patterns of hydropower perception worldwide. Such research should consider varying spatial scales, comparing the perspectives of locally affected communities with those of the broader population.

This paper has some limitations. Firstly, it is a cross-sectional study, which means that the conclusions drawn from this analysis are applicable only to the moment when the data were collected. Nevertheless, this approach is commonly used in research focused on public opinions, and future surveys conducted using the same methodology could assess whether these perceptions remain consistent or evolve over time. Another promising study design involves employing panel studies to track the same population over time, assessing changes in their perceptions regarding subjects such as different energy sources and their associated negative and positive outcomes.

Secondly, our national sample did not allow for the disaggregation of data into smaller geographical units within the country, such as states. This finer-grained analysis could have been valuable in examining whether regions receiving a higher concentration of hydropower projects in the Brazilian Amazon share the same perceptions as the directly affected Altamira population, or if their perceptions align more closely with the national sentiment. This limitation arose from the fact that our data collection took place in early 2022, during the ongoing COVID-19 pandemic, and using an online panel was the only reasonable way for obtaining a nationally representative sample at that time. Future studies could explore public perceptions of hydropower in areas affected by these power plants for a more extended period than in Altamira. This investigation would be able to determine whether, with the passage of more time, public attitudes towards the adverse effects of hydropower tend to diminish.

6. Conclusions

This paper has revealed that an overwhelming majority of the Brazilian population supports hydropower, and this support remains strong even in an area directly affected by the recent construction of a large hydropower dam. However, it is noteworthy the directly affected population tends to be more critical of the social and environmental impacts associated with this energy source.

Even with the utilization of technology to enhance electricity efficiency, countries in the Global South, including Brazil, still need to expand their available electricity supply. For instance, the rapid growth of electric cars could potentially strain the current energy infrastructure [96]. We contend that expanding energy production in the Global South should involve a planning process that actively engages the population. This way, we can gain insights into the population's preferences regarding energy sources and effectively inform residents about the positive and negative consequences associated with each option.

Each energy source comes with inherent impacts. For instance, hydropower is a renewable energy source that yields cost-effective energy from an economic perspective, but the construction of large dams entails substantial social and environmental consequences. Conversely, solar and wind energies typically result in less significant social and environmental impacts, albeit at the expense of generating costlier and intermittent energy due to their reliance on sunlight and wind for production. Wind and solar energy sources have been gaining prominence in Brazil's new power installation auctions, thanks to their improving cost-efficiency ratios [39]. The proportion of hydropower in the energy mix is gradually decreasing, being supplanted by solar and wind energy. This trend is expected to persist and would signify a positive development for the energy sector.

Furthermore, beyond the existing energy sources, there is an escalating demand for increased investments in research and development to facilitate the implementation of additional energy sources with minimized impacts. The mere reduction in greenhouse gas emissions is no longer sufficient for an energy source in our present context. The imperative is not solely to decrease the effects of energy production on climate change but also on local populations. Failing to do so would mean mitigating climate issues while perpetuating the same inequalities and injustices inherent in the current energy systems [97], particularly evident in countries of the Global South [98,99]. Along with the necessary progression of historical advancements, establishing

democratic communication with the entire population, and particularly with those directly affected by the construction of new power plants, is crucial. This communication should strive to facilitate informed decision-making and deliver more immediate benefits to affected populations, such as improving energy affordability. This approach is vital to ensure that these communities do not perceive themselves as sacrificial zones for the benefit of others. This study contributes to a deeper understanding that individuals residing in proximity to energy infrastructure should have the opportunity to voice their preferences and expectations.

Ethics statement

This investigation has taken as basis two surveys. One of them was conducted with the population of the urban area of the Brazilian municipality of Altamira, IRB number: 59652322.1.0000.8142, obtained at State University of Campinas, UNICAMP, Brazil. The other survey was carried on with the entire population of Brazil, IRB number: 00006967, obtained at Michigan State University, MSU, United States.

Submission declaration

The work described has not been published previously, it is not under consideration for publication elsewhere, its publication is approved by all authors, and, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

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CRediT authorship contribution statement

Igor Cavallini Johansen: Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Adam P. Mayer:** Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Emilio F. Moran:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no competing interest.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2024.103455.

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