Socioeconomic impacts of large hydroelectric power plants in Brazil: a synthetic control assessment of Estreito hydropower plant

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Abstract

In recent years, energy transition process has been directing the world's electrical systems in a search for the insertion of clean and renewable energy sources. In Brazil, hydroelectric generation plays a fundamental role, with 68% of energy supplied by hydraulic sources in 2019. However, despite hydroelectric generation being considered a renewable energy and with low emission of polluting gases, the construction of hydroelectric plants can cause significant consequences in the dynamics of territorial management, especially when located in regions of high socio-environmental complexity. Considering the importance of hydroelectric projects, it is essential to understand the impacts arising from their implementation in the Brazilian territory. This article aims to analyze the socioeconomic impacts arising from the construction of hydroelectric plants in municipalities affected by reservoirs. To this end, it is proposed to analyze the case study of the Estreito hydroelectric plant, located in Maranhão, through the application of the Synthetic Control impact assessment method. The results demonstrate that the positive externalities of the plant's implementation, when they exist, are short to medium term, except for the income dimension. On the other hand, the deterioration of the other dimensions analyzed indicates a possible reduction in the quality of life of the local population.

Highlights

- In Brazil, currently, the advance of large hydroelectric power plants (HPP) has been directed towards areas of great social and environmental vulnerability, such as the Amazon Region;
- The insertion of HPPs may not contribute to regional development, mainly in regions that present different appropriations and use of water resources;
- In general, the socioeconomic developments provided by Estreito HPP in its territory are experienced in the short to medium term, even the positive externalities;
- The positive effects tend to be concentrated in the municipality that directly allocate the project, as well as in municipalities that already occupy a regional polarizing position, created by greater economic dynamism and greater offer of public and private infrastructures and services, such as transportation, hospitals, schools and universities.

Key Words: Hydroelectric Power Plants; Impact Assessment; Synthetic Control; Energy transition.

Word Count: 7918

List of Abbreviations

CESTE - Estreito Energia Consortium

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COP21 - 21st Conference of the Parties
EIS - Environmental Impact Study
ERE - Energy Research Company
GDP-M - Gross Domestic Product
GHG - Greenhouse Gases
HDI - Human Development Index
HPP - Hydroelectric Power Plants
IL- Installation License
LBIS - Live Birth Information System
MHDI - Municipal Human Development Index
MIS - Mortality Information System
ANEEL – Nacional Electric Energy Agency
NWA - National Water Agency
OP - Operation License
PL - Preliminary License
PPA - Permanent Preservation Area
STDs - Sexually Transmitted Diseases
SVI - Social Vulnerability Indexes

1. Introduction

Since the commitment to reduce greenhouse gas (GHG) emissions, initiated with the Kyoto Protocol in 1997, numerous countries have been investing in the transition process to a renewable and less polluting energy matrix. The urgent need for actions to control climate change is increasingly being recognized internationally and was ratified by the 195 countries that attended the 21st Conference of the Parties (COP21), in Paris, in 2016.

Actions to reduce the effects of climate change in the electricity sector have been directed through three central vectors: i) decarbonization; ii) digitization; and iii) decentralization. Thus, in the generation segment, actions aimed at the decarbonization process appear to be associated with goals to increase the share of renewable and clean sources in the electrical matrix. In this context, unlike most countries, Brazil has an essentially renewable energy matrix, consolidating itself as an international reference in electrical systems with low emission of polluting gases. In 2018, the Brazilian energy matrix held 45.3% of its energy supply from renewable sources, well above 20%, which is approximately the average world matrix [1].

Due to its favorable physical and hydrological conditions, characterized by a substantial network of hydrographic basins, Brazil's hydroelectric generation plays a crucial role in supplying household electricity demand. According to the National Energy Balance, published by the Energy Research Company (ERC), the total supply of electricity in the country reached an 83.3% share of renewable sources in 2018, mostly supplied by hydraulic source with 66.6%, followed by natural gas (8.6%), biomass (8.5%), wind (7.6%), coal and derivatives (3.2%), nuclear (2.5%), petroleum derivatives (2.4%) and solar (0.5%).

In recent years, despite the increasing contribution of intermittent renewable energies in the Brazilian electricity matrix, hydroelectric power plants are still a fundamental technology. In 2017 and 2018, Brazil was the second largest investor in hydroelectric power plants projects in the world, surpassed only by China [3]. In 2019, the Brazilian Decennial Expansion Plan for 2029 presented an estimate of 1,914 MW of power coming exclusively from hydroelectric power plants (HPP) which are scheduled to come into operation by 2029 [2].

The HPPs are a consolidated technology for generating electricity from water sources and are considered to be renewable and clean. Although investments in hydroelectric projects are considered strategic in the diffusion of environmentally sustainable energy sources [4, 5], the implementation of HPPs is still a very controversial topic in the global electricity sector. If, on the one hand, hydroelectric projects can become vectors of economic and regional development, involving the expectation of economic growth and an improvement in the quality of life, mainly in the surrounding municipalities and those areas impacted by the project, on the other hand, despite providing an increase in economic growth, in the short term, the benefits are not distributed among the population and the municipalities, which may cause significant material and immaterial losses in the environmental, social and cultural dimensions, especially in the case of presence of traditional communities[6] [6]. Since most of these projects receive public funding, it is expected that these investments return into benefits and development for the impacted areas.

In Brazil, the negative consequences of hydroelectric projects are particularly noteworthy, due to the advance of the electric frontier towards the North Region. This region comprises the area of the Legal Amazon[7], marked by the existence of important biomes, such as the Amazon and Cerrado, and also different ways of life. According to [9], in 2010, 42% of the municipalities in the Legal Amazon had Social Vulnerability Indexes (SVI) categorized as "very high" and a large part of the territory corresponds to Conservation Units, Indigenous Territories and Areas of Priority for Biodiversity Conservation. Despite the socio-environmental restrictions in the region, in the last decade, large hydroelectric power plant projects were built, such as Belo Monte (PA) with 7,500 MW, Jirau and Santo Antônio (RO) with 3,300 MW and 3,150 MW capacity, respectively.

Given the historical and current relevance of HPPs construction in Brazil and the inherent economic, social and environmental effects caused by their implementation, the assessment of their impacts is essential. In these terms, this article aims to assess the socioeconomic impacts caused by the HPPs, through the case study of Estreito HPP (1,087MW), located in Maranhão (MA) and belonging to the Legal Amazon area. For this, the econometric method of impact assessment called Synthetic Control, proposed by [10] and [11], was used.

The article is structured in six sections. The second section presents the context of the main socioeconomic impacts arising from the implementation of HPPs, while the third section presents the main particularities of Estreito HPP construction. The fourth section addresses the steps of the methodological process applied and the fifth section brings an analysis of the results in comparison with the effects observed in the bibliographic and documentary review. Finally, the sixth section presents the study's final considerations, limitations and contributions to the theme.

2. The hydroelectric generation in Brazil and its socioeconomic impacts on the territory

Brazil is the largest producer of electricity in Latin America, generating approximately 50% of the continent's total supply. It is expected that by 2027, the country will achieve a production equivalent to 796 TWh of electric energy and most of it will be coming from hydroelectric generation [12]. Initially, HPPs were located close to major consumption centers in the Southeast.

[6] Traditional communities are groups with their own and particular forms of social organizations that use the territory and natural resources for social reproduction, based on cultural and tradition practices. Ref. [7] adds: "[...] peasant territories and populations that, although they do not use common areas a priori, end up building something that can be identified as the fruit of their history and "identification factor".

[7] Region comprising the states of Amazonas (AM), Pará (PA), Amapá (AP), Acre (AC), Roraima (RR), Rondônia (RO), Tocantins (TO), Mato Grosso (MT) and some municipalities in Maranhão (MA) located west of the 44º meridian [8].

However, along the sector's historical trajectory, the ventures reached increasingly distant regions, consolidating an extensive interconnected system of transmission networks [13].

In 2018, Brazil was exploiting 108 GW of the 176 GW of its inventoried hydroelectric potential, considering projects in operation and under construction. Among this potential, 52 GW are inventoried for HPP with a capacity greater than 30 MW, of which 18.6 GW are located in the Amazon region. By 2029, another three HPPs with 62% power increase are expected to be implemented in this region [2]. Thus, as can be seen in Figure 1, the remaining hydroelectric potentials are located in the North and Middle-West regions, while in the other regions a lower generation potential is observed, due to the saturation of the water resources exploitation for energy use [14].

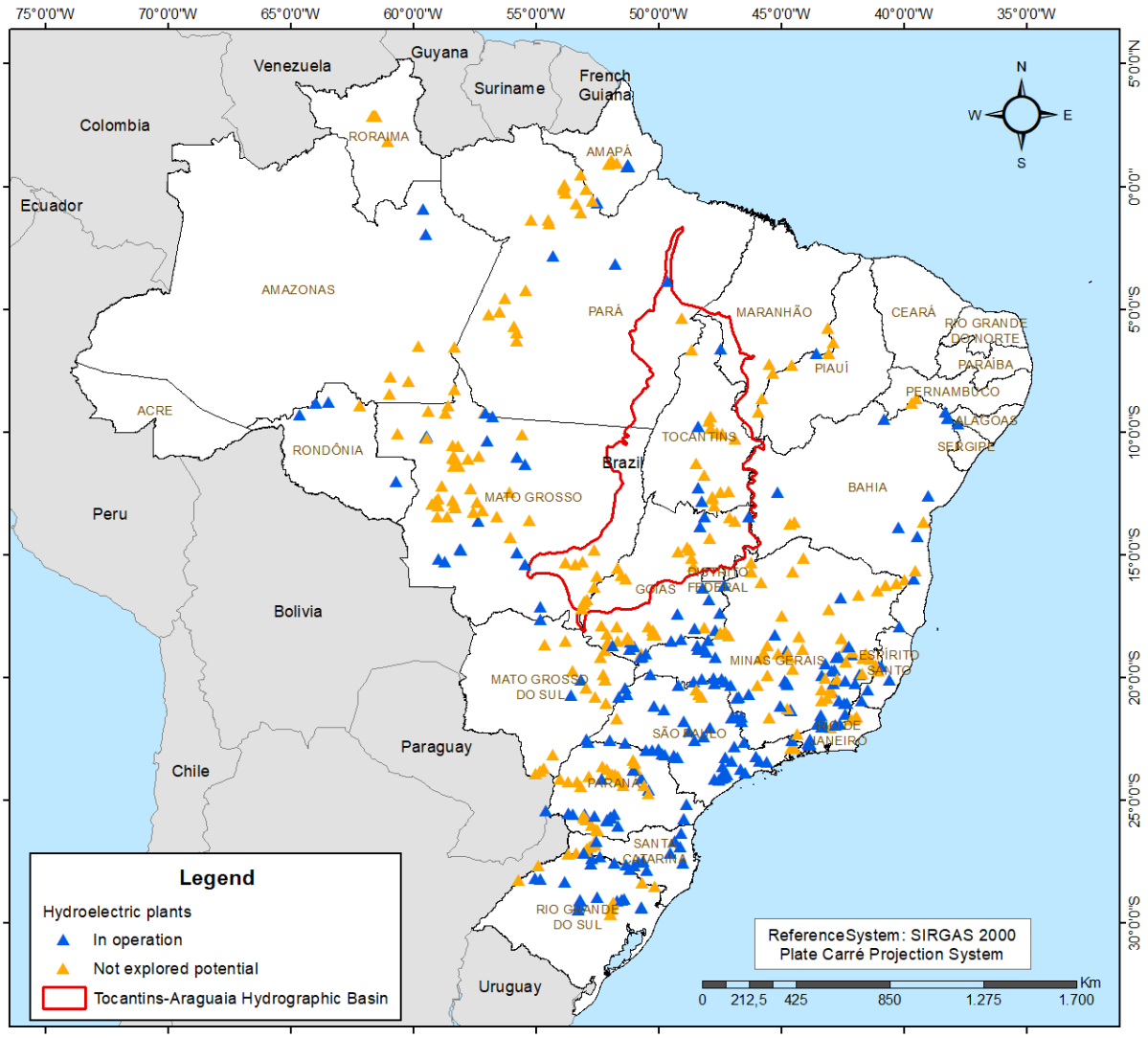


Figure 1: Distribution of the hydroelectric potential inventoried in 2018. Source: data from ref. [15].

In addition to being responsible for most of the national electricity generation, HPPs play a fundamental role in the energy transition process and in the change of the system's operating paradigm. Considering the strong growth of intermittent alternative renewable energies (wind and solar), the HPP accumulation reservoirs function as large batteries for energy storage, providing the quick adjustment, regularization and stability required by the system [16, 14].

Despite its importance for the functioning of the National Interconnected System, the construction of hydroelectric projects can cause several socioeconomic and environmental impacts

in the territory. Even in HPPs with reduced reservoirs (run-of-river), the externalities triggered by the construction and its operation are present.

In this context, studies on the impact of HPP in the territory have been a source of great debate in the scientific literature [17]. On the one hand, there are studies that highlights the economic and social advantages, such as the attraction of investments, heating up the local economy and boosting the service sector. This economic dynamism is reflected, in general, in the increase of the municipal Gross Domestic Product (M-GDP), generation of direct and indirect jobs, creation of new establishments and tax collection growth [18, 19].

On the other hand, this notable economic growth attracts migratory flows due to the project, which put pressure on public services and on municipal infrastructure. As in the case of many urban centers that receive mega projects that are previously lacking urban infrastructure and public services, such as sanitation, housing, transport and medical and hospital care, there is a worsening in access and care of these services, since that, quantitatively, the supply does not keep up with the demand growth. Neither are there any permanent qualitative improvements in health, safety and quality of life [20].

As a result of rapid and concentrated population growth, urban problems are amplified, such as the increase in the periphery of cities, given not only the housing deficit, but also the increase in land prices in the most of the central areas of urban centers. Other negative impacts can also be related to migratory processes and population growth in these areas, such as an increased urban violence, traffic violence, consumption and sale of illicit drugs, sexual violence, prostitution and sexually transmitted diseases. In addition to social impacts, it is observed a deterioration in the landscapes and the changes in the social productive arrangement of the affected population. In this perspective, [21, 22] highlights the suppression of natural elements and the damage to vegetation and fauna caused by the construction and filling of the reservoir. [23, 24] mention the effects on the quality of water resources and their hydrological regime (increase in water temperature and salinity, sedimentation of the reservoir, reduction of dissolved oxygen) and [25] indicate the negative impacts of induced displacement and resettlement of local communities, in general, submitted to homogenous compensation packages, that ignore the complexities of each social group.

Regarding the CO_2 emission per GWh, although the HPP present a low GHG emission rate, when compared to other sources of energy generation [26], when the HPP reservoirs are built in forested regions, the aerobic and anaerobic decomposition of organic matter causes the emission of gases such as CO_2, N_2O, CH_4 and H_2S. In these cases, the emission rate depends directly on the flooded forest area, the type of decomposing vegetation, the time taken to flood the area and the depth of the biomass [27]. [28] carried out several simulations to estimate CO_2 emission of some Brazilian HPP, which verified that emissions can be significant over time and that, under specific conditions, they may even be comparable to emissions from fossil fuel plants. [24] also studies the contribution of large dams in CO_2 emissions and in the incidence of endemic diseases, due to the increased proliferation of transmission vectors. In this context, it can be said that the socioeconomic development and the other positive impacts induced by HPPs are questionable.

In view of the relevance and contradiction of this theme, some qualitative and quantitative studies on the socioeconomic impacts of HPP were identified, especially those located in the Amazon Region and in the Tocantins-Araguaia Hydrographic Basin. From this survey, it was possible to identify two major dimensions of analysis: i) the biotic environment (fauna and flora) and/or ii) the social and cultural environment. From these dimensions, positive and negative impacts can be divided into seven thematic axes: i) economy; ii) employment and income; iii) infrastructure; iv) demography; v) socio-cultural; vi) health and education; and vii) environment.

Table 1 presents an overview of the socioeconomic impacts caused by HPPs, indicating a brief overview of the available literature. The impacts are organized by thematic axes, according to the identification of some effects and scientific works found during the research. Among the studies analyzed, some authors dedicated themselves to a more general approach on the impacts, while others pointed to a specific theme.

Table 1: Some socioeconomic impacts caused by HPP projects.

Thematic axes	Social, economic and environmental impacts	Authors
Economy	• Economy boosted by the demands established during the construction and by the increase in population; • Real estate and territorial speculation process; • Increase in the regional cost of living; • Increase in the number of companies, especially in the tertiary sector; • Increase in the collection of Tax over Services; • Increase in the collection of Urban and Territorial Property Tax; • GDP growth; • Increase in municipal revenues; • Benefits generated by the National Interconnected System; • Improvement/worsening of the navigability of rivers (implementation or not of locks);	[18] Del Río, Burguillo (2008) [19] De Faria *et al.* (2017) [29] Assunção *et al*. (2016) [30] Sgarbi *et al*. (2019); [31] Freire *et al*. (2018);
Employment and income	• Maintenance of agricultural activities and latex extraction; • Reduction of gold mining and commercial fishing, due to the loss of natural resources; • Compromising of the productive structure of riverside population (subsistence, small, medium and large producers); • Generation of temporary and low-paid jobs; • Increase in employment and formal average salary, especially during the construction phase; • Reduction of formal employment in the primary sector in the planning and operation phases;	[22] Von Sperling (2012) [29] Assunção *et al*. (2016) [30] Sgarbi *et al.* (2019); [32] Alves, Thomaz Júnior (2012); [33] Marin, Oliveira (2016)
Infrastructure	• Pressure on the supply of garbage collection services, piped water, sewage and electricity; • Disorganized occupation of areas surrounding the construction of the project; • Increase in the vehicle fleet;	[30] Sgarbi *et al*. (2019); [29] Assunção *et al*. (2016); [34] Reis, Souza (2016);
Demographic	• Population growth; • Intensification of migratory flux; • Growth/reduction in the number of births; • Accelerated growth of the urban population; • Increase in urban density;	[29] Assunção *et al*. (2016) [30] Sgarbi *et al*. (2019); [32] Alves, Thomaz Júnior (2012) [33] Marin, Oliveira (2016) [35] Silva (2013) [36] Catolico (2017)

Thematic axes	Social, economic and environmental impacts	Authors
Socio-cultural	• Generation of expectations; • Forced removal of populations; • Direct and indirect impacts on indigenous communities; • Increased pressure on indigenous lands; • Changes in the rural and urban landscape; • Suppression of landscapes such as beaches and waterfalls; • Increase in violence; • Increase in traffic accidents; • Increase in cases of prostitution and drug use; • Loss of family ties (kinship, neighborhood and crony relations); • Cultural loss (habits, beliefs, customs and traditions); • Sentimental losses (attachment, feeling of belonging to the place); • Interference with local power relations; • Possibility of land and water conflicts;	[37] Foschiera (2010) [38] Magalhães, Santos (2007) [39] Sieben, Cleps (2012) [40] Zitzke (2009) [41] Sigaud (1986) [42] Silva *et al.* (2008) [43] Vainer (2008) [44] Rocha (2016) [45] Silva Junior (2005) [46] Giusti (2014) [47] Hanna *et al.* (2016) [48] Parente, Miranda (2014) [49] CDDPH (2010) [50] Araújo, Moret (2016) [33] Marin, Oliveira (2016) [22] Von Sperling (2012) [51] Zhouri (2018) [52] Wang *et al.* (2012) [53] Stolerman *et al.* (2014) [54] Sevá (2008)
Health and Education	• Increase in endemic diseases (eg. malaria); • Reduction/increase of waterborne diseases; • Reduction of government spending on education and health; • Reduction in the number of primary school enrollments in public schools during the construction and operation phase;	[29] Assunção *et al*. (2016) [30] Sgarbi *et al.* (2019); [49] CDDPH (2010); [55] Gomes *et al*. (2014)
Environment	• Removal of vegetation in the reservoir construction area; • Increase in deforestation in nearby areas ; • Increased erosion process; • Increased risk of extinction of species of aquatic fauna and flora; • GHG emissions, due to the total removal of vegetation in the flooded areas; • Changes in air quality and increased noise pollution; • Reduction in the quality of water resources (increase in water temperature and salinity, sedimentation of the reservoir, reduction of dissolved oxygen); • Risk of water contamination; • Change of hydrological regime; • Disruption in migratory fish flows;	[14] Soito e Freitas (2011) [21] Mattmann *et al.* (2016) [22] Von Sperling (2012) [24] Fearnside (1997) [29] Assunção *et al*. (2016) [46] Giusti (2014) [52] Wang *et al.* (2012) [52] [56] Sharma *et al.* (2019) [57] Fearnside (1999) [58] Tahseen e Karney (2017) [59] Barrow (1988) [60] Rashad, Ismail (2000) [61] Rosenberg *et al*. (1997) [62] Celestino, Makrakis (2020)

3. The Estreito Hydroelectric Power Plant

The Estreito HPP is located in the mid-course region of Tocantins river, in the Tocantins-Araguaia Hydrographic Basin. Along the course of the river, Estreito HPP integrates a set of plants arranged in cascade, where Tucuruí HPP is downstream and Lajeado HPP is at upstream. In addition to the recognized hydroelectric potential, the region of the Tocantins-Araguaia Hydrographic Basin has a great diversity of natural resources, including extensive areas of agricultural land, agricultural frontiers, mineral resources and significant infrastructure projects. In this regard, its physical, biotic and geomorphological characteristics converge to consider this basin a strategic region from an economic, environmental and social point of view [63, 64].

In 2002, the Estreito Energia Consortium (CESTE), formed by Suez Energy South America Participações Ltda (now Engie), BHP Billiton Metais SA, Companhia Vale do Rio Doce, Alcoa Alumínio S.A. and Camargo Corrêa Energia Ltda., won the auction for the hydroelectric exploitation of Estreito. The plant operates with run-of-river technology, with an installed capacity of 1,087 MW, a reservoir of 555 km^2 and a flooded area of 400 km^2.

The municipalities of Estreito (MA), Carolina (MA), Babaçulândia (TO), Barra do Ouro (TO), Darcinópolis (TO), Filadelfia (TO), Itapiratins (TO), Palmeirante (TO), Palmeiras do Tocantins (TO), Aguiarnópolis (TO) and Tupirantins (TO) and the indigenous lands of Apinajé (TO), Krahô (TO) and Krikati (MA) constitute the impacted areas by the HPP [64]. Figure 2 shows the representation of the areas directly impacted (ADI) by the project.

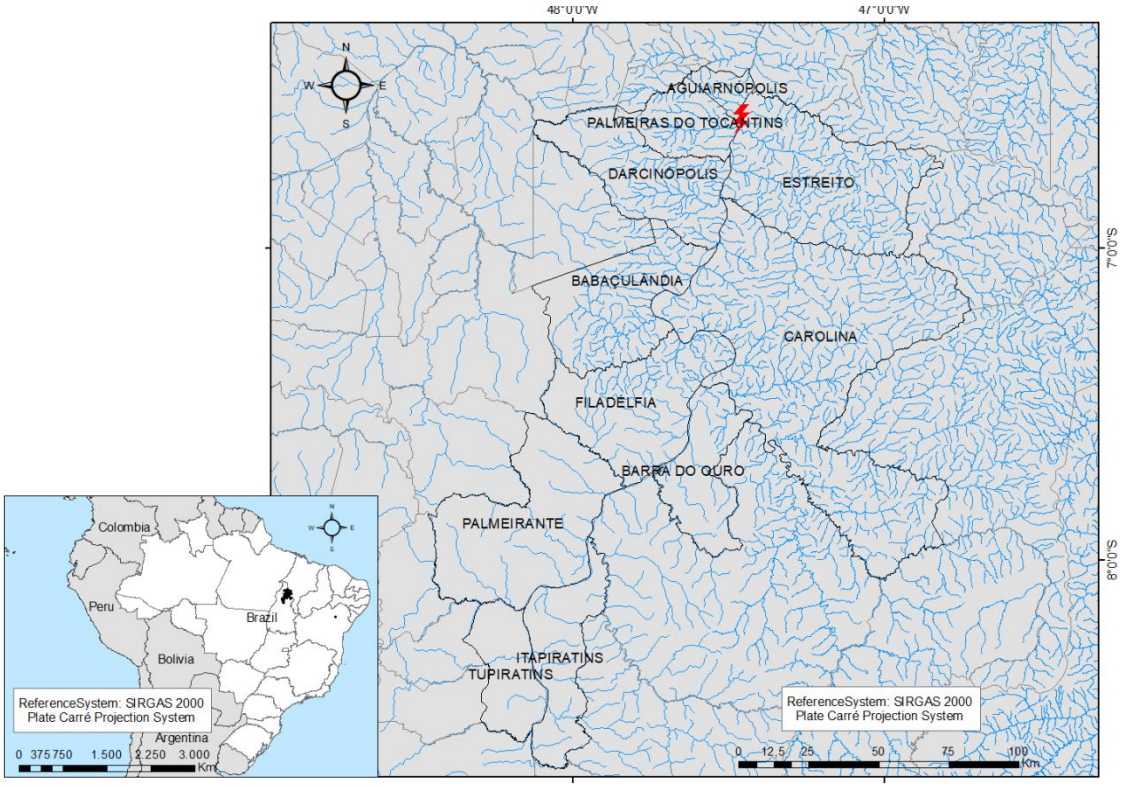


Figure 2: Location of the Estreito HPP and the affected municipalities.

In 2005, Ibama issued the Preliminary License (PL) for the project and the Installation License (IL) on the following year. The plant's civil works began in June 2007, in the municipalities of Estreito (MA) and Aguiarnópolis (TO), and the construction of the dam started in May 2010. At the end of 2010, the Operation License (OL) was issued, starting the reservoir filling process. In 2011, the plant's first generating unit went into operation and, in 2012, the eighth generating unit was completed, reaching the plant's total installed capacity [65].

In order to understand the characteristics of the region where the plant is located, Table 2 presents some social and economic indicators, derived from the 2010 Demographic Census, for the Tocantins-Araguaia Basin, in comparison to Brazil and the municipality of Estreito. When observing the values for the basin, all indicators have lower average values than the Brazilian average, except for the infrastructure dimension of the Social Vulnerability Index (SVIinfra). Even using the median, in theory a more robust indicator, most of the indicators remain below the Brazilian average.

The average Human Development Index (HDI) of the Tocantins-Araguaia Basin region can be categorized as average (0.600-0.699), as well its income dimension (HDIincome). For the education dimension (HDIedu), while it is rated as low (0.500-0.599), the longevity dimension (HDIlong) is high (0.700-0.799). These results demonstrate unsatisfactory quality of life conditions for social well-being.

In the municipality of Estreito, the behavior of the indicators are similar to the whole basin for the dimensions of Human Development Index (HDI) and Social Vulnerability Indicators (SVI). However, the municipality presents results above the Brazilian average and the Hydrographic Basin region for: Gini (Gini), SVI infrastructure dimension (SVIinfra), the percentage of the population with access to piped water (Wat), with garbage collection (Garb) and population with inadequate access to water and sewage (WatSew).

The major differences found between the minimum and maximum values of each indicator reveals the high heterogeneity of the region, where municipalities with very low social life conditions share the territory with regions of wide access to the provision of public services and investments in basic infrastructure. There are still municipalities in the region where access to electricity (EnEl) reaches only 58% of the population, the supply of piped water accounts for 15%, garbage collection reaches 25% and household income *per capita* (ICap) is less than 170 reals per month.

Table 2: Socioeconomic variables of the Tocantins-Araguaia Hydrographic Basin, Brazil, and municipality of Estreito in 2010.

Indicator	Tocantins-Araguaia Hydrographic Basin						Brazil	Estreito
	Minimum	Maximum	Average	Standard deviation	Median	Coefficient of variation		
HDI	0,50	0,82	0,65	0,05	0,66	0,08	0,73	0,66
HDIincome	0,49	0,86	0,63	0,06	0,66	0,09	0,74	0,67
HDIlong	0,69	0,87	0,80	0,03	0,81	0,04	0,82	0,80
HDIedu	0,32	0,75	0,55	0,08	0,56	0,14	0,64	0,54
SVI	0,18	0,65	0,37	0,11	0,36	0,28	0,33	0,35
SVIhumcap	0,22	0,79	0,46	0,12	0,45	0,24	0,36	0,54
SVIincome	0,16	0,71	0,43	0,10	0,42	0,24	0,32	0,38
SVIinfra	0,01	0,81	0,24	0,16	0,20	0,67	0,30	0,14
Gini	0,37	0,78	0,52	0,06	0,52	0,12	0,60	0,56
Wat	14,56	99,24	74,96	20,59	80,49	0,27	92,72	95,08
WatSew	0,14	72,22	11,25	12,18	6,63	1,08	6,12	5,22
Garb	24,98	100,00	91,73	11,78	96,21	0,13	97,02	97,36
EnEl	57,57	100,00	93,66	7,93	96,82	0,08	98,58	96,67
ICap (R$)	163,15	1.715,11	442,57	171,63	418,64	0,39	793,87	503,29

Source: data retrieved from IPEA and UNDP according to the 2010 Demographic Census.

According to the Environmental Impact Study (EIS) of Estreito HPP, carried out by [66], 5,937 inhabitants were impacted, where 4,789 belonged to the rural area and 1,148 to the urban area. In light of this, most of the affected population depends on productive areas for their economic activities and survival. On the other hand, the report indicated the generation of 5,204 direct temporary jobs and 1,600 indirect jobs, and also the concessionaire's commitment to 31 environmental programs.

The biotic and socio-environmental impacts pointed out by the EIS (2001) cover 26 archaeological sites (Petroglyph), 7 species of endangered fauna, 11 rural social and cultural

facilities (2 churches and 9 schools), loss of 8 areas for recreation, leisure and tourism (Filadélfia, Babaçulândia, Palmeirante and Barra do Ouro beaches, São Romão waterfall, Ilha dos Botes e Balnearios Praiolândia and Rio das Pedras) and the flooding of 6,600 hectares of Permanent Preservation Area (PPA) and 175 hectares of the Natural Monument of the Fossilized Trees. In addition, impacts on the regional road system and port facilities were also mentioned.

In view of the descriptive analysis of the study area, the region's socioeconomic fragility and losses observed in the physical-biotic and social environment are evident. Thus, the region is vulnerable to the implementation of large infrastructure projects, as any small change may impact the territory's demographic and spatial dynamics.

4. Methodology

The analysis of the impacts resulting from the installation of Estreito HPP was carried out using the econometric method of impact assessment entitled Synthetic Control. In summary, the methodological process can be divided into four stages. At first, the study area, the dimensions of analysis and the indicators to be used were defined. The next step consisted in choosing the quantitative method for the impact's assessment, while the third step covered the data collection and the definition of the variables of interest. Finally, the fourth step addressed the method application and its main results.

4.1. Selection of the study area, dimensions of analysis and indicators

The study area is formed by the limits of the Tocantins-Araguaia Hydrographic Basin, provided by the National Water Agency (NWA), and the municipalities that are connected or cut by these limits, as shown in Figure 3, totaling 383 counties. The map also shows the extent of the road network and the location of the Estreito HPP.

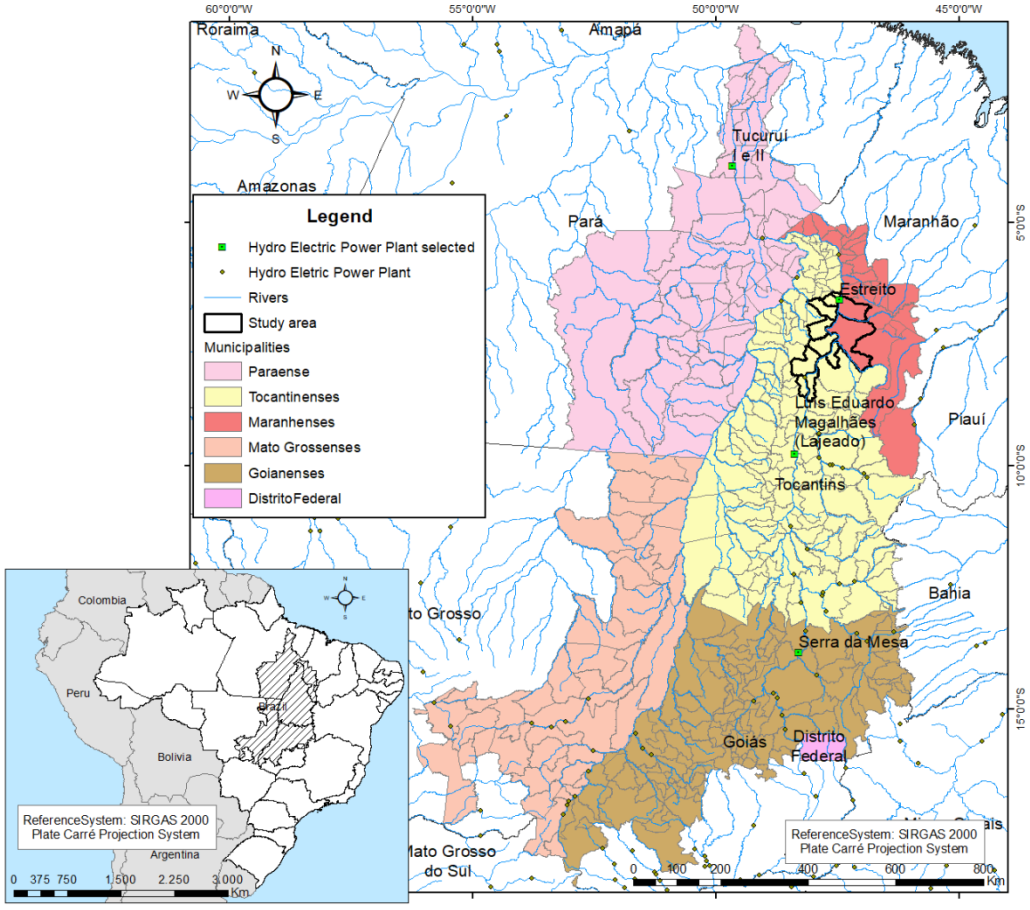


Figure 3: Section of the Tocantins-Araguaia River Basin region. Source: Own elaboration based on data from IBGE and NWA.

The Tocantins-Araguaia Hydrographic Basin is part of the Legal Amazon region and its population is composed of traditional groups with different ways of life. The region's water resources serve multiple purposes, from electricity production to irrigation, subsistence, leisure and transportation activities. These features make up a set of characteristics of high socio-environmental restrictions for the insertion of hydroelectric projects. In this way, the selected study area allows the analysis of old and current points of challenge and conflicts for the Brazilian electricity sector, especially in regard to the socio-environmental impacts of HPPs.

The analysis dimensions were selected from the literature review shown in Table 1. A set of variables was then defined that best fits the dimensions of interest for a sustainable regional insertion that fostered local development. In total, nine indicators were selected, which are described in Table 3 with their respective databases. At first, the violence dimension was analyzed through the variables "deaths from aggression", "deaths from homicides" and "deaths from traffic accidents". However, the synthetic control did not show a consistent trend due to the under-registration and under-coverage of existing databases. In view of this, the synthetic control method did not obtain satisfactory results, since it requires complete historical series for its application, therefore the authors chose to exclude these variables.

Table 3: Variables of interest analyzed in the impact assessment.

Dimension	Aspect	Indicator	Base
Income	Wealth level	Municipal GDP	IBGE
		Municipal GDP *per capita*	IBGE
Demographic	Density and migration	Municipality population	IBGE
Health	Reproductive Health	Born Alive	DATASUSU
		Access to prenatal coverage	DATASUS
Economic Development	Capacity to generate Jobs	Number of persons employed	RAIS
		Number of establishments	RAIS
		Average Monthly Salary per employee	RAIS
Environment	Ecology	Deforested area over municipal area	INPE

4.2. Selection of Impact Assessment Method: Synthetic Control

When the objective is to analyze impacts arising from a certain phenomenon, the simple comparison of developments in pre-intervention and post-intervention moments is not able to efficiently measure the desired effect, as it reflects the influence and action, not only arising from the construction of the enterprise, but also provided by the exposure to external economic, social and political agents and factors. Thus, it is not possible to guarantee the causality of the performance registered on the indicators strictly related to the construction of the plant.

In situations like this, the main objective is to eliminate the potential exogenous factors that may be contributing to explain the effect of the intervention, measuring the magnitude of the direct causal effect of the intervention (impact) on the analyzed results of interest. The effect can be analyzed with impact assessments centered on the question of causal inference. According to [64], these methods are based on the Counterfactual Theory to answer the question: what would have happened to the treated unit, if it had not been the target of such intervention?

Thus, groups of units based on the observable data, that are comparable to the analyzed unit, are sought. In this way, it is possible to calculate the average difference observed through the average effect of the treatment on the treaties. The causal impact corresponds to the difference between the result value in the presence of the program and in the absence of the program. In practice, it is not possible to observe, simultaneously, the result of interest in these two scenarios over time. As the condition "absence of the program" is always unobservable, counterfactual scenarios are used, measuring the desired effect through the difference in the results of the variable of interest in the units that underwent the intervention (treated units) and the counterfactual (synthetic unit) after the intervention [68].

Considering the existing methods and the characteristics of the proposed case study, which presents only one treatment unit, the synthetic control method is the most appropriate. In technical terms, this method seeks to obtain a synthetic unit for the treated unit, in order to compare the two trajectories. The counterfactual is determined by optimizing an intentional control group, built from a set of predictive variables, ensuring similarity between the two groups and avoiding the use of a counterfactual, arising from a subjective choice [11].

That said, suppose the existence of a sample composed of the treatment unit and potential control units, which were not impacted by the variable of interest during the analysis period (donor pool). Considering that this set of longitudinal data, observed in a period of time t, where t = 1, ..., T, has undergone an intervention in T_0, delimiting a pre-intervention period t = 1, ..., T_0 and post-intervention t = T_0, ..., T_1, so that T = T_0 + T_1. The result of interest for unit j, in period t is defined as Y_{jt}.

Thus, the synthetic control seeks to measure the effect of the intervention on the results of the variable of interest in the post-intervention period (t = T_0, ..., T_1), considering that it did not suffer any effects in the pre-intervention period (t = 1 , ..., T_0). The synthetic control uses a weighted average of the units in the donor pool to calculate the appropriate counterfactual.

In addition, the synthetic control intentionally induces the approximation of the path of the variable of interest in the synthetic unit during the pre-treatment period towards the path of the treated unit, in order to perform a path matching. According to [11], the longer the pre-treatment period analyzed, the more consistent the estimator will be.

In general, the statistical inference of the method is carried out through placebo tests. In these tests, the method is applied to all donor pool units, in the expectation that the effects will be nonexistent or less than those found in the treatment units. The construction of graphs is the most used representation for the analysis of the treatment effects, as it manages to capture the magnitude of the treatment estimation in comparison with the other placebo cases through the visual appeal of the data.

The relevance of the Synthetic Control for assessing the impact of HPPs, as one observes, in the literature, a small number of studies with a quantitative approach, either due to the lack and quality of the available databases, or due to the difficulty of a proxy identification that reliably reflects the desired impact. Given the advantages of its application and the ability to make comparative quantitative analyzes of case studies, this method has been widely used in the literature to assess the effects of public policies and interventions.

Ref. [58] and [66] also highlight that the impacts associated with HPPs are heterogeneous in view of the historical, political, economic, social and environmental specificities of each location. Thus, the analysis of a case study, such as the municipality of Estreito, is of great importance for understanding the particularities surrounding the impacts that occurred in regions of great socioeconomic vulnerability.

4.3. Definition of input variables for the Estreito HPP case

The proposed synthetic control analysis was performed using the Synth package in the Stata software. From the Financial Compensation database of the National Electric Energy Agency (ANEEL), it was possible to verify the municipalities that make up the area of direct influence (ADI) of the Estreito HPP and those that are not impacted concurrently by another plant, according to the wetland criterion (Table 4). These municipalities formed the treatment units of the study and, for each one, the synthetic control method was applied in isolation.

Table 4: Units treated for Estreito HPP.

Municipalities	Federative Unit	Area Km^2	Area %
Carolina	MA	206.43	32,47
Estreito	MA	48.85	7,68
Babaçulândia	TO	94.69	14,89
Barra do Ouro	TO	47.78	7,51
Darcinópolis	TO	39.04	6,14
Filadélfia	TO	114.44	17,99
Goiatins	TO	15.00	2,36
Itapiratins	TO	15.24	2,40
Palmeirante	TO	25.45	4,00
Palmeiras do Tocantins	TO	28.02	4,41
Tupiratins	TO	0.89	0.14
Aguiarnópolis	TO	0	0

Source: Data from ANEEL (2019).

The control group is formed by the other municipalities in the Tocantins-Araguaia Hydrographic Basin, excluding the municipalities that also have flooded areas due to the implementation of other HPPs and the municipalities with other major infrastructure investments in the period of analysis. By means of this, the donor pool built seeks to respect and consider regional complexities, since being part of the basin can point out issues that distinguish these municipalities from a representative set of Brazilian municipalities.

The plant's construction occurred between 2007 and 2011. The year 2007 was considered the year of intervention (T_0), therefore the pre-treatment period was evaluated from 2003 to 2007 and the post-treatment period from 2008 to 2014. The vector predictive variables are composed of the variable of interest Y for some years of the pre-treatment period (2003, 2004 and 2005), and up to five predictive characteristics, such as: population, participation in the added value of agriculture, M-GDP, M-GDP *per capita*, participation in the added value of services and credit operations. For each of these predictors, the annual mean value of the pre-treatment period (2002-2007) was used.

5. Results and Discussion

The results are sectioned according to the socioeconomic indicators and their respective dimensions of analysis. For all indicators, it is possible to perceive the greater intensity and concentration of positive and negative developments in the municipality of Estreito, where the project was being built. Before the HPP construction period, the Estreito municipality already stood out as one of the most economically developed in the surrounding area, mainly because of agricultural activities. In this way, greater emphasis will be placed on this municipality.

Within all dimensions and indicators analyzed, it was possible to verify that the onset of effects occurred up to two years before the construction of the HPP, that is, between 2005 and 2006. Ref [70] had already pointed out the existence of territorial developments prior to the construction, categorized as “speculative impacts”. The authors report that the news released by the media or even the emerging rumors about the beginning of the works quickly spread in the surrounding regions and, by pointing out the first signs of construction, a considerable population contingent was already beginning to migrate to the municipality. This migratory flow consisted of individuals in search of jobs, with expectations of better living conditions and opportunities for social growth.

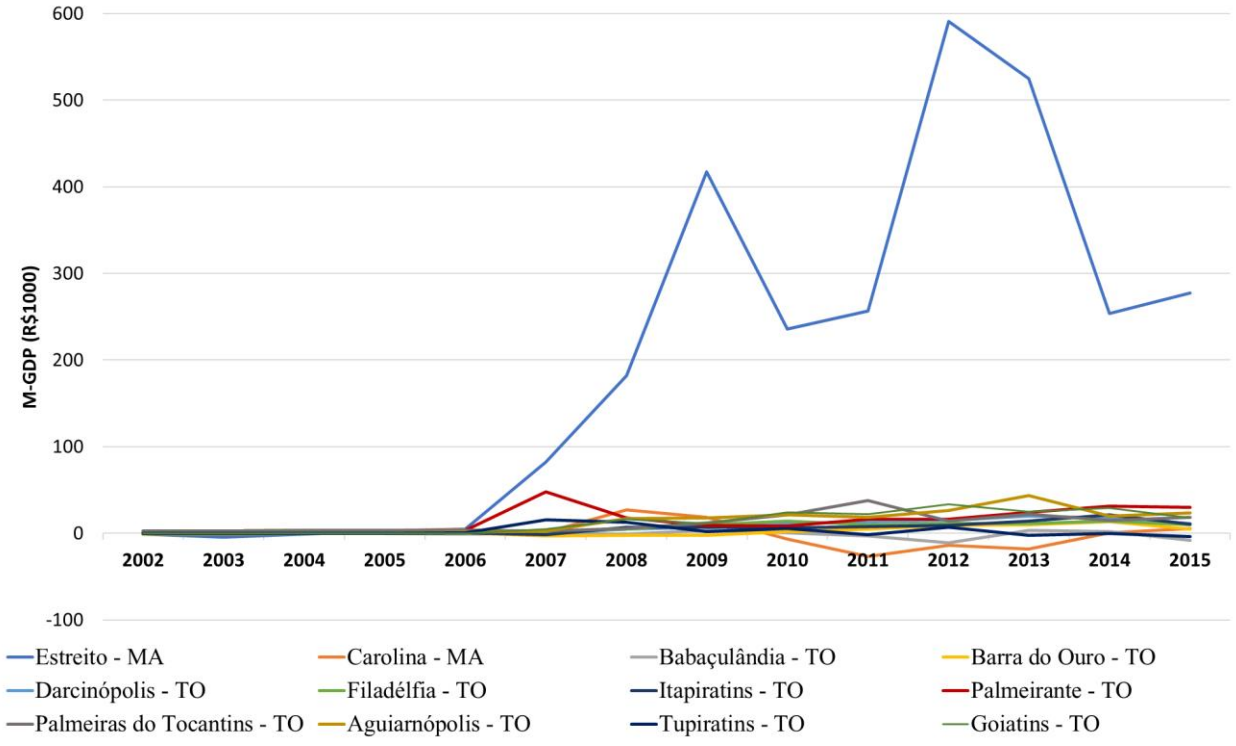
5.1. Economy Dimension

The economic dimension was analyzed by the variables of interest “M-GDP” and “M-GDP per capita”. It is important to remember that these indicators do not efficiently reflect phenomena such as concentration and income inequality, since it does not inform the way in which income is distributed within families and population groups. However, there are no indicators available at the municipal level or annual periodicity for this propose.

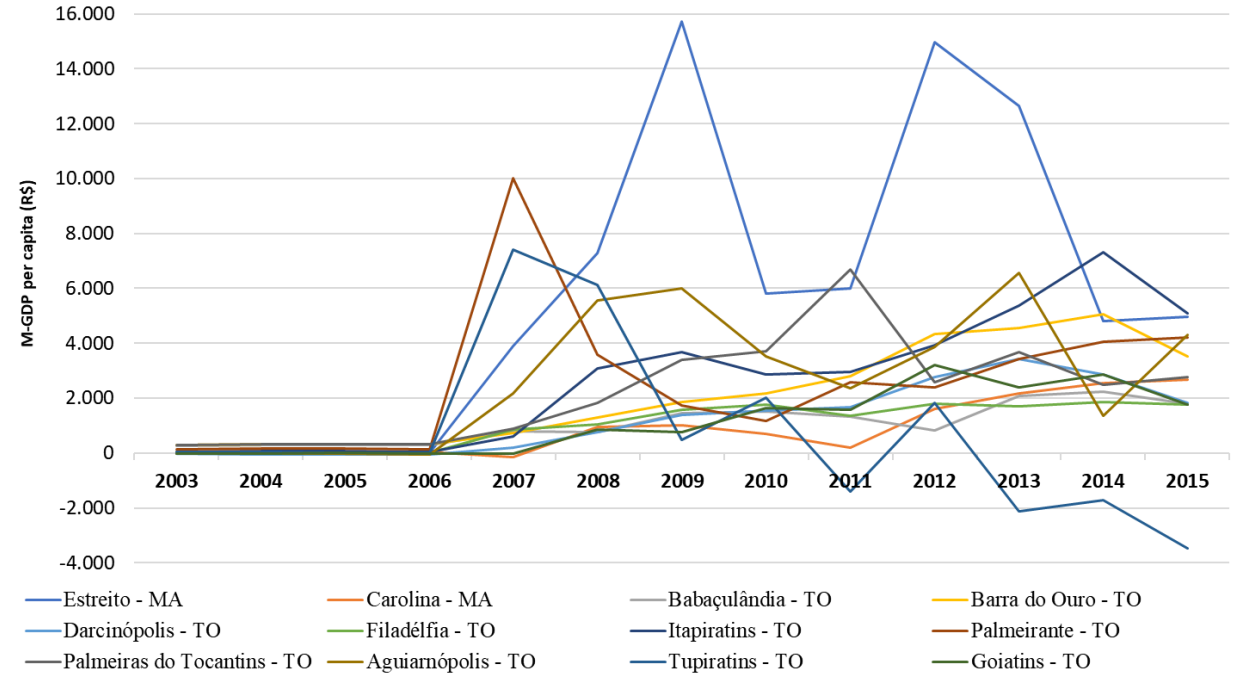
Before the HPP construction, the highest M-GDP value was found in the municipality of Goiatins, followed by Babaçulândia and Filadélfia. In 2012, one year after the beginning of Estreito HPP operation, this picture was quite different in the municipality of Estreito, registering a M-GDP about 600 times higher than in 2002.

It is possible to observe, in Figure 4a and 4b graphs, the effect of the project's implementation on the variable of interest for each of the treated municipalities, that is, the difference value between the treated municipality and its counterfactual (the gap). The effects on the variables were more intense in the first two years of construction, with the effect of M-GDP *per capita* being more significant in a larger group of municipalities. In general, the behavior of the variables is marked by successive episodes of progression and regression, a result that is in line with what was exposed by [19, 29].

In addition, there is also a concentration of positive effects in the municipality of Estreito, with a much higher gap than the other treatment municipalities, showing a positive effect of great magnitude for both variables. In 2006, one year before the start of the power plant construction, this growth was exponential, which continued until 2009. In 2010, there was a reduction in these values, which grew and reached a peak in 2012, equivalent to an increase in M-GDP of 591,000 reals compared to the counterfactual. From 2013, the M-GDP reduction rate takes the data series to a lower level, however, still higher than the values registered for the other units.



a)



b)

Figure 4: Effects of the variable of interest a) M-GDP; and b) M-GDP *per capita*. Source: IBGE data.

During the construction phase, there was a large influx of immigrants that contributed to momentarily increase the local economy, mainly caused by activities in the tertiary sector. In addition to the effect caused by the economic dynamism, the municipalities that present flooded areas receive financial compensation for the use of water resources, in accordance with Law nº13.661/2018, which establishes a transfer percentage to the municipalities of 65%.

The behavior of the variables of interest in the municipality of Estreito can be explained by the hypothesis that by 2009, M-GDP and M-GDP *per capita* had increased due to the dynamism of the local economy. After the peak of the initial works, which occurred in the first two years of construction, the M-GDP suffered a significant drop, growing again after the beginning of the operation in 2012, when the municipality started receiving royalties.

5.2. Demography Dimension

The demographic dimension was analyzed using the variable of interest "population". The effect also began in 2006, one year before the intervention, as shown in Figure 5 graph. Until 2009, the increase was not very pronounced, presenting, from then on, a new level of growth.

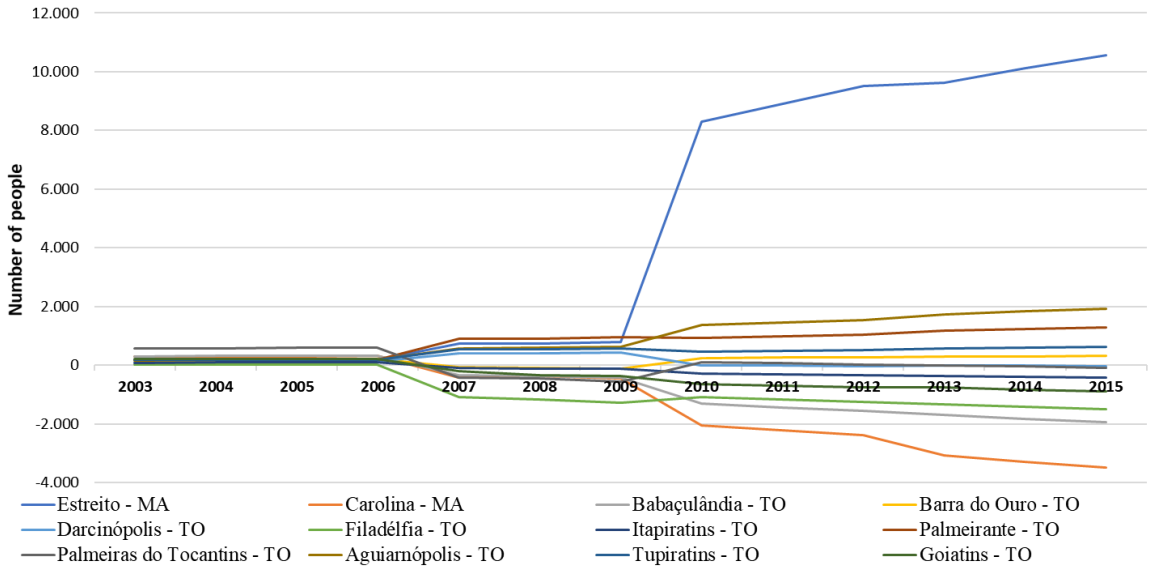


Figure 5: Effects of the population interest variable. Source: IBGE data.

In Estreito municipality occurred a peak of growth in 2009, observed in relation to the synthetic municipalities. In 2015, the demographic effect of the construction reached a contingent of 10,549 people. This increase can be explained by the strong migratory flow, driven by the expectation of better life conditions attractiveness. Considering that Estreito municipality is the location of the plant's construction, this flux may have been intensified. The non-return of immigrants to their places of origin resulted in a new level of population contingent, an effect also seen in other HPPs in the region, such as Belo Monte [33], Jirau and Santo Antônio [33].

The construction phase comprises the largest flow of population migration [46]. Large contingent of immigrants increases the pressure on the public services infrastructure of the municipalities around the enterprise. These services generally include health, education, transport, sewage, water supply, access to electricity, collection and disposal of solid waste and public safety.

Considering that, in the case of Estreito municipality, the existing basic infrastructure equipment was already insufficient to serve the local population (Table 1), pointing out that the influx of immigrants becomes an aggravating factor. Therefore, depending on the management of public services and the economy, this effect can be considered negative for the region.

5.3. Employment and Income Dimension

The employment and income dimension were analyzed using the indicators "capacity to generate employment", "number of establishments" and "average salary". In general, the

construction of large enterprises boosts the local economy, directly increasing the number of companies installed in the region. In this way, machinery, engineering, commerce and service companies are often installed at this stage. Another point to be considered is the increase in companies providing services to the public sphere, due to the additional revenues coming from financial compensation measures.

The Figure 6 graph shows that the effects on the variable of interest "number of establishments" started in 2005, two years before the construction period, and last for the entire analyzed period, reaching its peak in 2011, when the construction ended. The HPP construction resulted in 131 new establishments in Estreito municipality. Although more intense in Estreito, the effect on the number of establishments is also significant in the other affected municipalities and remains after the plant starts operating. The ref. [30] also revealed an increase in the number of establishments in the construction sector.

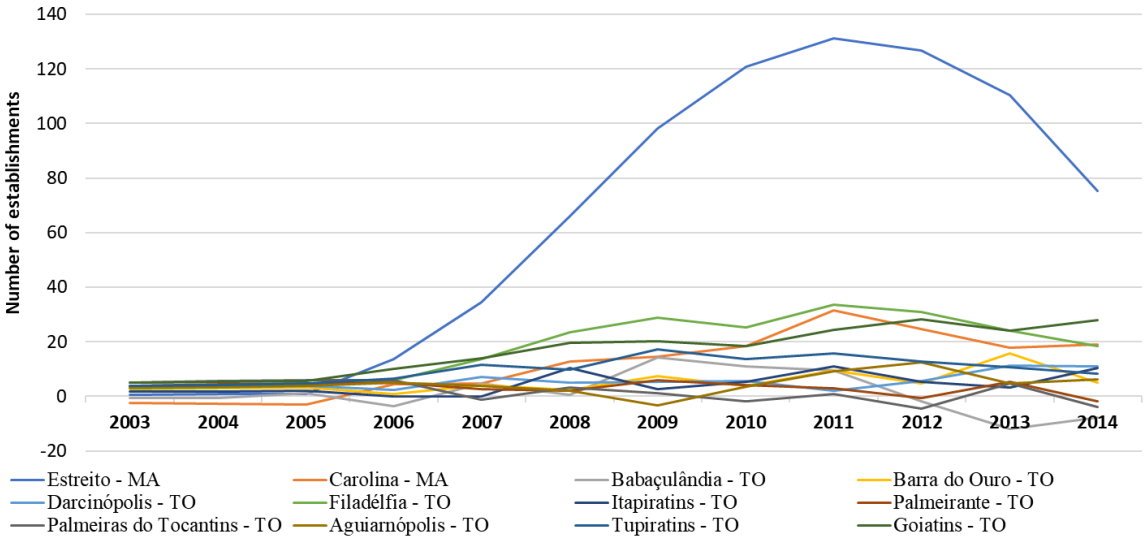


Figure 6: Effects for the variable of interest number of establishments. Source: RAIS data.

Figure 7 graph shows the effects of the Estreito HPP insertion in the variable "job creation". These effects start in the pre-construction period and extend throughout the construction period, reaching a peak in 2009, with 7,947 jobs generated. In 2014, the intervention of Estreito HPP no longer has an effect on the number of jobs created, that is, in the long run, it can be said that the construction of the plant did not contribute to an increase in job creation.

As highlighted by [32], the first two years of construction cover the largest number of workers hired, reaching its peak in 2009, around the 31st month from the beginning of the works. The authors highlight that a large part of the workforce was employed in low-paid temporary activities that cover the most diverse functions, from the construction of the HPP to the implementation of the support infrastructure, including accommodation, food, transportation, maintenance, among others.

According to [66], at Estreito HPP, moments of high labor absorption were expected between the 20th and 40th months, with a peak between the 22nd and 34th months, where the hiring would reach 5,800 workers. Among these jobs, 48% were classified with level II of qualification (carpenters, masons, mechanics, operators etc.) and 30% with level I, or, unskilled (helpers, servants, janitors). As, in general, these activities are of low quality and the companies choose to hire individuals residing in the rural and urban surroundings of the construction of the enterprise.

The results confirm the positive effects of the HPP insertion in jobs generation, during the construction period, as pointed out by [22]. Especially in the cities affected in Brazil, [30] also

reveals a higher increase in the number of jobs during the construction phase in relation to the operation phase, with emphasis on the tertiary sector.

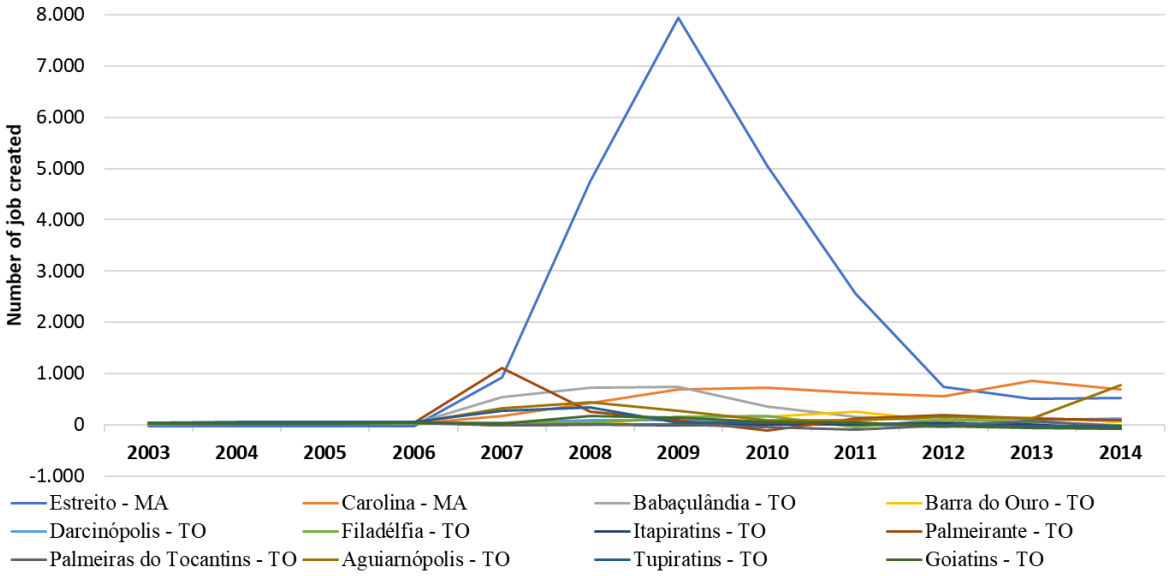


Figure 7 Effects for the job creation interest variable. Source: RAIS data.

Figure 8 graph shows the effect of the "average wage" variable. The effects start in 2005, when the municipalities of Aguianópolis, Tupiratins and Palmeirante have already shown growth peaks in 2007, which is when the construction started. In 2008 and 2009, the effect was already null or even negative for these municipalities. In other municipalities, such as Goiatins, Darcinópolis and Filadélfia, the variable's effect is negative since 2005, remaining so for almost the entire period of analysis. In Barra do Ouro and Babaçulândia, the negative effect shows dips around 2012.

In Estreito municipality, the effects peaked around the same year of job creation, in 2010. The fact that the plant and the construction site are located in this municipality may explain the peak along the data series, compared to a more balanced behavior of the other municipalities. As of 2011, the average wage has been reduced, but remained at higher levels than those recorded before the construction of the plant. Ref. [30] also showed an increase in the average salary in the HPP construction phase, that was concentrated in the tertiary sector.

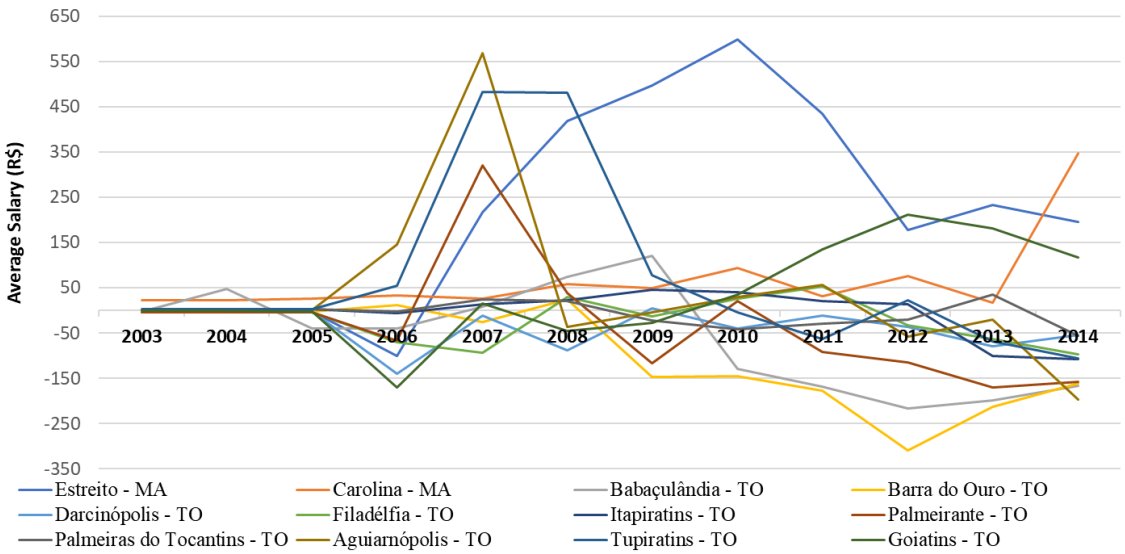


Figure 8: Effects for the average wage interest variable. Source: Own elaboration, based on RAIS data.

5.4. Health Dimension

As for the health dimension, the variables of interest "number of live births" and "number of accesses to the prenatal exam" were used. Figure 9 and 10 graphs show that the effects of the variables started in 2006, with an almost identical path, which presupposes that most of the live births underwent prenatal examination. However, the growth of the two variables is almost entirely dissipated at the end of the construction period.

The results were inconsistent and heterogeneous among the affected municipalities. Estreito and Carolina municipalities stood out with positive effects during the period of the plant construction (2007-2011), returning to null or even negative in 2012, that is, the effects were not in the long term. In Estreito municipality, the number of births peaked in 2011, registering an effect of 137 live births and in line with the indicators of population growth and job creation. The municipality of Darcinópolis, in turn, had negative effects over almost the entire period analyzed.

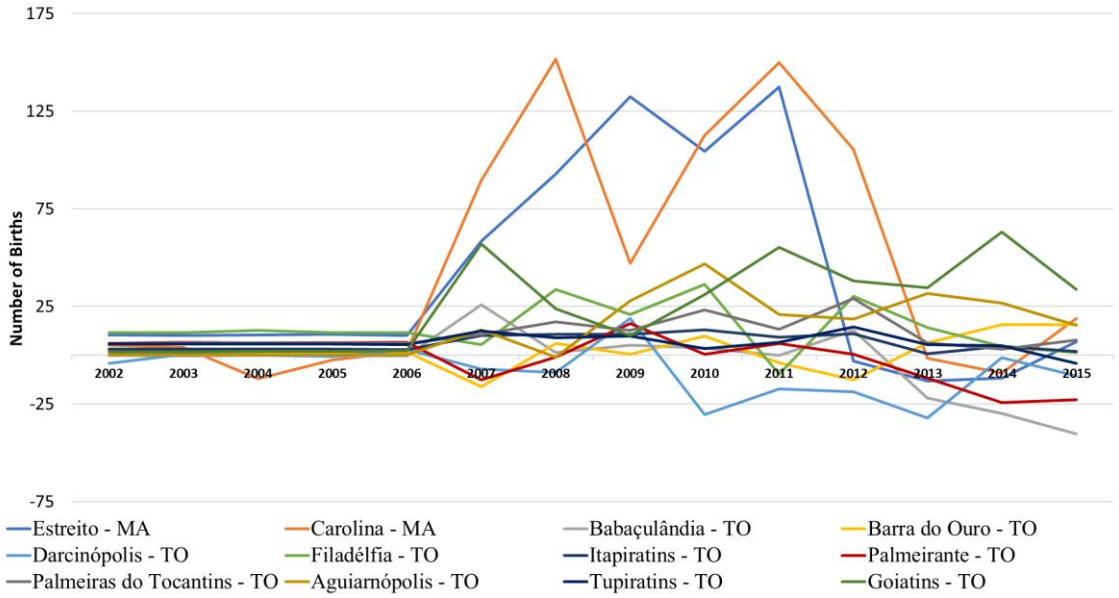


Figure 9: Effects for the variable of interest number of live births. Source: DATASUS data.

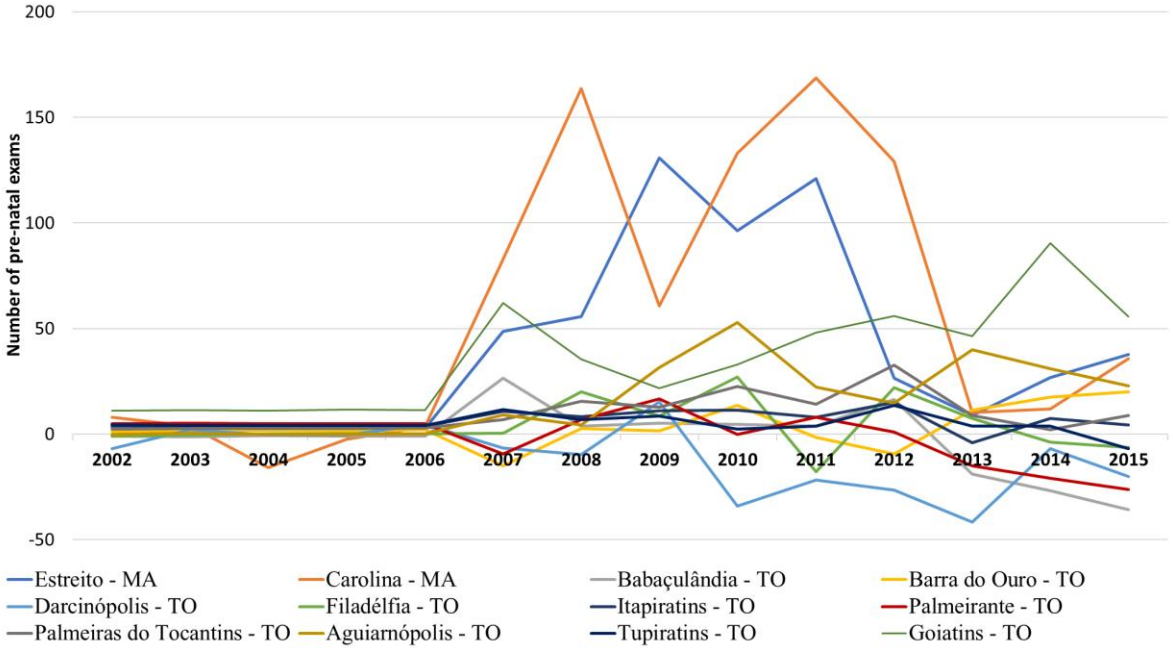


Figure 10: Effects for the variable number of prenatal exams performed. Source: Own elaboration, based on DATASUS data.

The increase in the number of live births may be associated with population growth. Additionally, [46] emphasizes that the insertion of construction sites in the vicinity of the project intensifies the circulation of people, mainly males, unaccompanied and with low education. A phenomenon that can contribute to the increase in the number of live births, given the frequent records of cases of unwanted pregnancies in such events. In this context, [19] reports an evidence of impact on the number of HIV cases, which may also be indicating an increase in sexual relations.

5.5. Environmental Dimension

The environmental dimension was analyzed using the variable of interest "deforestation area". In addition to removing the affected population, the construction of dams and HPP reservoirs involves deforestation and earthworks, not only in the area that will be flooded by the construction of the reservoir, but also in the region that will be occupied by flower beds and access roads [52, 56]. Another driving factor for deforestation is the intensification of population growth, given the encouragement of primary extractive activities, such as mining, agriculture and extensive livestock.

Figure 11 graph shows that the municipalities of Aguiarnópolis, Palmeirante do Tocantins and Darcinópolis already had deforestation effects prior to the pre-treatment period. The effect is noteworthy in Aguiarnópolis, one of the municipalities receiving the project next to Estreito. In Estreito municipality, there was an increase in the deforested area in 2005, up to two years before the beginning of the construction. From then on, these values were not significant when compared to the synthetic counterfactual. The municipalities of Carolina, Barra do Ouro, Filadélfia and Tupiratins did not have available data for analysis.

Thus, it can be concluded that the effect on the area of deforestation occurred in a reduced way and only during the period of the plant construction. The results found by [29, 30] also reveal the low effect on this variable of interest. According to [29], deforestation is concentrated in the construction area of the plant and is short term.

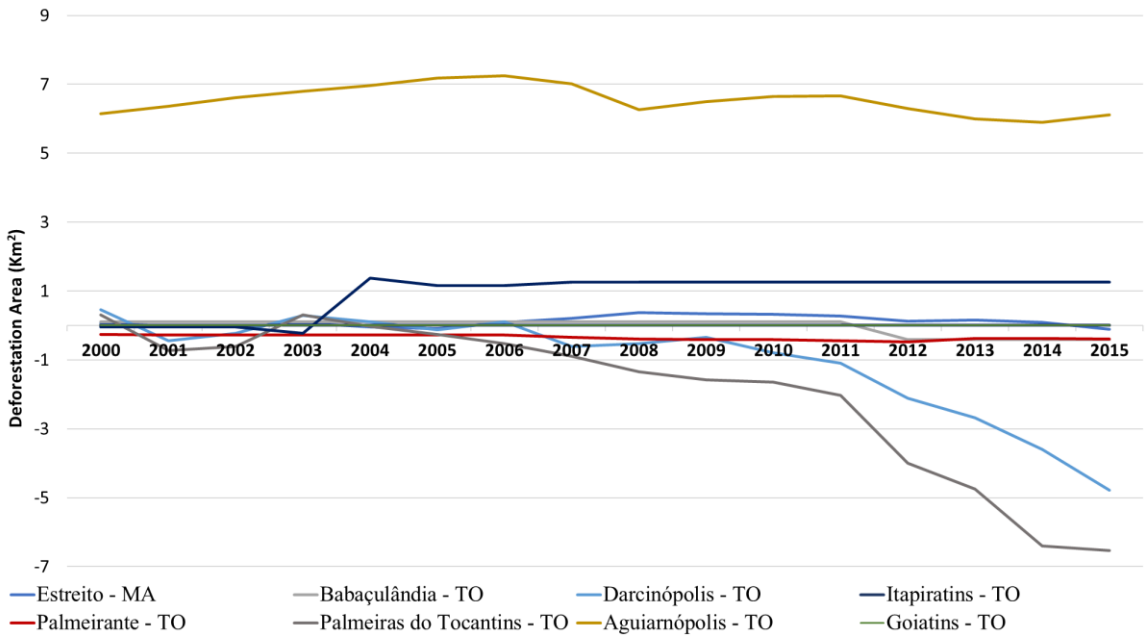


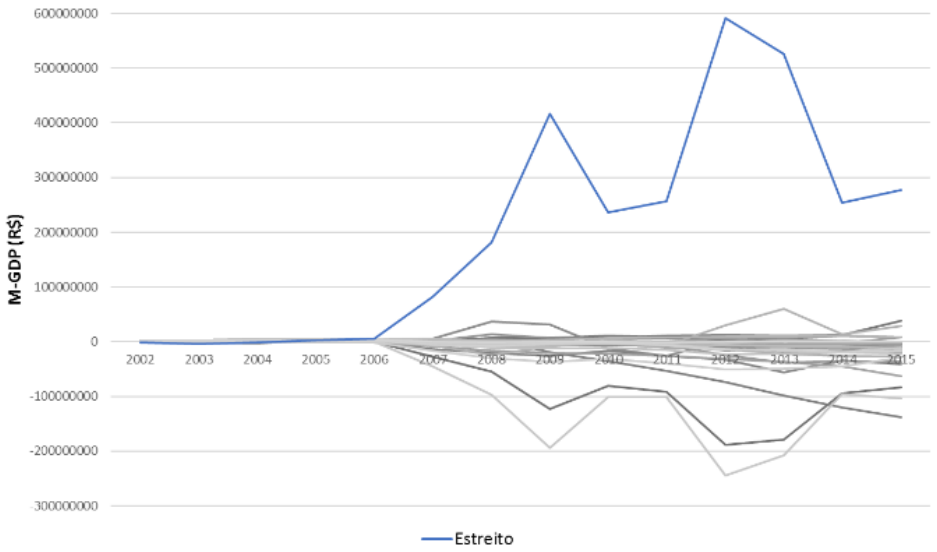
Figure 11: Effects for the variable of interest deforestation area. Source: data from INPE.

5.6. Robustness Tests

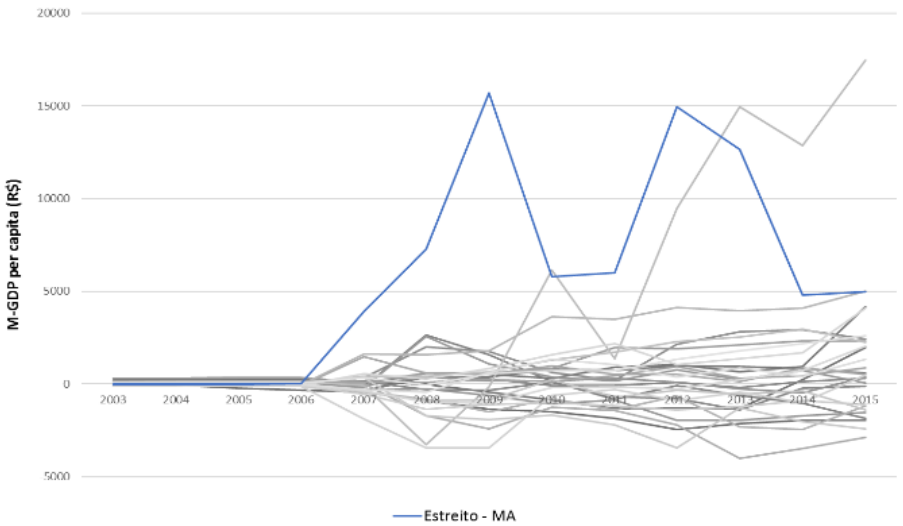
The robustness of the method was analyzed through placebo tests, which included the construction of synthetic units for the other municipalities in the control group. As these municipalities have not suffered HPP interventions, it is expected that the effects in the treatment municipalities will stand out.

In Figures 12a to 12i, it is observable that among all the municipalities analyzed, the difference between Estreito municipality and its counterfactual stands out, being much higher than those found in placebos. The exception is the "deforestation" variable, where the Estreito municipality did not stand out, revealing the low causal effect of the intervention on the variable of interest. For the other treatment municipalities, the effects of the variables are mixed with those found by the placebo units, revealing that there was no significant effect in these municipalities.

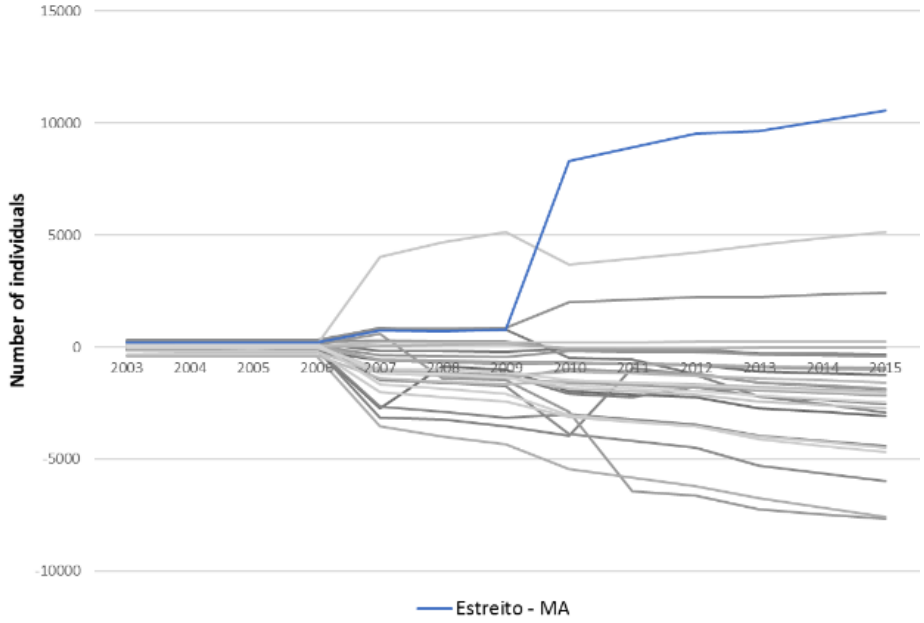
In general, only in Estreito municipality, the probability of the effects occurring at random is low. Thus, it can be said that the effects found in Estreito were most likely due to the phenomenon of Estreito HPP insertion.



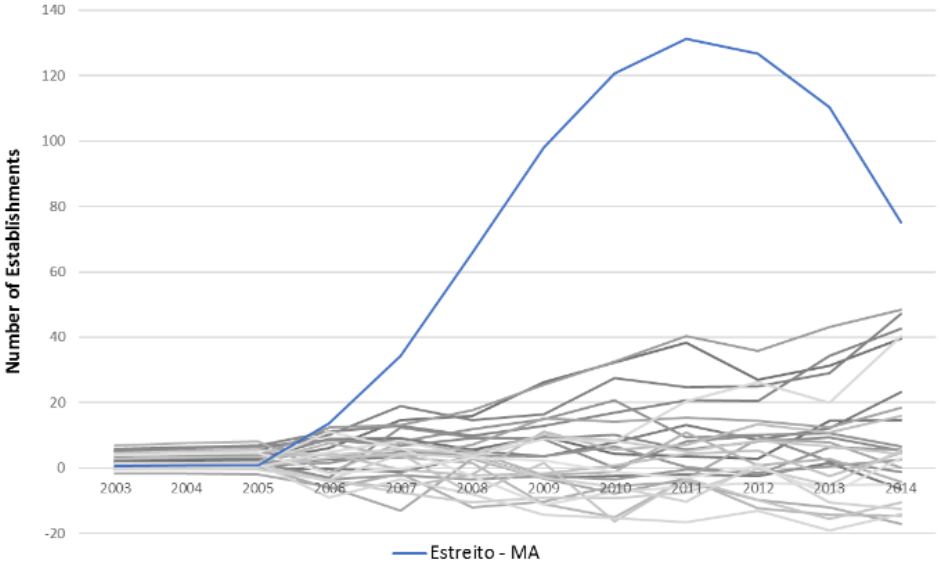
a) Placebo teste for M-GDP.



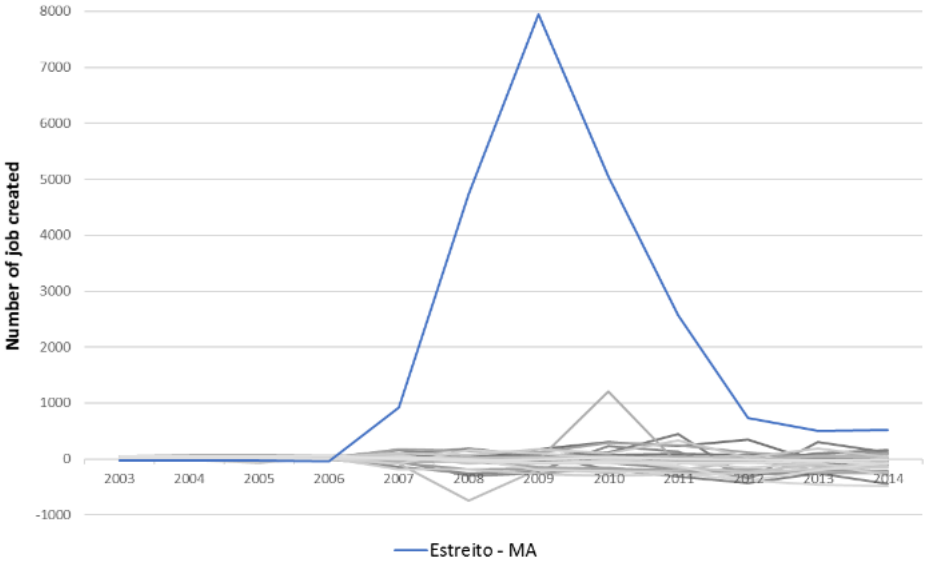
b) Placebo test for M-GDP *per capita.*



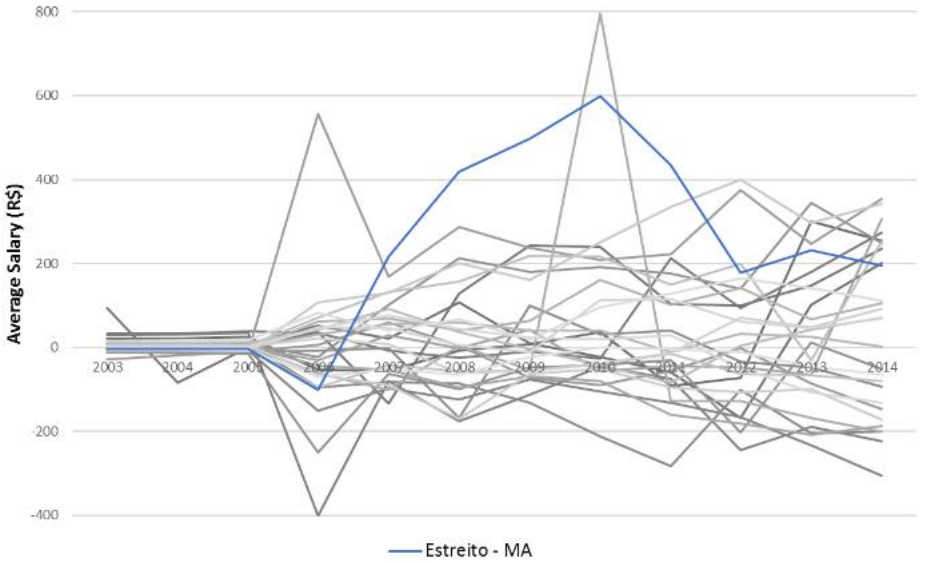
c) Placebo test for Population.



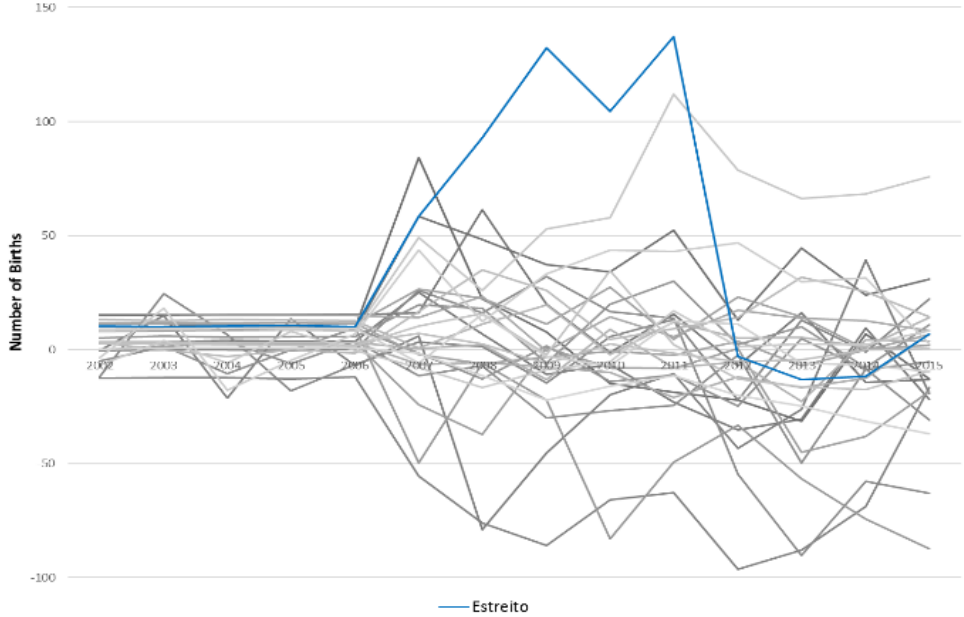
d) Placebo test for Number of establishments.



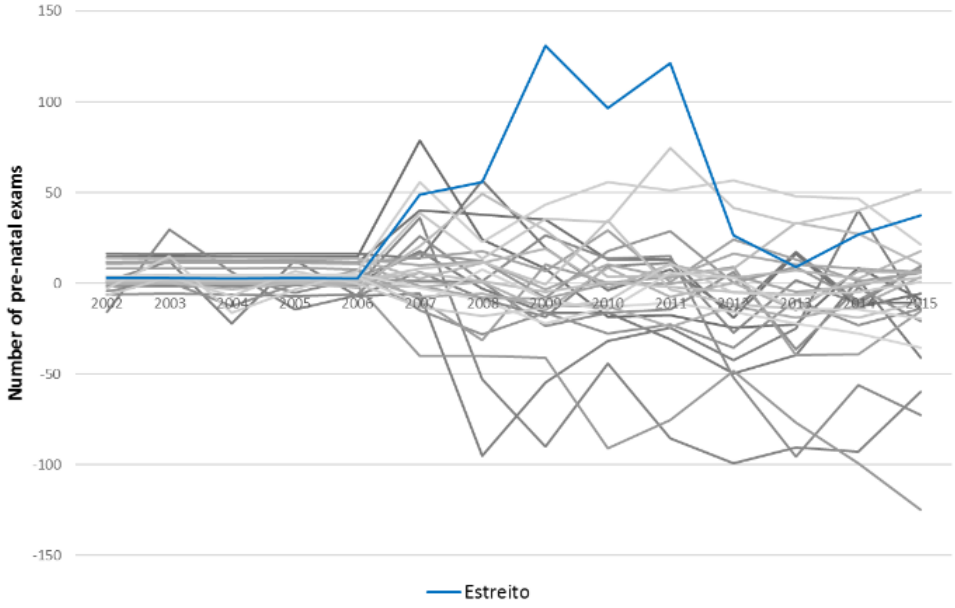
e) Placebo test for Job creation



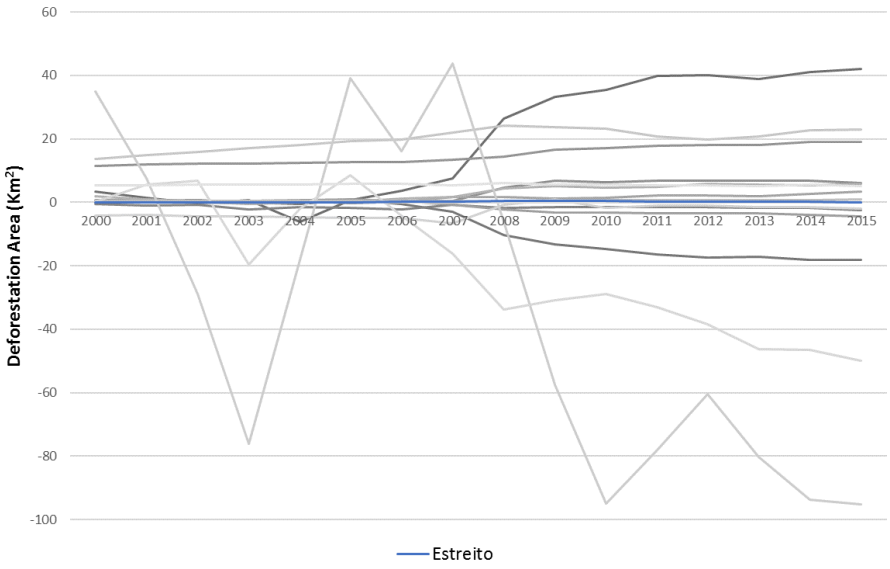
f) Placebo test for Average salary



g) Placebo test for live Births



h) Placebo test for Pre-natal examination



i) Placebo test for deforestation area.

Figure **12**: Placebo test for the variables of interest. Source: Stata software output.

6. Final Considerations

Conducting a detailed HPP impact assessment covering the different interests of the actors involved is extremely important for ensuring the well-being and distribution of the generated benefits for the population. Thus, seeking to offer public policy makers subsidies for future decision making, the impacts of implementing HPP in the territory were analyzed according to different socioeconomic dimensions.

As also highlighted by [20], the speech that gives rhetorical support to the construction of large investment projects, such as HPP, highlights the potential effects that can be observed in the improvement of socioeconomic indicators and the infrastructure perspective in regional development. If, on the one hand, this rhetoric justifies investments and sectoral policies, on the other hand, it can create a certain expectation in part of the population that lives in the territories that will allocate these projects, which influences the acceptance of environmental and social costs, in favor of the supposed improvement in their living conditions, through job offers, economic dynamism and infrastructural improvements.

However, the results of the study pointed to another perspective. The positive effects are not that strong in the long term and tend to be concentrated in the municipality that directly allocate the project, as well as in municipalities that already occupy a regional polarizing position, which is created by a greater economic dynamism and greater offer of public and private infrastructures and services, such as transportation, hospitals, schools and universities.

In general, the effects on the local territorial dynamics, when large projects are implemented, begin to appear before the start of the construction stage, revealing the speculative character generated by the insertion of these projects. In the case of Estreito municipality, this showed a strong initial detachment compared to the synthetic municipality, for all variables of interest, although the positive externalities did not remain at the end of the construction stage. However, the temporal analysis of the indicators showed that even before the HPP implantation, the municipality could already be considered a polarizer of the economic development of the region. In addition, the

deteriorating picture of socioeconomic dimensions may indicate a worsening in the living conditions of the local population.

The results show that the externalities presented as positive, by the project decision makers, were not able to reduce the conditions of economic vulnerability of the other impacted municipalities, results that meet those exposed by [20]. And even in the municipality of Estreito, most of the positive effects did not remain in the long run. Even in some affected municipalities, such as Tupiratins, the effects on M-GDP and M-GDP *per capita* were negative, widening the disparities between the municipalities.

In addition, the effects characterized as positive were manifested, in general, in the economic sphere, citing the increase in the generation of jobs, in the number of commercial establishments and in the M-GDP. Indicators that, if not equitably distributed in the territory and democratically accessible to the entire population to meet their local needs, cannot be identified as promoters of improvements in living conditions.

There is also the issue that these sites attract intense migratory flows, especially during the construction period. The arrival, in a short period of time, of this migrant population formed by workers directly involved in the construction and eventually including their families, as well as other workers and investors in search of opportunities, can lead to an abrupt demographic increase.

This demographic growth, temporarily concentrated, promotes greater anthropic pressure on infrastructure services and an increase in economic dynamism. Since most of these centers did not previously had infrastructural reinforcements, the effects are short-term and a series of negative impacts, such as increased violence and reduced quality of life, are still emerging in the region.

In addition, with regard to regional development, given that the positive economic effects were concentrated in a single municipality, Estreito, which was already considered a center of the region's economic development which had a short-term duration, it can be said that the HPP insertion had a low level of contribution to overall regional development and is unsatisfactory and distant from the expectations disclosed by the consortium. Furthermore, the deteriorating picture of socioeconomic dimensions may be showing an overall loss of living conditions for the local population, results that were also discussed by [71].

Regarding the application of Synthetic Control, the study found the main limitations: the availability of databases with quality and time coverage adequate to the proposed analyzes; problems with the level of municipal geographic breakdown and annual periodicity, mainly in the North Region. Due to socio-environmental complexities, cases of under-registration and under-coverage of data are frequent, especially in the databases of the National Sanitation Information System (SNIS) and the Department of Single Health System (DATASUS). These problems directly compromised the application of the synthetic control method, mainly in the analysis of the dimensions of violence and infrastructure services.

It should be noted that most of the variables of interest dealt within the economic sphere did not indicate, by itself, an improvement in social development and life conditions indicators. Consequently, in future works, a triangulation of methods is indicated, where the results of qualitative research can also be considered, to cover the impacts that cannot be translated by indicators, such as the oral history of the affected local population. In this case, the qualitative approach provides a subsidy in the exercise of diagnosing and evaluating the socioeconomic impacts of HPPs in the territory.

In conclusion, the impact assessment process applied in this paper allows the identification of the benefits effectiveness and the existing challenges in HPPs implementation. The importance of integrating sectoral policies and mega infrastructure projects with a regional development proposal

is also highlighted, considering the particularities of local ways of life, especially in regions of great vulnerability, such as the Tocantins-Araguaia Hydrographic Basin.

Along these lines, it is possible to increase the quality of future projects with regard to the environmental and regional development. It is expected that the notes and information collected will contribute to the process of continuous improvement in the development and implementation of public policies for the insertion of HPP, aiming at regional development and social well-being.

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References

[1] EPE, Empresa de Pesquisa Energética. Balanço Energético Nacional. Brasília, 2019a.

[2] EPE, Empresa de Pesquisa Energética. Plano Decenal de Energia, 2019b.

[3] REN21. Renewables 2019 – Global status report. Paris: REN21 Secretariat, 2019

[4] BROWN P H, XU K. Hydropower development and resettlement policy on China's Nu River. Journal of Contemporary China, v. 19, n. 66, p. 777-797, 2010. DOI:0.1080/10670564.2010.485409

[5] BARTLE A. Hydropower potential and development activities. Energy policy, v. 30, n. 14, p. 1231-1239, 2002. https://doi.org/10.1016/S0301-4215(02)00084-8.

[6] ANDRADE A, SANTOS M A. Hydroelectric plants environmental viability: Strategic environmental assessment application in Brazil. Renewable and Sustainable Energy Reviews v. 52, p. 1413-1423, 2015. https://doi.org/10.1016/j.rser.2015.07.152.

[7] LEROY J P. Mercado ou Bens Comuns? O papel dos povos indígenas, comunidades tradicionais e setores do campesinato diante da crise ambiental. FASE, Rio de Janeiro, 2016. ISBN 978-85-86471-87-2

[8] BRASIL. Lei Complementar nº 124 de 3 de janeiro de 2007.

[9] IPEA, Instituto de Pesquisa Econômica Aplicada. Atlas da Vulnerabilidade Social. Disponível em: <http://IVS.ipea.gov.br/index.php/pt/sobre>. Access in 20/01/2018.

[10] ABADIE A, GARDEAZABAL J. The Economic Costs of Conflict: A Case Study of the Basque Country. American Economic Review, 93 (1), 112–132, 2003. DOI:10.1257/000282803321455188.

[11] ABADIE A, DIAMOND A, HAINMUELLER J. Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. Journal of the American Statistical Association Applications and Case Studies. June 2010, v. 105, n. 490. https://doi.org/10.1198/jasa.2009.ap08746

[12] IEA, International Energy Agency. Next Generation Wind and Solar Power From Cost to Value. Full Report. Paris, France, 2016.

[13] SOUZA A C C. Assessment and statistics of Brazilian hydroelectric power plants: Dam areas versus installed and firm power. Renewable and sustainable energy reviews, v. 12, issue 7, p. 1843-1863, 2008. https://doi.org/10.1016/j.rser.2007.04.005.

[14] SOITO J L, FREITAS M A. Amazon and the expansion of hydropower in Brazil: vulnerability, impacts and possibilities for adaptation to global climate change. Renewable and Sustainable Energy Reviews. v.15, issue 6, p.3165-3177, 2011. https://doi.org/10.1016/j.rser.2011.04.006

[15] ANEEL, Agência Nacional de Energia Elétrica Disponível em: < http://www2.aneel.gov.br>. Access in 16/03/2020.

[16] BENITEZ L E, BENITEZ P C, VAN KOOTEN G C. The economics of wind power with energy storage. Energy Economics, v. 30, n. 4, p. 1973-1989, 2008. https://doi.org/10.1016/j.eneco.2007.01.017

[17] PRADO JR F A, ATHAYDE S, MOSSA J, BOHLMAN S, LEITE F, OLIVER-SMITH A. How much is enough? An integrated examination of energy security, economic growth and climate change related to hydropower expansion in Brazil. Renewable and Sustainable Energy Reviews. v.53, p.1132-1136, 2016. https://doi.org/10.1016/j.rser.2015.09.050

[18] DEL RÍO P, BURGUILLO M. Assessing the impact of renewable energy deployment on local sustainability: Towards a theoretical framework. Renewable and Sustainable Energy reviews, v. 12, n. 5, p. 1325-1344, 2008. https://doi.org/10.1016/j.rser.2007.03.004

[19] FARIA F, DAVIS A, SEVERINI E, JARAMILLO P. The local socio-economic impacts of large hydropower plant development in a developing country. Energy Economics, v. 67, p. 533-544, 2017. DOI: 10.1016/j.eneco.2017.08.025

[20] GOMES C S, ROQUETTI D R, PULICE S, MORETTO E M. Usinas Hidrelétricas e Desenvolvimento Municipal: o caso das usinas hidrelétricas do Complexo Pelotas-Uruguai. Revista de Gestão Ambiental e Sustentabilidade. Vol.6, n.2, p.150-163, 2017. DOI: 10.5585/geas.v6i2.931

[21] MATTMANN M, LOGAR I, BROUWER R. Hydropower externalities: a meta-analysis. Energy Economics, v. 57, p. 66-77, 2016. DOI: 10.1016/j.eneco.2016.04.016

[22] VON SPERLING E. Hydropower in Brazil: overview of positive and negative environmental aspects. Energy Procedia, v. 18, p. 110-118, 2012. DOI: 10.1016/j.egypro.2012.05.023

[23] SICILIANO G, URBAN F, TAN-MULLINS M, MOHAN G. Large dams, energy justice and the divergence between international, national and local developmental needs and priorities in the global South. Energy Research & Social Science. Volume 41, p.199-209, 2018. https://doi.org/10.1016/j.erss.2018.03.029

[24] FEARNSIDE P M. Greenhouse gases emissions from Amazonia hydroelectric reservoirs: the exemple of Brazil's Tucuruí Dam as compared to fussil fuel alternatives. Environmental Conservation, v.214, n.1, p.64-75, 1997. DOI: https://doi.org/10.1017/S0376892997000118

[25] ZHAO X, WU L, QI Y. The Energy injustice of hydropower: Development, resettlement, and social exclusion at the Hongjiang and Wanmipo hydropower stations in China. Energy Research & Social Science v.62, 2020. https://doi.org/10.1016/j.erss.2019.101366

[26] WORLD NUCLEAR ASSOCIATION REPORT. Comparision of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources. July 2011.

[27] SANTOS M A. Inventário de emissões de gases de efeito estufa derivadas de hidrelétricas. Universidade Federal do Rio de Janeiro. Tese de Doutorado. Planejamento Energético. Rio de Janeiro, 2000.

[28] DE FARIA F A M, JARAMILLO P, SAWAKUCHI H O, RICHEY J E, BARROS N. Estimating Greenhouse Gas Emissions from future Amazonian Hydroelectric Reservoirs. Environmental Reseearch Letters, Vol. 10 n.12, 2015. DOI:10.1088/1748-9326/10/12/124019

[29] ASSUNÇÃO J, SZERMAN D, COSTA F. Efeitos locais de hidrelétricas no Brasil. Rio de Janeiro: Climate Policy Initiative, 2016. https://www.inputbrasil.org/wpcontent/uploads/2017/01/CPI__Estudo_Efeitos-Locais-dehidreletricas_no_Brasil.pdf. Access in 21 set. 2018.

[30] SGARBI F A, UHLIG A, GOLDEMBERG J E. An assessment of the socioeconomic externalities of hydropower plants in Brazil. Energy Policy. v.129, p.868-879, 2019. https://doi.org/10.1016/j.enpol.2019.02.072

[31] FREIRE L, LIMA J S, SILVA E V. Belo Monte: fatos e impactos envolvidos na implantação da usina hidrelétrica na região Amazônica Paraense. Sociedade e Natureza. Uberlândia, v.30, n.3, p.18-41, 2018. DOI: 10.14393/SN-v30n3-2018-2

[32] ALVES J, THOMAZ JÚNIOR A. A migração do trabalho para o complexo hidrelétrico Madeira. XII Jornada do Trabalho. Presidente Prudente (SP), outubro, 2012. ISNN: 9788560711192

[33] MARIN R E A, OLIVEIRA A C. Violence and public health in the Altamira region. Regions & Cohesion. Volume 6, issue 1, Spring, 2016, p.116-134. https://doi.org/10.3167/reco.2016.060106

[34] REIS J F G, SOUZA J L C. Grandes projetos na Amazônia: A hidrelétrica de Belo Monte e seus efeitos na segurança pública. Dilemas, revista de estudos de conflitos e controle social. v. 9, n. 2, 2016. ISSN: 2178-2792

[35] SILVA R C P. Qualidade de vida em Porto Velho, Rondônia: perspectivas do processo de desenvolvimento regional. Tese de doutorado. Universidade Federal do Pará. Núcleo de altos estudos amazônicos. Belém, 2013.

[36] CATOLICO A C C. Impacts of the implementation of Jirau and Santo Antônio Hydroelectric Power Plants: migrations movements in the municipality of Porto Velho. 23rd International Sustainable Development Research Society Conference, 2017, Bogotá, 2017.

[37] FOSCHIERA A A Conhecendo a Trajetória de Organização dos Atingidos por Barragens. Caminhos de Geografia (UFU), v. 11, p. 113-128, 2010. ISSN 1678-6343

[38] MAGALHÃES F J, SANTOS N. O instituto da compensação ambiental no contexto da multidisciplinaridade. Estudos, Goiânia, vol. 34, n. 11/12, 2007, p. 875-886. http://dx.doi.org/10.18224/est.v34i6.246

[39] SIEBEN A, CLEPS J. Política Energética na Amazônia: A UHE Estreito e os camponeses tradicionais de Palmatuba/Babaçulândia (TO). Sociedade & Natureza (UFU. Online), v. 24, p. 183-196, 2012. http://dx.doi.org/10.1590/S1982-45132012000200002.

[40] ZITZKE V A. A desterritorialização de populações pelos projetos de grande escala do setor elétrico no Tocantins: o caso da UHE de Estreito. In: I Simpósio nacional de geografia política, território e poder, Curitiba, 2009.

[41] SIGAUD L. Efeitos sociais de grandes projetos hidrelétricos – as barragens de Sobradinho e Machadinho. Universidade Federal do Rio de Janeiro. Programa de Pós-Graduação em Antropologia Social. 1986.

[42] SILVA R G C, NUNES D D, AMARA J J O, LACERDA M M C, SILVA J M, BATISTA J. F. Territorial politics in western Amazon: an approach on Madeira river hydroelectric project in Rondônia. Técnica Administrativa. V.07, n.1, Buenos Aires, 2008. ISSN-e 1666-1680

[43] VAINER C B. Conceito de "atingido": uma revisão do debate e diretrizes. Vidas Alagadas, 2008, p.39-63. DOI: 10.12957/dep.2015.12698

[44] ROCHA J. Usina Hidrelétrica de Estreito e desterritorialização: impactos sobre a saúde e resistência das famílias atingidas. Dissertação de Mestrado. Fiocruz. Rio de Janeiro, 2016.

[45] SILVA JÚNIOR. J. M. Uma retrospectiva da expansão do sistema elétrico na bacia do rio Tocantins, com estudo de caso na região de Lajeado – Palmas – Porto Nacional, (TO), 1996-2003. Dissertação de Mestrado. Universidade Federal do Tocantins. Palmas, 2005.

[46] GIUSTI F A B. Análise crítica do licenciamento ambiental de UHES na Amazônia brasileira. Tese de Doutorado. Universidade Federal do Rio de Janeiro. Rio de Janeiro, maio, 2014.

[47] HANNA P, VANCLAY F, LANGDON E J. The importance of cultural aspects in impact assessment and project development: reflections from a case study of a hydroelectric dam in Brazil. JO - Impact Assessment and Project Appraisal. 2016.
https://doi.org/10.1080/14615517.2016.1184501

[48] PARENTE T G, MIRANDA C M. Impactos socioculturais e gênero nos reassentamentos da Usina Luis Eduardo Magalhães – TO. Varia História. vol.30 n.53 Belo Horizonte, 2014.
http://dx.doi.org/10.1590/S0104-87752014000200011

[49] CDDPH. Conselho de Defesa dos Direitos da Pessoa Humana. Comissão Especial Atingidos por Barragens. Brasília, 2010.

[50] ARAUJO N C, MORET A S. Direitos humanos e hidrelétricas: uma análise dos impactos socioambientais e econômicos gerados em Rondônia. Veredas do Direito: Direito Ambiental e Desenvolvimento Sustentável, v. 13, n. 26, p.167-194, 2016.

[51] ZHOURI, A. Megaprojects, epistemological violence and environmental conflicts in Brazil. Perfiles Econômicos. V.5 p.7-33, 2018. DOI: https://doi.org/10.22370/rpe.2018.5.1235

[52] WANG Q G, DU Y H, SU Y, CHEN K Q. Environmental Impact Post-Assessment of Dam and Reservoir Projects: A Review. Procedia Environmental Sciences, vol.13, p.1439-1443, 2012.
https://doi.org/10.1016/j.proenv.2012.01.135

[53] STOLERMAN P, SANTOS S C, SILVA A A, FLORIANI N A implantação da Usina Hidrelétrica de Jirau no rio Madeira e os processos de desterritorialização em Rondônia. Terra Plural. Ponta Grossa, v. 8, n. 2, p. 371-387, julho/dezembro, 2014.
DOI:10.5212/TerraPlural.v.8i2.0007

[54] SEVÁ O. Estranhas catedrais. Notas sobre o capital hidrelétrico, a natureza e a sociedade. Revista Ciência e Cultura. v. 60, n.3. São Paulo, 2008. ISSN 2317-6660.

[55] GOMES H. Perfil epidemiológico de zoonoses nos municípios afetados diretamente pela usina hidrelétrica Estreito (MA). Dissertação de Mestrado. Pontífica Universidade Católica de Goiás. Pós-graduação em Ciências Ambientais e Saúde. Março, 2014.

[56] SHARMA S, WALDMAN J, AFSHARI S, FEKETE B. Status, trends and significance hydropower in the changing energy landscape. Renewable and Sustainable Energy Reviews 101, p.112-122, 2019. https://doi.org/10.1016/j.rser.2018.10.028

[57] FEARNSIDE P M. Impactos sociais da hidrelétrica de Tucuruí. Instituto Nacional de Pesquisas da Amazônia. 1999. DOI: 10.1007/s002679900248

[58] TAHSEEEN S, KARNY B. Reviewing and critiquing published aproches to the sustainability assessment of hydropower. Renewable and sustainable energy reviews, n. 67, p. 225-234, 2017. https://doi.org/10.1016/j.rser.2016.09.031

[59] BARROW C. The Impact of Hydroelectric Development on the Amazonian Environment: With Particular Reference to the Tucurui Project. Journal of Biogeography, v. 15, n. 1, Biogeography and Development in the Humid Tropics, p. 67-78, 1988. DOI: 10.2307/2845047

[60] RASHAD S M, ISMAIL M A. Environmental-impact assessment of hydro-power in Egypt. Applied Energy. V. 65, p.285-302, 2000. https://doi.org/10.1016/S0306-2619(99)00068-9

[61] ROSENBERG D M, BERKERS F, BODALY R A, HECKY R E, KELLY C A, RUDD J W M. Large-scale impacts of hydroelectric development. Environmental Reviews, v.5 p.27-54, 1997. https://doi.org/10.1139/a97-001

[62] CELESTINO L F, MAKRAKIS S. Barragens do Brasil e conservação de peixes migradores: o que aprendemos com a experiência do Alto Rio Paraná. Rios, Terras e Culturas: Aprendendo com o Sistema Socioecológico do Tocantins. Porto Alegre, RS: Editora Fi, 2020. DOI - 10.22350/9786587340197

[63] MMA, Ministério do Meio Ambiente. Caderno da região hidrográfica Tocantins – Araguaia, 2006.

[64] ANA, Agência Nacional de Recursos Hídricos. Planejamento de Recursos Hídricos. Plano Estratégico de Recursos Hídricos da Bacia Hidrográfica dos Rios Tocantins e Araguaia. Superintendência de Planejamento de Recursos Hídricos. Brasília, 28 de maio de 2009.

[65] CESTE. Consórcio Estreito Energia. Disponível em: http://uhe-estreito.com.br/. Access in 18 de novembro de 2019.

[66] CESTE. Consórcio Estreito Energia. Estudo de Impacto Ambiental, 2007.

[67] GERTLER P J, MARTINEZ S, PREMAND P, RAWLINGS L B, VERMEERSCH M J. Impact Evaluation in Practice. 2º Edition. World Bank Group. 2016.

[68] ITAU SOCIAL. Avaliação Econômica de projetos sociais. Fundação Itaú Social. 3ª edição. São Paulo, 2017.

[69] BOTELHO A, FERREIRA P, LIMA F, PINTO L M C, SOUSA SA. Assesssment of environmental impacts associated with hydropower. Renewable and Sustainable Energy Reviews, v. 12, n. 70, p. 896-904, 2017. https://doi.org/10.1016/j.rser.2016.11.271

[70] CAVALCANTE M M A, NUNES D D. Transformações Territoriais no Alto do Rio Madeira. Dissertação de Mestrado. Universidade Federal de Rondônia. Programa de Pós-graduação em Geografia. Porto Velho, 2008.

[71] MORAN E. Esquecendo as pessoas no desenvolvimento energético de Belo Monte e outras barragens. Rios, Terras e Culturas: Aprendendo com o Sistema Socioecológico do Tocantins. Porto Alegre, RS: Editora Fi, 2020. DOI -10.22350/9786587340197