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ACCESSES TO WATER, ELECTRICITY AND SUSTAINABLE DEVELOPMENT: EVIDENCE FROM THE AMAZONIAN STATE OF PARÀ*

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Abstract. According to the UN's Sustainable Development Agenda, to effectively achieve sustainable development, strategies for building economic growth should also address social needs, including access to essential services. Sustainable integrated management of water resources for both primary use and energy production is crucial, especially in territories such as the Amazonian State of Pará, where a primary good like fresh water is also the main source of electricity. However, the territorial transformations occurring in Pará over installing new hydroelectric plants have jeopardised local development. This was mainly caused by the top-down approach underlying national strategic projects that have paid little attention to local needs, thus paving the way for detrimental conditions for implementing the UN's 2030 Agenda. This paper aims to analyse the relationship between a municipality's level of development and quality of life and the most relevant key determinants of sustainable development in Pará. To this end, we consider a spatial regression analysis, with particular attention devoted to the role of access to both energy and water. The presence of significant spillover effects implies that providing public services on a geographically broad basis could induce self-reinforcing benefits.

Keywords: access to water; access to electricity; Amazônia Legal; sustainability; spatial regression analysis

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1. Introduction

The interdependence between energy consumption and economic growth has been extensively examined in the literature (Ozturk, 2010; Payne, 2010a; Payne, 2010b). For instance, Apergis and Payne (2012) find a bidirectional causality between energy consumption and growth, with both renewable and non-renewable energy consumption having a positive impact on real GDP in the long run and little difference in the elasticity estimates between the two energy sources. However, it is well known that "*GDP is not an expression of human development but only of economic growth*" (Sen, 1990). In this sense, the energy consumption-growth nexus does not necessarily provide insightful hints about the relationship between energy consumption and human

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development, significantly linked to the difference between consumption and access to services within a society. Per capita electricity consumption, for instance, aggregates the consumption of end users with that of the production system and does not provide information on users' access to energy services, thus hiding potential inequalities and enclaves (Magnani and Vaona, 2016).

In fact, according to the UN's Sustainable Development Goals – SDGs (United Nations, 2015) to effectively achieve sustainable development, strategies for building economic growth should also address a number of social needs like access to water and energy, as well as education, health, inequality, food availability, housing and job opportunities, while at the same time tackling climate change and environmental protection. Recall that all UN Member States adopted the 17 Sustainable Development Goals in 2015 as part of the 2030 Agenda for Sustainable Development; aims of the Goals include ending poverty, protecting the planet and improving the lives and prospects of all individuals. It is important to stress that all the Goals are interconnected, and sustainable development can be achieved in the long run only by considering them all. Goal 7, for instance, relates to making energy more sustainable and widely available; in this sense, energy production, which is a driver of economic growth (Ohler and Fetters, 2014), can also become a driver of sustainable development only if it is produced using sources that are sustainable for both environment and the humanity and if it is supported by the right infrastructure to facilitate access to it (Brand-Correa and Steinberger, 2017).

Interestingly, similar conclusions about the importance of an integrated management of development drivers are reached also within the *Water, Energy and Food Security Nexus* framework (Bonn2011 Nexus Conference, 2011), whose foundation is the interdependency between water, energy and food security and the underlying natural resources, *i.e.*, water, soil, land and related ecosystems. Global trends such as population growth and increasing economic prosperity could result in shortages of resources and failure to recognise the influence of one sector on another (decisions on the type of energy generation, for instance, can notably influence water demand) can prevent economic development, lead to social and geopolitical tensions, and damage the environment irreversibly.

Notice that a sustainable integrated management of water resources and energy production is crucial, especially in territories such as the Brazilian Amazon where a primary good like water is also the main source of electricity. Alternative uses of water may affect water quality and rivers' flow, impacting relevant fields like health (through the availability of clean water) or education (because of the use of rivers for mobility). Although hydropower is often considered a renewable technology, many doubts arise about its actual sustainability, especially for major projects not accompanied by coherent, supportive socio-environmental policies (Fearnside, 2016; Manyari and de Carvalho, 2007).

The present work focuses specifically on the Brazilian Amazon and, as a case study, considers the Federal State of Pará, the most significant hydroelectricity producer in the area. Notice that Brazil uses more renewable sources than the rest of the world. Its energy mix is 44,8% from renewable origin, while hydroelectric power accounts for 57% of the electricity matrix (EPE, 2021; ANEEL, 2019). The enormous endowment of water (and therefore energy potential) has fuelled economic growth, so Brazil became a major contributor to the global GDP (OECD, 2021). However, Brazil does not perform equally well from the point of view of human development, remaining far beyond the average of developed countries (UNDP, 2020). It is interesting to notice that this gap between growth and development also occurs within the Federal States such as Pará that are great energy producers, thus suggesting that production does not necessarily drag access and that energy production cannot be regarded as a sensible indicator of development (Conigliani et al., 2023; UNDP, IPEA, FJP, 2013). Thus, there is a need to further investigate the relationship between human development and access to water and electricity, which is the main objective of the present paper, while controlling for other relevant dimensions among those indicated by the UN's Sustainable Development Goals.

The paper is organised as follows. Section 2 will detail the characteristics of the case study and the rationale behind its choice in the context of what has been discussed so far on energy access, hydropower production and human development. Section 3 illustrates the variables that will be included in our analysis, taking into account the different dimensions of the UN's Sustainable Development Goals and the characteristics of the region we are considering, making some dimensions more relevant than others. Section 4 motivates the choice of the spatial regression model for investigating the relationship between human development and the different predictors in the Federal State of Pará. Finally, the results of the econometric analysis are discussed in Section 5, while Section 6 presents some conclusions and policy implications.

2. Regional background

Brazil's energy strategy has been influenced by its endowment of water resources well before any declaration of climate commitment. This led to hydropower specialisation and negligible diversification of the energy and electricity matrixes (Kileber and Parente, 2015). In fact, according to the energy ladder theory, countries are usually induced to progressively switch from polluting and exhaustible energy sources to clean and renewable ones; only in a more advanced development phase they should provide for energy diversification to meet the increasing energy demand and ensure countries' energy security (Kileber and Parente, 2015). Brazilian energy and electricity mix development have been following quite a different path due to the initial availability of renewable sources. After World War II, in particular, Brazil started installing hydroelectric power plants throughout the country, and from the 1970s onwards, the demand for energy increased due to both demographic growth and industrial development. This scenario drew attention to the Federal State of Pará, among the largest in the Brazilian Amazon (*Amazônia Legal*) and between two large catchments.

The abundance of water resources in Pará led to a significant national initiative, the *Grande Carajás Program* (da Costa and Filho, 1987) and to the installation of the Tucuruí UHE (UHE is the Brazilian Portuguese acronym for "Hydroelectric Plant"), the biggest power plant in Brazil at the time of opening in the mid-1980s, and to date still one of the largest. The project's objective was to increase the country's installed capacity and, at the same time, to enhance the urban development of a predominantly rural area (Rocha, 2008). In fact, almost 57% of the Brazilian electricity matrix is still supplied by hydroelectric power, and nearly 19% of this share is provided through Pará (EPE, 2021). Instead, from the point of view of the development of the region, the installation of the Tucuruí UHE led to mixed results. On the one hand, since the mid-1980s, the trend of economic growth in Pará has accelerated faster than the Country trend (IBGE, 2020). On the other hand, the Tucuruí UHE project led to water use conflicts, and most of the power generated by it has been supplying energy for multinational aluminium plants rather than reaching the households of those who live in the surrounding area through an efficient distribution infrastructure (Pinto, 2012).

Indeed, the Tucuruí UHE's environmental and social costs have been substantial, as has been the case for other hydroelectric infrastructures in the area (Scherer and de Oliveira, 2006). Environmental costs include forest loss, greenhouse gas emissions, hindrances to fish migration, and radical changes in aquatic ecosystems (Fearnside, 2001). Social costs include displacement of the population in the submergence area, collapse of the fishery that traditionally had supported the population downstream of the dam, health effects including malaria and mercury contamination, displacement and disruption of indigenous groups (Fearnside, 1999; Magalhães, 1990). It is estimated that over 32.000 people had to be dislocated from the submergence area of Tucuruí UHE and adjacent locations, in addition to the indigenous population; they consisted mainly of small producers whose subsistence activities were connected to riverine life and came essentially from family-based agriculture (Fearnside, 1999). Notice that some families were relocated in small lots with no access to water and electricity, far from roads or means of transportation; for others the compensation was a small amount of cash rather than land, or no compensation at all due to lack of land legal titles. It is also estimated that in 1985, one year after opening the plant, about 1500 families remained homeless (Fearnside, 1999). Note that the grave social tensions that derived from the lack of a real relocation plan were exacerbated by the attraction of the population drawn to the region because of the dam building, i.e., short/medium-run employment opportunities (Fearnside, 1999; Magalhães, 1990). In the long run, this process of territorial transformation, which paid little attention to decent housing with guaranteed access to essential services, appears to have paved the way for detrimental conditions for implementing the UN 2030 Agenda in Pará.

It is important to note that to investigate the relationship between human development and access to essential services such as water and electricity, which is the main objective of the present paper, we consider the whole State of Pará and not just the Tucuruí area. The first reason for this is that the impact of a power station can reach many neighbouring municipalities; this is an important point that, in fact, has also guided the choice of the (spatial) econometric model for the empirical analysis of Section 4. The second reason is that Tucuruí UHE is not the only national project realised in Pará (in accordance with the rationale of the *Grande Carajás Program*); in fact, other dams have been built in various locations in Amazonia to provide power to cities that Tucuruí could have supplied if the output of Tucuruí had not been allocated beforehand to the aluminium smelters (Fearnside, 2001). Ultimately, Tucuruí UHE is a model of centralised governance, which is not always positive for local realities but has been consolidated in Brazil since the Tucuruí UHE experience (Farias and Vilenha, 2021).

3. Data

The purpose of the present work is to analyse the role of selected key determinants of sustainable development in shaping the level of human development achieved by the Federal State of Pará municipalities, with particular attention devoted to access to basic services such as water and electricity. The different variables involved in the analysis are defined in Table 1 and were selected by considering both the setting of the UN's Sustainable Development Agenda and the socio-economic background of the case study, as detailed in Sections 1 and 2.

The data source is the *Atlas of Human Development in Brazil* (UNDP, IPEA, FJP, 2013), which is an open-source platform intended for gathering and processing data acquired by the Brazilian Institute of Geography and Statistics (IBGE) through the census surveys in 1991, 2000 and 2010 (on July 2023 IBGE released the first results of the Census 2022). The creation of the platform and its related database, which has been available for consultation since 2013, has been supported by the United Nations Development Programme (UNDP), also relying on the participation of the João Pinheiro Foundation (FJP) and the Brazilian Institute of Applied Economic Research (IPEA). The municipality disaggregation of the data within the *Atlas* allows for detailed socio-economic analyses supporting regional and local policies, which often suffer from a lack of data. In particular, the *Atlas* sets up dimensions of human development that are aligned with the Sustainable Development Goals. It provides a measurement of human development at the municipal level, the Municipal Human Development Index (MHDI), for each of the 5.570 Brazilian municipalities (UNDP, IPEA, FJP, 2013).

Table 1. Description of the variables involved in the analysis.

Variable		**Methodology**	**Reference to 2030 Agenda**
MHDI	Municipal Human Development Index	The geometric mean of three sub-indices representing the Income dimension (based on the municipal income per capita), the Health dimension (based on life expectancy at birth), and the Education dimension (based on the educational level of the adult population and of young people), with equal weights.	Crosscutting
Access to electricity	Percentage of the population living in households with electricity	Ratio of the population living in permanent private households with electric lighting to the total population living in permanent private households multiplied by 100. It considers the illumination coming or not from a general network, with or without energy meter.	SDG 7
Access to water	Percentage of the population living in households with bathrooms and running water	Ratio of the population living in permanent private households with water channeled to one or more rooms to the total population living in permanent private households multiplied by 100. Water may be provided by the general network, from a well, directly from the source or from reservoirs supplied by rainwater or by tank trucks for water.	SDG 6
Household density	Percentage of the population living in households with a density of more than 2 persons per dormitory	Ratio of the population living in permanent private households with a density greater than 2 to the total population living in permanent private households multiplied by 100. The density of the household is given by the ratio of the total number of dwellers in the household to the total number of rooms used as a dormitory.	SDG11
Exp years of education	Expectation of years of study at age of 18	Average number of years of study that a generation of children entering school must complete at age 18 if current standards are maintained throughout their school life.	SDG 3
Illiteracy	Illiteracy rate of the population aged 11 years and over	Ratio of people aged 11 years or over who cannot read or write a straightforward ticket to the total number of people in the same age group multiplied by 100. It is computed as the mean (weighted for population) of the illiteracy rates in four age groups (11-14;15-17;18-24; over 25).	SDG 4
Inequality	Gini index	Measures the degree of inequality in the distribution of individuals by household income per capita. It varies from 0 (no inequality) to 1 (maximum inequality). The universe of individuals is limited to those living in permanent private households.	SDG 10

Notice that the methodology used by UNDP to build the MHDI differs from that used for building the Human Development Index – HDI (UNDP, 1990) at the country level. Although it considers the same three dimensions, namely income, health and education, it adapts the global methodology to the Brazilian local socio-economic context and the availability of data. To evaluate education, in particular, the MHDI uses schooling of the adult population (i.e., the percentage of adults that concluded primary school) and school flow of young people (*i.e.* the percentage of young people that, depending on their age group, is attending or has completed primary school or secondary school), while the global HDI uses the average years of schooling and the expected years of schooling.

As underlined in the previous sections, the interest in analysing the determinants of human development in the Federal State of Pará relies on the fact that, despite the enormous endowment of water (and therefore of electricity) and despite the trend of economic growth that has been observed since the mid-1980s, from the point of view of human development Pará is still well below the Country standard. In fact, it went from being one of the 20 Brazilian states (out of 26 states plus the Federal District) with very low human development in 1991 (MHDI = 0.413), to being one of the 14 states with medium human development in 2010 (MHDI = 0.646), with all the remaining states having either high or very high human development. In 2017 Pará was still one of the four Brazilian federative units which did not manage to improve their human development index and were still classified as having a medium one (with MHDI = 0.698) (http://www.atlasbrasil.org.br/ranking). Interestingly, as shown by Figure 1, this poor performance of Pará from the point of view of MHDI has been consistently due to the education dimension, and in recent years also to income.

Note that the MHDI will be the response variable of our models in Section 4. In accordance with the discussion of Sections 1 and 2 about the abundance of water resources in the area and the hydropower production, the two main predictors that we selected among the key determinants of sustainable development provided by the 2030 Agenda are access to water and electricity. The evolution in time of these variables, as well as the comparison between the State of Pará and Brazil from the point of view of the different variables involved in the analysis, is shown in Table 2 and, despite a considerable improvement over time, emphasises the dramatic situation of Pará with respect to both facilities.

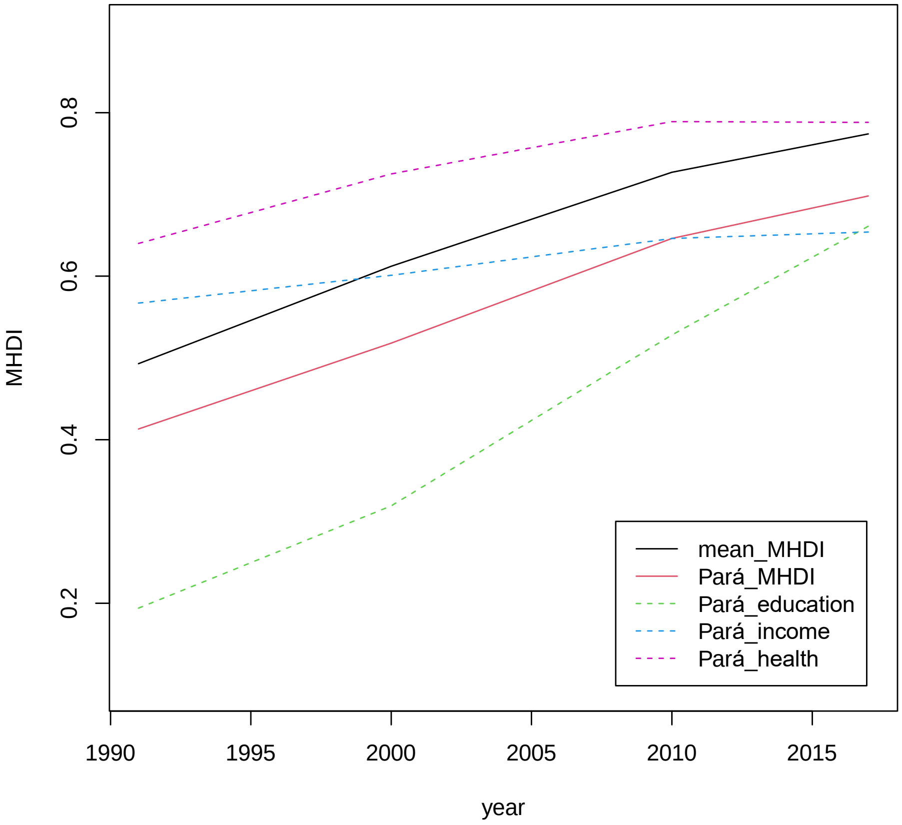

Figure 1. Federal State of Pará: MHDI and its constituents over time. Personal elaboration from UNDP, IPEA, FJP (2013).

Table 2. Federal State of Pará vs Brazil (mean values).

	1991		2000		2010	
	Pará	**Brazil**	**Pará**	**Brazil**	**Pará**	**Brazil**
Access to water	31.97	66.97	36.93	76.72	57.50	87.16
Access to electricity	63.99	84.84	76.73	93.46	91.89	98.58
Household density	71.37	50.08	61.04	39.13	49.40	27.83
Inequality	0.62	0.63	0.65	0.64	0.62	0.60
Exp years of education	6.48	8.18	6.80	8.76	8.49	9.54
Illiteracy rate – 11-14 years old	25.04	16.08	11.49	6.26	6.32	3.24
Illiteracy rate – 15-17 years old	15.85	12.42	7.16	4.85	3.55	2.20
Illiteracy rate – 18-24 years old	15.95	11.97	8.84	6.26	4.13	2.61
Illiteracy rate – 25 years old or older	29.14	23.45	21.29	16.75	14.98	11.82

Source: Personal elaboration from UNDP, IPEA, FJP (2013).

The next two predictors are both related to education, and their introduction into the analysis was justified by the crucial role of the education dimension for building the MHDI shown in Figure 1. They are the expected number of years of education at the age of 18 for children entering the school system and the illiteracy rate of the population aged 11 years and over. Notice that both variables pick up different aspects related to education with respect to those which enters the calculation of MHDI. Again, as emphasised from Table 2, Pará is doing worse than Brazil from the point of view of both expected years of education and illiteracy for all age ranges, consistently in time.

The last two predictors included in our analysis are the percentage of the population living in households with a density of more than 2 person per dormitory and the Gini inequality index. In fact, it is important to recall that both aspects, one related to housing and urbanisation and the other one to income inequality, have been and still are critical issues for the whole country (de Freita Barbosa, 2012). Housing, in particular, in Brazil is one of the main urban problems in contemporary times, and it is significantly linked to the urbanisation process that took place in the country (Monteiro and Veras, 2017). Interestingly, Brazilian urbanisation is a recent phenomenon, with rates that started increasing in the 1940s, reaching 84.36% by 2010. This strong urbanisation was due to both the growth of the Brazilian population (resulting from high birth rates and declining mortality) and an intense rural-urban migratory flow (resulting from the expansion of industrialisation in the cities, which attracted workers from the countryside, and from the modernisation of agriculture, which implied increased productivity). Industry, however, could not absorb all this contingent of workers, and the increase in the supply of urban services did not occur at the same rate as the growth of cities. The combination of these factors then led to the expansion of precarious, self-built housing settlements with no basic services and infrastructures, mainly in the more peripheral areas of the cities (Maricato, 2011). According to IPEA, the housing deficit in Brazil in 2012 was 5.24 million households. Although this problem has been affecting the whole country, Table 2 shows that it has been particularly dramatic in the State of Pará, both from the point of view of access to basic services such as water and electricity and to the percentage of the population living in domiciles with density greater than 2.

Notably, inequality is strongly related to the housing problem in Brazil. In fact, after being known as one of the most unequal countries in the world for decades (Chancel et al., 2022), with the northeast region having the worst situation, at the beginning of the new millennium, inequality started decreasing and fell consistently until 2014, when it began growing again, with labour earnings being at the core of both trends (Neri, 2018). Interestingly, Table 2 shows that income inequality is probably the variable among those included in the analysis that less distinguishes Pará from the whole country.

4. A spatial regression analysis

Recent Brazilian socioeconomic studies using data related to spatial units, such as municipalities or minimum comparable areas, are progressively embracing the spatial approach to econometric analysis (Lins et al., 2015; Reis, 2014; Barufi et al., 2012; Amaral et al., 2010; Magalhães et al., 2005). This is due to the fact that when the data exhibit spatial autocorrelation, i.e., correlation among response values due to the relative location proximity of the units, not taking it into account in formulating a regression model can lead to inconsistent and inefficient estimates (Elhorst, 2014; Baltagi, 2008).

Notice that different interaction effects can explain why an observation at a specific location may depend on observations at other locations (Elhorst, 2014). The first are endogenous interaction effects, where the response of a particular unit depends on the response of neighbouring units. The second are exogenous interaction effects, where the response of a particular unit depends on explanatory variables of neighbouring units. The third are interactions among the error terms, that represent for instance a situation where the determinants of the response omitted from the model are spatially autocorrelated. Also, notice that all these spatial interaction effects can be introduced in a spatial econometric model by means of a spatial weights' matrix, that is, by a negative and usually symmetric matrix *W* that describes the spatial configuration of the units in the sample.

Following Elhorst (2014), the General Nesting Spatial model (GNS), which include all possible interaction effects, can be written as:

$$\begin{aligned} Y &= \rho WY + a\iota_N + X\beta + WX\theta + u \\ u &= \lambda Wu + \bar{\mathrm{I}}\mu \end{aligned} \qquad (1)$$

where *WY* represents the endogenous interaction effect and ρ is the corresponding spatial autoregressive coefficient, *WX* represents the exogenous interaction effect and θ is the corresponding vector of parameters, *Wu* represents the interaction effect among the error terms and λ is the corresponding spatial error parameter, and ε is a well-behaved error term.

It is important to note however that the GNS model is usually over-parametrised, so that most empirical studies resort to simpler models that can be obtained from it by imposing restrictions on one or more of its parameters. In particular, among the models that include only two spatial interaction effects, we find the *Spatial Autoregressive Combined Model* (SAC), which assumes no exogenous interactions, the *Spatial Durbin Model* (SDM), which assumes no interaction effects among the error terms, the *Spatial Durbin Error Model* (SDEM), that assumes no endogenous interactions. Instead, among the simpler models, we find the *Spatial Lag of X model* (SLX), that only includes exogenous interaction, the *Spatial Autoregressive Model* (SAR), that only includes endogenous interactions, and the *Spatial Error Model* (SEM), that only includes interaction effects among the error terms (LeSage and Pace, 2009; Anselin, 1988; Elhorst, 2014).

Choosing the appropriate spatial regression model is indeed a critical step in conducting an effective analysis. Interestingly, one feature of the SAR, SAC and SDM, that include endogenous interactions, is that the spillover effects that they produce are global, in the sense that a change of a predictor in a particular location potentially impacts the response in all the locations, including those that according to *W* are not connected to it. In our setting this seems difficult to justify (Halleck Vega and Elhorst, 2015; Elhorst, 2017). Another limitation of the SAR and the SAC is that they impose restrictions on the magnitude of spatial spillovers, since the ratio between the indirect and the direct effect that they produce is the same for every explanatory variable, which is not very likely in many practical applications (Elhorst, 2014). Thus, the starting point of our analysis will be a SDEM, that includes exogenous spatial interactions and interaction effects among the error terms, that can eventually be simplified into one of the simpler models that it nests (namely the SLX and the SEM) if the spatial error parameter λ or the θ parameters corresponding to the exogenous interaction effects turn out to be not significant.

For our purpose, we consider data from three census years (1991, 2000, and 2010) and control for a possible time trend. Notice that as our sample is exhaustive, i.e., it consists of 143 units representing all the municipalities of the state of Pará, we find it appropriate to focus on fixed effects (FE) models rather than random effects (RE) ones, which assume that the units are representative of a larger population (Elhorst, 2014). The analysis is based on a 1st-order binary contiguity matrix, i.e., on a spatial weights matrix whose elements are equal to 1 if the corresponding municipalities have common borders (and therefore can be regarded as neighbours) and is equal to 0 otherwise. In what follows we will explore the behaviour of both a row-normalised spatial weights matrix and of a spatial weights' matrix normalised as in Ord (1975), that retains symmetry. Notice that the need to take into account the spatial configuration of the data in our case is confirmed by the Pesaran's CD(p) test for local cross-sectional dependence, i.e., dependence between neighbours, computed on the residuals of a fixed effects model with no spatial interaction effects, which rejects the null hypothesis of no cross-sectional dependence with a p-value < 2.2e-16 (Millo and Carmeci, 2011; Pesaran, 2021; Bivand et al., 2021).

Note that all our FE models have been estimated with the R package **splm** (Millo and Piras, 2012) with data stacked first by time period and then by cross-section. For purposes of comparison, we applied both maximum likelihood estimators, through the **spml** function, and the generalised moment estimators, through the **spgm** function; interestingly, the latter is designed to handle spatial models for panel data of short time dimension, as in the present case (Millo and Piras, 2012), but does not allow estimating the covariance of the spatial error parameter and testing its significance. Despite this difference, most of the parameter estimates obtained with the two methods are identical up to the fifth decimal; for this reason, in what follows, we will only show the results obtained with the **spml** function. Moreover, in acknowledging the fact that the standard technique for eliminating individual fixed effects, i.e., time-demeaning the variables, induces artificial serial correlation in the residuals that disappears as the number of time points diverges, but in short panels leads to biased estimates of the errors' variance (Millo and Piras, 2012), in **spml** we apply the orthonormal transformation of Lee and Yu (2010). It is also important to recall that with a large number of observations and a small number of time points, the incidental parameter problem may occur; however, this might lead to inconsistent estimates of the individual fixed effects but not of the model parameters (Millo and Piras, 2012).

5. Results

Table 3 shows the results obtained with the SDEM corresponding to a row-normalised spatial weights matrix and to a spatial weights matrix normalised as in Ord (1975); in both cases, as it is usual with the SDEM, the direct effects are represented by the β parameters and the spillover effects by the θ parameters of equation (1).

Table 3. Fixed effects SDEM: direct and spillover marginal effects corresponding to different normalised spatial weights matrices

	Row-normalised W		**Ord-normalised W**	
	Direct effects (β)	**Spillover effects (θ)**	**Direct effects (β)**	**Spillover effects (θ)**
Access to water $_{it}$	0.000721***	0.000643*	0.000724***	0.000575*
Access to electricity $_{it}$	0.000390**	0.000013	0.000364**	0.000058
Household density $_{it}$	-0.000776***	0.000160	-0.000795***	0.000347
Exp years of education $_{it}$	0.008051***	-0.002314	0.007458***	-0.006318
Illiteracy $_{it}$	-0.001932***	0.000103	-0.002020***	0.000347
Inequality $_{it}$	0.057778**	0.036031	0.061362**	0.038385
Dummy_Year_2000	0.070855***		0.075991***	
Dummy_Year_2010	0.144945***		0.164006***	
λ	0.352254***		0.376219***	
AIC	-752.1834		-755.4245	

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Various points arise from the analysis of the results of the fixed effects SDEM from Table 3. First, the two spatial weights matrices lead to very similar results, with the Ord-normalised one being preferred in terms of the AIC of the model. In both cases the spatial error parameter λ is significant, the only significant spillover effect is that corresponding to access to water, and there is a positive time trend, so that controlling for everything else, human development has been increasing over time. Moreover, the results confirm the positive relationship between human development and access to water (with total effects equal to 0.0014 and 0.0013 under the row-normalised W and the Ord-normalised W respectively) and access to electricity (with direct effects equal to 0.0004 under both spatial weights matrices), as well as the expected number of years of education (with direct effects equal to 0.0080 and to 0.0075 respectively). Notice that the significance and the positive sign of the spillover effect corresponding to access to water can be interpreted as evidence that the provision of water and sanitation on a geographically broad basis could induce self-reinforcing benefits. A similar finding in terms of the advantages deriving from appropriate regional policies can be found, for instance, in Barufi et al. (2012). The results of Table 3 also confirm the expected negative relationship between human development and the percentage of the population living in households with a density of more than 2 person per dormitory (with direct effect equal to -0.0008 under both spatial weights matrices), as well as illiteracy (with direct effects equal to -0.0019 and to -0.0020 respectively).

It is interesting to note that similar findings in terms of significance of accesses and education can be found in Barufi et al. (2012), that estimate a fixed effects SDEM to study the relationship between infant mortality rate (used as an inverse measure of human development) and different socio-economic and living conditions variables in Brazil between 1980 and 2000. One point on which our results differ from those in Barufi et al. (2012), and that is worth a few more considerations, concerns the relationship between human development and inequality, that in their case is negative while is positive in the results of Table 3.

In fact, there is a substantial literature assessing that inequalities in income distribution have an inverse U-shaped relationship with economic growth, so that the inequality increases in the initial phase of economic development and decreases in more advanced phases (Kuznets, 1955; Kuznets, 1963; Robinson, 1976; Barro, 2000). With reference to Brazil, the existence of this relationship has been verified for instance by Daudelin and Samy (2011) and da Silva Jr et al. (2016), while another part of the literature is critical of the Kuznets approach (Acemoglu and Robinson, 2002; Deininger and Squire, 1998). Our estimate of the inequality coefficient, that is positive and significant under both models, seems to support the Kuznets approach. However, in some sense also the negative relationship found in Barufi et al. (2012) is compatible with the Kuznets approach, as they take into account the whole country, that includes also areas with higher levels of both human and economic development.

6. Conclusions

Notice that although attention to access has not always been the focus of local policies in the study area, an increase in access to both water and electricity has been observed over time within the municipalities of Pará. It is also noticeable that this slow but consistent improvement has taken place also with respect to other dimensions, first and foremost education, as well as to the municipal human development index.

In the present work, the tie between accesses and development has been investigated by means of a fixed effect spatial regression model that found a significant and positive relationship. The results of our analysis confirm that integrated water and energy management strategies to ensure access are crucial for the national electricity sector to be able to drive also local development. In particular, the increase in MHDI observed in Pará over the two decades under consideration can be ascribed to improving living conditions mainly due to access and education. These results also suggest that a further increase of access to water and energy could be a valid driver to obtain higher levels of development, especially given the abundance of water resources present in the area (Lipscomb et al. 2013; Iorio et al., 2018; Monni et al., 2018; Iorio et al., 2019; de Souza et al., 2016). The detected spillover effects associated with water and sanitation indicate that providing these services on a geographically broad basis could induce self-reinforcing benefits.

Interestingly, as the starting point of the present work was the effect of hydropower on local development, it is worth concluding our analysis by recalling the taxonomy proposed by Magnani and Vaona (2016), who draw attention to the *energy justice* problem, which is threefold in terms of distribution, procedure and reconnaissance (Conigliani et al., 2023). In fact, according to Fearnside (1999), all three types of injustice occurred in the process of building the Tucuruí power plant. The displacement of people due to the diversion of the rivers or the inadequate allowances allocated to compensate losses in traditional economic activities, for instance, has led to a problem of *distribution justice*. The fact that indigenous reserves or protected areas have been directly or indirectly affected by unilateral decisions that were neither shared nor discussed with all possible stakeholders, on the other hand, has led to an issue of *procedural justice*. Finally, the lack of rural electrification in the area surrounding the power plant has led to an issue of *recognition justice* (van Els et al., 2012).

It follows that policies aiming at increasing sustainable development in this area should be oriented towards restoring energy justice, bearing in mind that allocating a valuable asset such as water for energy purposes can have a very high opportunity cost, especially in the presence of huge infrastructures. Measures such as providing compensations commensurate with the actual social and environmental changes or limiting the increase in the cost of energy for end users, for instance, may be useful to re-establish *distribution justice* (ABRADEE, 2018). Similarly, the enlargement of the low-voltage electrical network, i.e., the one linked to domestic consumption, could re-establish *recognition justice*, making rural electrification an effective driver of development (ONS, 2020). Finally, from the point of view of *procedural justice*, adopting a participatory process rather than a top-down approach could enhance both the economic and human development of areas like Pará. Hence, the pivotal role of education in human development processes arises from both our results and those of Barufi et al. (2012). As pointed out, for instance, by James (2017), education is crucial not just for human capital accumulation but also for boosting the participatory approach within a *capacity-building* framework.

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