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WATER, ENERGY AND HUMAN DEVELOPMENT IN THE BRAZILIAN AMAZON: A MUNICIPAL HUMAN DEVELOPMENT INDEX ADJUSTED FOR ACCESSES*

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Abstract. Thanks to its enormous untapped water potential, Brazil provides its electricity matrix with more than 60% hydroelectric power. This technology has had controversial impacts, which questioned its sustainability and stressed its likelihood to jeopardize the development of affected areas. We analyze here one of the main electricity producers: the state of Pará. By using a human development perspective, we integrate the Municipal Human Development Index (MHDI) with indicators of water and energy access through a principal components analysis. The comparison between the achievements of the municipalities affected and not affected by hydroelectric projects advocates policy makers to improve accesses in order to convey development, not just growth.

Keywords: energy access; Amazônia Legal; human development; Principal Component Analysis

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JEL Classifications: O13, O15, C23

1. Introduction

Hydroelectric power stations in Brazil meet roughly 60% of energy needs and 80% of electricity matrix (ANEEL, 2019). In recent years the enormous endowment of water (and therefore electricity) fuelled a significant economic growth, and Brazil became one of the major contributors to the global GDP (OECD, 2021). However, the level of development achieved by Brazil is still not comparable with that of the developed countries (UNDP, 2020; UNDP, IPEA, FJP, 2016 and 2019), and the gap between growth and development is significant also in Federal States that are great energy producers, such as the state of Pará.

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Notice that various authors investigating economic development stress the need to go beyond the ‘economic growth-energy consumption’ nexus and to empirically studying the relationship between human development and access to energy, especially in less developed areas (Brand-Correa & Steinberger, 2017; Magnani & Vaona, 2016, Rus et al., 2020). In fact, although the economic development is driven by the increase in energy consumption, which has a positive and significant effect on economic growth (Apergis & Payne, 2012; Ohler & Fetters, 2014), access to energy heavily affects fields related to human development like education and health (Kumar, 2018; United Nations, 2015). In fact, in particular where energy production is from hydro power, access to water as a primary commodity should also be taken into account for its effects on relevant fields like health (United Nations, 2015). Moreover, the exploitation of water resources aimed at increasing the production of energy may impact directly local reality, especially in presence of inadequate local development policies (Becker, 2005; Bielschowsky & Mussi, 2012; Lipscomb et al., 2013; Chehabeddine, Grabowska, Adekola, 2022). In fact, it might rise conflicts of use and force the adjustment of economic activities, thus creating an issue of access to water (Manyari & de Carvalho, 2007; Fearnside, 2016; Ioris, 2020) .

In the light of the above, the case of Brazil and of the Federal State of Pará is particularly interesting (Iorio & Monni, 2019). In fact, since the late 80s, when Brazil started shifting from fossils to renewable sources, its energy strategy has led to the intensive exploitation of areas like Pará for energy purposes of national interest (Iorio & Monni, 2018; 2021). This approach has been blamed to endanger environmental conservation and threaten local culture and economic activities (Costantini & Monni, 2008). Aim of this paper is to give empirical evidence of the role played by accesses to both energy and water on development. In particular, we discuss whether the Municipal Human Development Index (MHDI) provided by the Atlas of Human Development in Brazil (UNDP, IPEA, FJP, 2013) is an adequate measure of the human development at the municipal level in Pará (Alkire & Foster, 2011; Booysen, 2002). Notice that the MHDI is based on the same three dimensions of the global Human Development Index for countries (UNDP, 1990), namely income, education and health, but its calculation requires alternative specific indicators that better fits local reality (Sen, 1988).[†] After discussing the characteristics of the case study and the rationale behind its choice in Section 2, in Section 3 we consider the formulation of an alternative and more comprehensive municipal HDI that takes into account also other aspects of human life as suggested by the UN’s Sustainable Development Goals (United Nations, 2015), such as the access to water (Goal 6) and the access to energy (Goal 7). The analysis involves all 143 municipalities of Pará and three census years (1991, 2000, 2010). The analysis reinforces the conclusion that energy production cannot be considered as an indicator of development, since production does not necessarily drag access (UNDP, IPEA, FJP, 2013). Section 4 is dedicated to concluding remarks and ideas for future reflections.

2. Regional background: the State of Pará

Pará is one of the largest States in the Brazilian Amazon and it is located between two huge catchment areas, the Amazonas and the Tocantins. Because of this, it has great amount of water resources, almost all its municipalities are located near harbours (at present, river transport is a key part of the logistics of the State), and its hydroelectric potential corresponds to about 40% of the total potential of the area (Monni, Iorio, Realini, 2018; Eletrobras, 2017). However, in all the census years that we took into account, the human development of Pará has been unsatisfactory, and did not show much improvement over time: if in 1991 it had the seventeenth MHDI out of 27 Brazilian states, in 2010 it became the twenty-fourth (Iorio, de Miranda Rocha, Monni, 2021). In this sense, the

[†] 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 mean years of schooling and expected years of schooling.

State of Pará represents an interesting case study from the point of view of its economic and human development (Iorio & Monni, 2019).

In fact, according to the five development bands‡ defined by the *Atlas of Human Development in Brazil* (UNDP, IPEA, FJP, 2013), in 2010 Pará achieved an intermediate level of human development, with a MHDI equal to 0.646, having gained 0.233 points since 1991. This improvement, however, did not led the Federal State to reach the development level of Brazil as a whole, that went from having a very low (0.493) to a medium (0.612) MHDI in the decade 1991-2000, and reached a high (0.727) MHDI in 2010. Interestingly, this occurred despite Pará's economic growth (+56%) being greater than that of Brazil (+47%) in the period under consideration. Thus, the interest in understanding the role of accesses in shaping the level of human development in this region. In this sense it is interesting to look at Table 1, that for each census year shows the median, the minimum and the maximum for the percentage of population living in households with piped water and sanitation, that hereafter represents the access to water in the municipality, and for the percentage of population living in households with electricity, that hereafter represents the access to electricity in the municipality. The results, especially as far as access to water is concerned, are appalling: in 2010 still in half of the municipalities of Pará the percentage of population with access to water and sanitation did not reach 45%.

Table 1. Access to water and energy in the municipalities of Pará: descriptive statistics.

	Access to water			**Access to electricity**		
	min	**max**	**median**	**min**	**max**	**median**
1991	0,00	68,29	10,99	3,02	98,96	40,21
2000	1,26	73,68	15,39	22,44	99,50	61,05
2010	6,68	86,84	44,83	62,55	99,97	90,35

Source: Personal elaboration from UNDP, FJP and IPEA, 2013.

Looking in particular at the ten municipalities of Pará with the highest MHDI in 2010, we find that eight of them belong to large cities or metropolises with at least 51.000 inhabitants (IBGE, 2017), such as Belém (0.746) and Ananindeua (0.718), which have a MHDI comparable to that of the rest of the country. Not surprisingly, for all the municipalities in this subset, in 2010 the access to water and to electricity were at least 80% and 90% respectively. It is also interesting to notice that out of the three components that enter the MHDI, the lower one in most cases is that related to education. For example, in 2010 Belém scored 0.751 in MHDI-income, 0.822 in MHDI-health, and just 0.673 in MHDI-education. Similarly, Ananindeua scored 0.684 in MHDI-income, 0.821 in MHDI-health and just 0.658 in MHDI-education.

Conversely, focusing on the ten municipalities of Pará with the lowest MHDI in 2010, we find that only two of them are large cities, while the majority have less than 27.000 inhabitants (IBGE, 2017). The municipality of Melgaço, for instance, was the least developed of the whole country, with a MHDI equal to 0.418. Again, it is

‡ *Very low* - below 0.5; *low* – between 0.5 and 0.599; *medium* – between 0.599 and 0.699; *high* – between 0.699 and 0.799; *very high* - 0.8 and over (UNDP, FJP, & IPEA, 2013).

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interesting to notice that this bad result is determined in particular by MHDI-education (0.207) rather than by MHDI-income (0.454) or MHDI-health (0.776). However, it is also striking to point out that in Melgaço, in 2010, the access to water and to electricity did not reach 22% and 65% respectively.

This discussion suggests that the increase of energy production and growth observed at the national level in the last decades has not resulted in a structural development of the local context, with a few exceptions regarding large cities (Almeida Prado et al., 2016; Tundisi et al., 2014; Van Els et al., 2012). Moreover, it stresses the strong relationship between human development and accesses that motivates the interest in a more comprehensive indicator of human development.

3. A Principal Component Analysis for the formulation of a new municipal HDI

Principal Component Analysis (PCA) is a statistical technique that can be used to synthetize a set of (possibly correlated) observed variables into a smaller set of uncorrelated artificial variables that retain most of the information (i.e. the variability) contained in the original set. Here, in order to obtain a more comprehensive municipal HDI, we are going to apply PCA to a set of variables that includes both the usual dimensions of human development and new dimensions such as the accesses to electricity and water.

More in details, the variables included in our analysis are income per capita (Income_pc), life expectancy at birth (Life_exp), a human development index of education (HDEdu), computed as the geometric mean of the percentage of schooled adult population and the school flow of young population, as well as the aforementioned accesses to water and electricity.

The results are presented in Table 2 for the three census years 1991, 2000, 2010, and two points emerge clearly from it. First, in all three analyses the first principal component (PC1) resumes at least 61% of the total variability, and well accounts for both the original dimensions of the MHDI and the additional access variables. Moreover, looking at the correlation coefficients between the first principal component and the original variables, we can see that in all census years PC1 can be regarded as a direct measure of municipal human development adjusted for accesses, that in the following will be referred to as the adjusted MHDI.

Table 2. Correlation between PC1 and the original variables.

1991	**Access to water**	**Access to electricity**	**Income_pc**	**HDEdu**	**Life_exp**	**% Variability**
	0,876	0,846	0,740	0,903	0,520	0,63
2000	**Access to water**	**Access to electricity**	**Income_pc**	**HDEdu**	**Life_exp**	**% Variability**
	0,899	0,859	0,708	0,891	0,565	0,63
2010	**Access to water**	**Access to electricity**	**Income_pc**	**HDEdu**	**Life_exp**	**% Variability**
	0,777	0,840	0,826	0,875	0,523	0,61

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

Then it is interesting to compare the distribution of the standard MHDI and that of the adjusted MHDI in order to verify to what extent taking into account the accesses modify the measurement of the human development. Figure 1 shows the relative position of each municipality in terms of both the MHDI and the adjusted MHDI and points out that for all census years the two rankings are significantly related. However especially in 1991, when accesses

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in Pará were often limited, for some of the municipalities they differ significantly, with the MHDI displaying a higher human development with respect to the adjusted MHDI. Similar conclusions are reached when looking at the Spearman rank correlation coefficient, that for the three census years was equal to 0.9, 0.92, 0.95, thus showing that the strength of the relationship has been increasing over time (together with the accesses). This is an important point: on the one hand, the fact that the differences in the two rankings have reduced in the two decades is an indication that accesses in Pará have become more widespread, as it is confirmed by the median and the minimum of the two distributions shown in Table 1. On the other hand, it shows that when the accesses are limited, as in 1991, not taking them into account when measuring the human development can lead to misleading results.

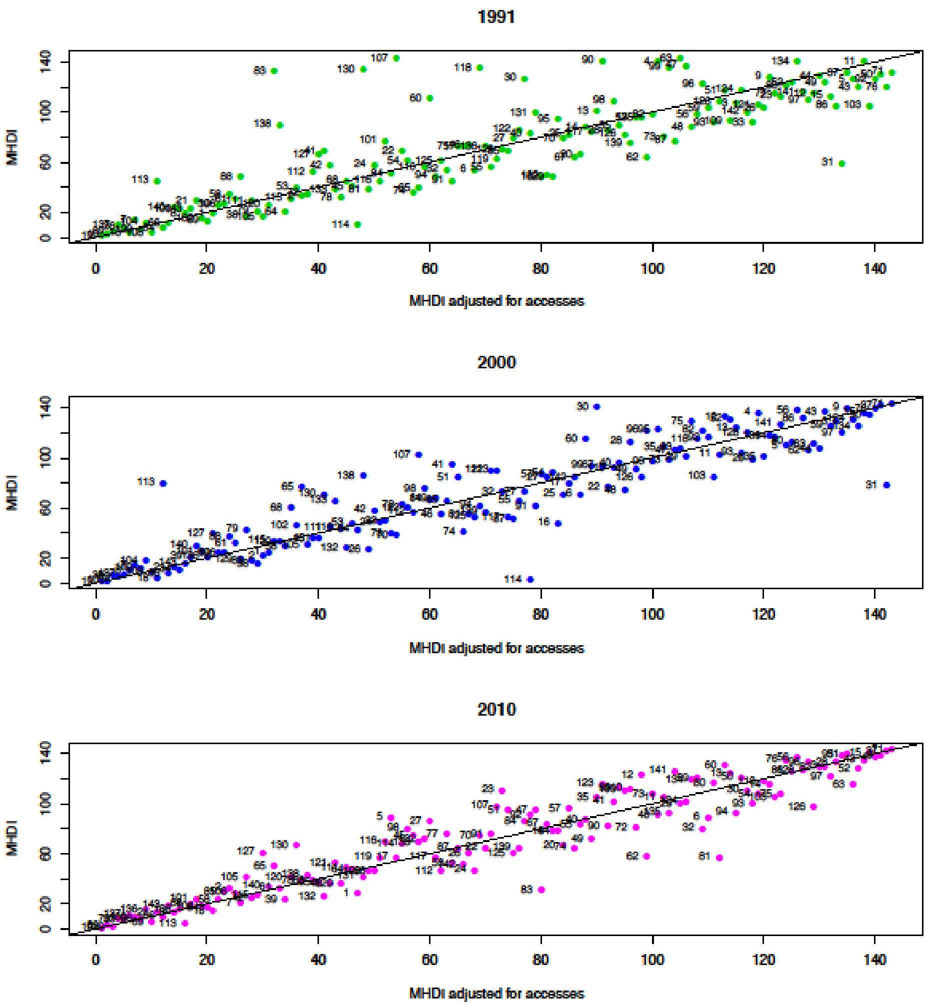

Figure 1. Comparing the rankings obtained with the MHDI and the adjusted MHDI
Source: Personal elaboration from UNDP, FJP, IPEA, 2013

Evidence from the micro-region of Tucuruí

The focus on the micro-region of Tucuruí, shown in the map in Figure 2, allows the observation of the socio-economic achievements of the area surrounding the biggest hydroelectric plant in Brazil in terms of production, that was built in 1984 (La Rovere and Mendes, 2000; Sudo, 2006). The relevance of this case study is even greater if we consider that the brand-new hydroelectric power plant of Belo Monte, which was built in 2016, is likely to reproduce the same development pattern (Fearnside, 2001; Pinto, 2012).

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In fact, if the enormous amount of water in the surroundings of Tucuruí allows the production of the electricity that supports the economic growth of the whole country, the 12 municipalities belonging to this area show a particularly low level of human development compared to the rest of the State, especially if this is measured by taking into account the accesses. In fact, looking in particular at 1991, which out of the three census year is the most critical from the point of view of accesses, we find that the maximum value of the adjusted MHDI in the micro-region of Tucuruí is less than half the corresponding value for the whole of Pará; interestingly, the same is not perceived by the standard MHDI, that in 1991 in the micro-region of Tucuruí is only slightly lower than the corresponding value for Pará.

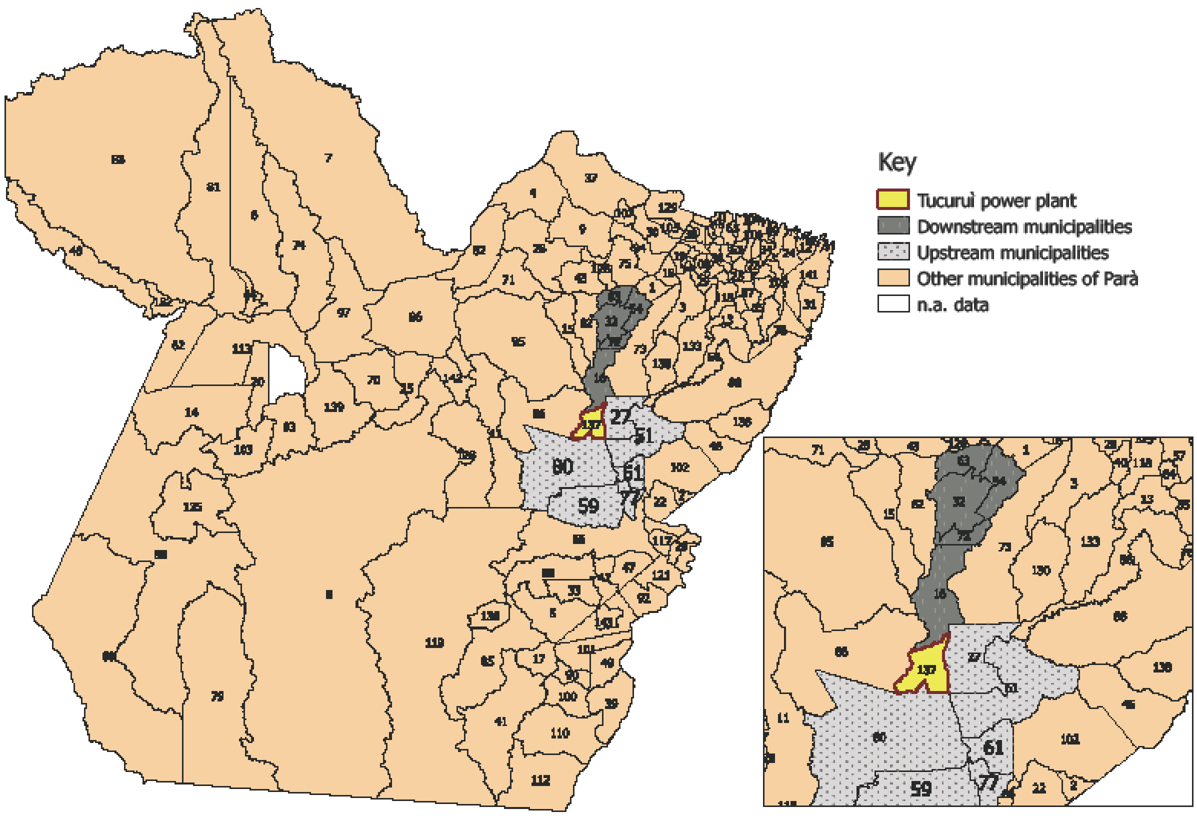

Figure 2. Contiguity map of Pará
Source: Personal elaboration from IBGE, 2017

It is also important to notice that in general, according to the literature, the social and environmental impacts of a hydroelectric power plant reach the municipalities both upstream and downstream the dam, with those located downstream suffering the most (Manyari & de Carvalho, 2007; Richter et al., 2010). This point is confirmed by the analysis of the adjusted MHDI in micro-region of Tucuruí. In fact, looking at the five municipalities located downstream[§], we find that only Baião was able to improve its adjusted MHDI in both decades (1991-2000 and 2000-2010), while Cametá showed an improvement only in the second one. Instead, looking at the six

[§] Baião, Cametá, Igarapé-Miri, Limoeiro do Ajurú, Mocajuba.

municipalities located upstream[**], in both decades we find that half of them improved their adjusted MHDI. It is also worth mentioning that Tucuruí itself in both decades was not able to improve its adjusted MHDI.

The analysis of the performance of the municipalities situated upstream and downstream the dam can also be strengthen by taking into account other aspects of human development that neither the standard MHDI or the adjusted MHDI consider. One example is inequality, that is typically measured by the Gini index. In fact, it is interesting to note that during the entire reference period, the value of the Gini index for the municipalities in the Tucuruí area was between 0.44 (in 1991) and 0.62 (in 2010), so that none of them achieved an *efficient inequality range* (Cornia & Court, 2001). In particular, looking at both the adjusted MHDI and the municipal Gini index, we find that in the first decade (1991-2000) there are no municipalities that were able to reduce the level of inequality, while four municipalities (Breu Branco, Goianésia do Pará, Nova Ipixuna, Baião) were capable of improving at least their adjusted MHDI, with only Baião being downstream. The remaining municipalities, that had a bad performance from the point of view of both dimensions, are equally divided between upstream and downstream. The second decade (2000-2010) shows an overall improvement, in that we find three municipalities (Breu Branco, Novo Repartimento, Baião) that over time achieved a gain in both dimensions, two of which are upstream. We also find four municipalities (Igarapé-Miri, Limoeiro do Ajuru, Mocajuba, Tucuruí) that had a bad performance from the point of view of both dimensions, three of which are downstream. Of the remaining municipalities, with the sole improvement of access conditions or inequality, one is downstream and four are upstream.

Thus, in spite of the improvements registered in the second decade, the joint analysis of the adjusted MHDI and the Gini index of inequality seem to confirm previous insights: the municipalities located downstream the dam end up suffering more from the impacts of hydropower than those upstream.

4. Discussion and conclusions

As pointed out in the Introduction, aim of the present work was to investigate the existence of a ‘development-access’ nexus. Our analysis shows that accesses are indeed important for economic development. In fact, the case of Pará, in the Brazilian Amazon, reveal that the accesses to water and electricity are not widespread, so that it is necessary to adjust the standard MHDI in order to get a more suitable and comprehensive measure of human development. This has been attempted in Section 3 through the use of a Principal Component Analysis.

The analysis of the micro-region of Tucuruí, in particular, that highlighted the strong spatial correlation between accesses and human development, suggests further investigating this relationship within a spatial regression model. This will be object of future research.

Focusing specifically on the issue of access to energy, it is worth recalling the taxonomy proposed by Magnani & Vaona (2016), who draw attention to the *energy justice* problem, which is threefold in terms of distribution, procedure and reconnaissance. First of all, there is no *distribution justice* if there is no proper sharing of costs and benefits deriving from the application of technologies for energy production, which mainly represents the opportunity cost for the use of water. This is for example the case of the displacement of people due to the diversion of the river, or the case of the depletion of the local biodiversity, in addition to the inadequate compensation allocated to compensate losses in traditional economic activities (Caravaggio et al., 2017). Secondly, there is no *procedural justice* (which requires the use of fair and transparent decision-making procedures for the sake of the inclusion of all possible stakeholders) whenever indigenous reserves or protected areas are directly or indirectly involved by the unilateral decision that is neither shared nor duly discussed (Herrera, 2019). Finally, there is no *recognition justice* when the heterogeneity of the needs of the beneficiaries is

[**] Breu Branco, Goianêsia do Pará, Itupiranga, Jacundá, Nova Ipixuna and Novo Repartimento.

not recognized neither taken into account, as in the case of lack of rural electrification (Van Els et al., 2012). According to Fearnside (1999), in the process of building the Tucuruí power plant, that is the main hydroelectric plant in the State, all the above described injustices occurred. It follows that policies aiming at increasing human 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 adapting compensation to the real needs arising from social and environmental changes or limiting the increase in the cost of energy for end users may be useful to re-establish a *distribution justice* (ABRADEE, 2018). Otherwise, the enlargement of the low-voltage electrical network, i.e. the one linked to domestic consumption, is pivotal to boost development in rural areas, especially when these surround large power plants as in the micro-region of Tucuruí. This kind of intervention 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 the human development of areas like Pará. Hence the pivotal role of education in human development processes, that arise both from our results and from those of Barufi et al. (2012). In fact, education it is not important just for human capital accumulation, but it can also have a role in terms of boosting the participatory approach within a *capacity building* framework (James, 2017).

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