LETTER

The power of light: socio-economic and environmental implications of a rural electrification program in Brazil

Paula Borges da Silveira Bezerra, Camila Ludovique Callegari, Aline Ribas, André F P Lucena, Joana Portugal-Pereira, Alexandre Koberle, Alexandre Szklo and Roberto Schaeffer

Energy Planning Program, Graduate School of Engineering, Universidade Federal do Rio de Janeiro, Brazil

E-mail: roberto@ppe.ufrj.br

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Abstract

Universal access to electricity is deemed critical for improving living standards and indispensable for eradicating poverty and achieving sustainable development. In 2003, the ‘Luz para Todos’ (LpT—Light for All) program was launched aiming to universalize access to electricity in Brazil. The program focused on rural and isolated areas, also targeting to bring development to those regions along with electrification. This paper evaluates the results of the LpT program in improving socio-economic development in the poorest regions of Brazil. After an initial qualitative analysis, an empirical quantitative assessment of the influence of increased electrification rates on the components of the Human Development Index (HDI) is performed. The empirical results of this study showed that electrification had a positive influence on all dimensions of the HDI, with the education component having the strongest effect. Although complementary policies were needed to achieve this, results show that electricity access is a major requirement to improve quality of life.

1. Introduction

Some 13 million people did not have access to electricity in Brazil in 2000. This represented 7% of all households in the country, around 3 million. The situation became even more alarming when considering the distribution of such households according to their income and location. From the aforementioned 3 million households, approximately 2 million were located in rural areas. This represented 29% of rural homes in Brazil at that time. Depending on the region, these numbers also varied significantly: around 1% of the Southeast’s households did not have access to electricity, while in the North almost 18% were in that situation (IBGE 2000).

Electrification provides a solid basis for development of local communities. Once a community has access to electricity, it can also have access to safe potable water, better health conditions, food security, as well as lighting and information. In addition, it reduces the need for collecting and using other traditional sources of energy, such as firewood, animal dung, and crop residues for cooking and heating (Goldemberg et al. 2000), which cause harmful indoor air pollution (WHO 2014). In poorly ventilated dwellings, indoor smoke can be 100 times higher than acceptable levels, causing significant health damages (WHO 2016). Access to electricity not only releases people from hard work, but also increases productive working hours and provides opportunities for self-employment, in particular for women in rural areas (Dinkelman 2011).

Universal access to electricity is not only critical for improving living standards but deemed indispensable for eradicating poverty and achieving sustainable development (GNESD 2007). Because this is widely accepted today, ensuring universal access to affordable electricity by 2030 was incorporated directly in the Sustainable Development Goals (UNGA 2015). Increasing income by itself cannot guarantee some basic services and needs and cannot improve living conditions if it is not combined with infrastructure (UNDP 2002, Cook 2011).

A National Program of Universalization of Access and Use of Electricity (Light for All), the ‘Luz para Todos’ (LpT) program, was launched by the Brazilian government in 2003 with the goal of extending access to electricity to all rural communities in the country.
Some studies evaluated the extent to which the LpT program increased income and promoted the social inclusion of benefitted communities (Coelho and Goldenberg 2013, Gómez and Silveira 2012, Pereira et al 2010, Slough et al 2015). However, there is a lack of formal empirical assessments that attempted to quantitatively measure the socio-economic improvements associated with the LpT program.

This paper evaluates the results of the LpT program in improving socio-economic development in the poorest regions of Brazil. To do so, an initial qualitative analysis is made based on existing data, literature and assessments of the program. On a second stage, an empirical quantitative assessment of the program’s results is performed, which contributes to the existing body of analysis on the impacts of rural electrification in the country.

This paper is organized in five sections. Following the introduction, a background section overviews the socio-economic context of the LpT program and its policy framework. From this point, in section 3, implications for economic, social and environmental development are unveiled qualitatively. Section 4 details results of the empirical assessment conducted to quantitatively measure the socio-economic improvements associated with the program. This is followed by final remarks.

2. Background

Inequality in access to electricity was a reality since the introduction of this basic service in Brazil. It is hard to say precisely when the Federal Government started to put efforts on the electrification process. In fact, electricity came as a natural consequence of the urbanization process that occurred during the 1940s and 1950s. With low population density and large distances between properties, rates of electrification in rural areas have always been lower than in urban regions (Bittencourt 2010).

The first efforts to promote rural electrification in Brazil started with the creation of rural cooperatives, after the 1940s. Rural cooperatives were an initiative created by local communities to be able to finance the installation of transmission lines and guarantee access to electricity. During the decades that followed, other initiatives took place, for instance: the Rural Electrification Fund (FUER—Fundo de Eletrificação Rural, in Portuguese), created in the mid-1950s; the Executive Group for Rural Electrification (GEER—Grupo Executivo de Eletrificação Rural, in Portuguese), created in 1970; the First and Second National Rural Electrification Plan (PNER—Plano Nacional de Eletrificação Rural, in Portuguese), implemented during the 1970s; the Program for Energy Development of States and Municipalities (PRODEEM—Programa de Desenvolvimento Energético de Estados e Municípios, in Portuguese), launched in 1994; and later the Light in the Countryside (Luz no Campo, in Portuguese), created in 1999.

Figure 1 shows the rate of electricity access in Brazil between 1950 and 2000. Despite the evolution observed after the 1970s, there were still significant differences between the level of electrification in urban and rural areas. In 1991, 97% of the population of urban areas already had access to electricity, while, in the countryside, this number did not reach 50% (ANEEL 2005).

2.1. The national program of universalization of access and use of electricity—LpT (Light for all)

In November 2003, the LpT Program was established by decree Nº 4873 (Fugimoto 2005). The program was coordinated by the Ministry of Mines and Energy (MME) and came as a consequence of Law 10 438 of 2002 that had set parameters to guarantee universalization of electricity. The program aimed to increase the electrification rate in the country, providing power to 10 million people until 2008, especially those living in rural areas (Brazil 2003). This was the first social oriented electricity access policy in Brazil, in which

For a detailed description of these programs, see Gómez and Silveira (2010) and Borges et al (2016).
beneficiaries did not have to contribute financially (Goldemberg et al 2004). To meet this initial goal, US$ 2.3 billion were invested. The program was extended first until 2014 and more recently until 2018 (MME 2017). Until May 2016, it had reached 15.6 million people, with an overall investment of US$ 7 billion.

Rural electrification was seen by the government as a key element to achieve social development in rural areas. Thus, projects with higher social development outcomes were highly ranked and prioritized, when compared to those with limited social benefits. New electricity demand was identified through the so-called *Luz para Todos*’ agents (LpT agents). These agents worked close to local communities, informing about the program execution and its benefits. During the work execution, LpT agents were also responsible for identifying, together with communities, possible productive uses for electricity and complementary actions of social inclusion. Besides, these agents acted as a communication channel between local citizens and program executors. Rural populations were able to request new electrical connections through the LpT agents. In this way, communities were partially involved in the program’s decision-making process, helping to recognize population needs for demand and productive applications of electricity in the region. Also, utility companies conducted educational and awareness campaigns about appropriate, efficient and secure use of electricity (Gómez and Silveira 2010).

Technically, the program focused on low-cost transmission and distribution grid extensions. Alternatively, where connection to the grid would not be feasible, electricity could come from decentralized generation grids in isolated systems. To be approved, the construction plan had to detail the technical, material and equipment criteria to be used.

Decentralized generation projects must be cost competitive with grid extension to be endorsed (MME 2004). Also, for decentralized and isolated system generation, the projects must consider environmental aspects, end-user capacity building, and overall sustainability. The technological options for off-grid generation foreseen by the program are hydro, wind, diesel fuel and biomass, with special focus given to solar in recent operational manuals. The program, therefore, did not clearly promote the deployment of renewables until recently. This is, actually, one of the critical aspects of Brazil’s universal energy access strategy.

After the initial period of the program (2004–2008), LpT was extended four times. During the initial execution, between 2004 and 2008, the program could not reach its initial target of providing access to 10 million people. In addition, agents also identified a higher number of families with no access to electricity than the number accounted for in the year 2000 census. This new demand was related to population growth, not considered before, and to the return of some families to rural areas. These facts led to the implementation of new phases of the program, continuing it and setting new targets (MME 2008).

Table 1 summarizes the initial targets and achievements of each phase of the LpT program.

Table 1. Summary of the different stages of the LpT program.

| Phase | Period | Goals and achievements |
|-------|--------|------------------------|
| Phase I | 2004–2008 | Provide universal power access to rural communities not connected to the grid. |
| Phase II | 2008–2010 | Provide power access to 1 million families that had not been connected in the first stage, reaching almost 3 million households. |
| Phase II extension | 2010–2011 | Provide electricity access to isolated communities, areas with no connection to distribution lines, low population density, difficult access and poor infrastructure, reaching further 1.7 million new electrical connections. |
| Phase III | 2011–2014 | As the majority of the population already had access to electricity, the focus of this extension was to reach communities living in areas with significant logistic and infrastructure difficulties, particularly in the North and Northeast regions. The target for the period was the connection of 795 000 new households (MME 2011). |
| Phase IV | 2014–2018 | Expected to provide power access in isolated areas and the Amazon region. |

Source: Borges et al (2016).

As noted further in section 2.2, the program’s operationalization prioritized grid extension. Until 2014, new connections entailed primarily grid extensions with less than 1% involving installation of isolated individual systems. After regulatory framework on the use of isolated micro-grids was introduced in 2012, distribution utilities started to plan for the installation of isolated systems to reach the population without access to electricity, about 30 000 families according to government estimates from December 2014 (MME 2017).

The distribution utilities, as executing agents, are responsible for complying with these requirements. To provide guidance and support them, Eletrobras, the institution managing the program, established a technical cooperation project with the Inter-American Institute for Cooperation on Agriculture (IICA) in 2009 (Eletrobras 2015). Capacity building is deemed a critical barrier to the electrification of isolated areas in Brazil both at the utilities’ and end-users’ levels (Valer et al 2017).
2.2. Challenges and overall evaluation
Despite the impressive numbers of the LpT program, the target of giving electricity access to all of the Brazilian population has not been achieved yet. The extension of the grid could readily benefit a significant number of people, but as the grid extension approaches its physical and economic limits, reaching some areas becomes difficult or even unfeasible. Therefore, universalization goals become increasingly difficult to achieve (Gómez and Silveira 2015).

The Brazilian national grid structure has a centralized structure, concentrated on the coast, which is very effective to meet industrial consumers and urban area needs, but fails to promote electrification of isolated communities, especially in the Amazon region. This structure makes connecting island regions to the grid a hard task and a challenge to reaching households far from urban centres in a vast country of continental dimensions. In terms of institutional structure and operations, LpT prioritized the extension of the grid (Slough et al 2015).

As the program proceeded, the need for off-grid solutions increased. The program reached its limits in connecting areas closer to the grid and the average cost per connection increased, creating a challenge to take electricity to isolated areas far from the existing grid. In this context, less expensive technological alternatives should be considered, since utilities would pressure for high tariffs to compensate this adverse situation (Di Lascio and Barreto 2009). Capital costs to electrify most isolated communities can be twice as high than new grid connections (Sanchez et al 2015).

Observing the connections made by year, it can be noted that fewer new connections were made as time passed (figure 2). After 2010, Brazil achieved a 98.6% electrification rate, but the remaining 1.4% became harder to reach. The third phase of the program, after 2011, faced this challenge, and the connections in 2013 and 2014 were lower than 100,000 yr⁻¹.

According to Pereira et al (2010), in order to reach isolated communities it is necessary that decision makers work together with regulatory agencies, universities and research centres. The efforts must include the development of cleaner technologies and improvement of management models, respecting the cultural, economic and environmental aspects of using renewable technologies in a decentralized or self-generation manner.

In the case of the Amazon region, challenges are even harder. The region has an extensive area with a complicated topography, surrounded by rivers and highly dense rainforest. In addition, it has a very small and low-density population with low-income levels, and mostly concentrated in rural areas (Gómez and Silveira 2015). These particular characteristics pose specific challenges to providing electrification in that area. The people that already have access to electricity are concentrated in regions with previously existing physical grid infrastructure. Cities and communities are mostly located in regions of high deforestation, with highways and agriculture, which facilitated the connection with the national electric grid. However, this is not the case for many parts of the region (Di Lascio and Barreto 2009).

Currently, there are mainly three obstacles to foster universal access to electricity in remote areas. The first one is the need to adapt the existing institutional structures. The second is the choice of technology or supply solutions that comply with the local environment and infrastructure. The third one is a more effective use of government funds within the context of the current subsidy scheme. A new rural electrification model in which local, resource-based technologies are supported by an adapted institutional framework and existing funding structures is needed to reach this last mile (Gómez and Silveira 2015). Finally, a major challenge is related to guaranteeing the continuity of electricity affordability for low-income households benefitted by LpT after the end of the Program. Actually, electricity affordability is being sustained by cross-subsidies provided by the Brazilian interconnected electricity system, in order to compensate the higher costs incurred by local power utilities to serve remote areas. After 2018, it is not yet clear whether and how these subsidies will be maintained (Brazil 2016b).

3. Implications for economic development, social welfare and environmental sustainability
The LpT program exceeded the initial target of providing electricity access to 10 million citizens. During its 10 years of execution, the program...
reached over 3.3 million households, equivalent to more than 15 million people (MME 2017). More than enabling access to electricity, an important benefit of the program was recognizing electricity supply as a way to promote social and economic development in less developed regions of the country. The program was a key component of the national strategy for poverty reduction, sustainable development and reduction of social inequality (Gómez and Silveira 2010).

Therefore, the results of electrification projects should not be measured just by the number of new households connected, but also by the social and economic benefits promoted by electricity access. Identifying social, environmental and infrastructure evolution caused by the implementation of the LpT policy is critical to understanding the welfare improvement and evaluating the return of the capital invested in the program (Gómez and Silveira 2010). Table 2 identifies potential improvements to welfare associated with electricity service in rural areas (Motta and Reiche 2001).

Table 2 shows that electricity uses are associated with many dimensions of development. Not only can the population have the choice of consuming electrical appliances, but also education and health improvement can be achieved. Moreover, electrification can change the local reality in terms of social, economic and environmental aspects.

### 3.1. Environmental aspects

Access to electricity can change in many forms the way of living in a community. In addition to social and economic impacts related to electrification, there are also some environmental impacts. One of the main choices in the electrification process is which energy sources to use in isolated areas, where grid connection is not possible.

Electricity generation in Brazil is highly based on renewable energy sources. In 2014, 77.2% of total electricity supply was provided by renewables sources. This contrasts with only 28.2% in isolated areas, where fossil fuels are responsible for 71.8% of electricity generation. To supply the county’s electric system in 2014, 78.30 MtCO2 were emitted, from which almost 10% came from isolated systems where electricity consumption is only 0.8% of total demand in Brazil. In that sense, the choice of supply source for isolated systems is critical for improving energy access without increasing total greenhouse gas emissions (EPE 2015).

Historically, thermal-power plants fuelled by diesel were the main supply choice for isolated systems, but renewable energy systems are being increasingly regarded as a favourable option for providing power to isolated communities. Despite the higher capital cost, generation from renewable sources can have lower operational costs. When considering local realities of isolated communities, the use of renewable energy options can be a preferable solution to providing electricity access (Di Lascio and Barreto 2009, Gómez and Silveira 2015, Sanchez et al 2015).

The use of government incentives in the form of laws, technological research and institutional frameworks is important to change the current fossil-fuel-based generation in isolated communities (Pereira et al 2010). The LpT program can be considered as a mean to foster the use of renewable energy sources. In November 2008, the MME promoted activities to assist local utilities in developing and implementing small projects for electricity supply using renewable energy sources. These activities were executed with the support of Inter-American Development Bank and focused on training professionals and utilities to find solutions based on local capacities for using alternative energy sources (Barreto 2008).

### Table 2. Electricity service related to improvements in types of uses.

| Household social and community uses | Productive uses | Education uses | Health uses | Public administration uses |
|-------------------------------------|----------------|---------------|------------|---------------------------|
| Improved quality of life (light, TV, radio). Light: children and women gain additional time at night (reading, homework); improved light quality (200 times brighter) and cost per lumen; reduced cooking times and easier cleaning due to illuminated room; increases productivity for self-consumption. Safety: street lighting allows children and women to socialize at night; facilitates community activities (light, TV, radio, discotheques); potential effect on birth rates. | Raises productivity; increased profit and employment e.g. light extends work time; electricity allows applications such as water pumping (irrigation), soldering, motive applications (drilling, sawing, mills), cold chain (e.g. for small shops and restaurants, milk processing, beef storage), fish ponds, electric fences, video, cinemas, etc, permits use of ICT. | Studying at night; adult education; allows retention of qualified teachers. Schools can serve as anchor clients for service providers. Subsidizing public services is an efficient way of targeting subsidies with reduced free rider effects. | Light for emergencies, childbirths, vaccine fridges; HIV. Domestic light seems to be correlated with more whitewashed walls and fewer insects. | Allows for more efficient public administration. Increase working time and improves quality of service. |

Source: Motta and Reiche (2001).
Also, after 2009, the LpT program launched special project guidelines with the main objective of developing the use of renewable energies in areas with difficult access, by preferably funding projects in isolated regions with the use of renewable energy sources considering the regions’ potentials. There is a significant potential for increasing electricity access in isolated systems through the use of PV, biomass, and small hydro. In addition to being appropriate to local reality, these projects also guarantee electricity supply with lower environmental impacts, and energy independence for the communities (Di Lascio and Barreto 2009). Sanchez et al (2015) evaluated the most significant rural electrification projects using renewable sources in isolated areas of the Brazilian Amazon region during the first stages of the LpT program (2003–2011). These projects showed the convenience of substituting, totally or partially, the use of diesel, which had to be shipped in. More importantly, they showed that electricity generation from local renewable sources is a way of empowering disadvantaged communities, giving them energy independence along with the benefits of electricity access.

Pereira et al (2010) compared the energy consumption mix of an average household before and after getting access to electricity (figure 3). Before access to electricity, LPG, firewood and diesel combined represented 58% of total energy demand, the remaining 42% was due to the use of charcoal, gasoline, kerosene and others, from a total of 5.16 GJ yr$^{-1}$ per capita. After getting access to electricity, the total consumption increased 28%, and the share of those energy sources dropped to 65%. Also, it is worth highlighting the fast penetration of electricity, reaching 34% of the average energy consumption basket. The control group confirmed that electricity access was responsible for this change in the composition of the average household’s energy basket.

Changes in the energy basket used by households were also observed in a national survey made in 2013 with beneficiaries of the LpT program. This survey showed a transition in a family’s energy basket from kerosene lamps and candles as the main sources of lighting. After accessing electricity, family expenses with kerosene, diesel, oil, gas and batteries dropped to half the initial values, indicating a substitution of fossil fuel sources by electricity (MME 2013).

Concerning land use impacts, electrification can have two opposing effects as a result of changes in agricultural productivity. Electricity access can lead to an improvement in agricultural productivity, as it allows a more efficient irrigation with the use of water pumps, as shown in Assunção et al (2015). The study suggests that a 10% increase in electrification could lead to a 0.66% increase in the proportion of farms with irrigation and a 9.8% increase in agricultural production per hectare.

However the same study found that such improvements can lead to two opposing effects on the protection of forests and native vegetation: (i) an expansion of farm size and/or frontier land conversions, and (ii) a shift away from cattle ranching, which is more environmentally destructive, and into crop cultivation, allowing farmers to retain more native vegetation within rural settlements. Even though the authors estimated that electrification caused a small net decrease in deforestation in a specific region in Brazil, decreases in deforestation cannot be correlated to higher electricity access given that it depends on many other key variables, including the type of agricultural crops involved. Yet, electricity can add value to local traditional production of extracted products from native forests reinforcing subsistence agriculture, which can account for a high share of family income. Therefore, extensive agriculture is not used as a substitute for improving family income and local vegetation can be preserved (Di Lascio and Barreto 2009).

### 3.2. Socio-economic development

To measure socio-economic impacts, a survey developed by MME (2013) evaluated the profile of beneficiaries and the impacts of the program in the communities. Results show that 89.8% of the beneficiary families had a total monthly income equal.
to or below two times the minimum wage\(^6\) and 18.8% only received half the minimum wage. Nearly half of the targeted families were rural workers. Among the families interviewed by the program’s survey, 41.2% considered that the program brought income rise and 40.5% saw an increase in the amount of job opportunities. This adds to the evidence of the positive social and economic co-benefits of the program.

The income per capita in each state between 2000 and 2010 improved significantly. Regions, such as the Northeast and Midwest, showed a higher monthly income in 2010 than in 2000. The Southeast and South regions had the highest electrification rates and income per capita in 2000, while the lowest values were in the North and Northeast regions, for both cases. In 2010, an improvement could be observed in the latter regions in both dimensions.

Table 3 compares electrification rates and per capita income in each Brazilian state in 2000 and 2010. The greatest increases in electrification rates were in the poorest and largely rural states (mostly in the North and Northeast regions). Generally speaking, the regions with the highest electrification rates also had a higher income increase in the same period.

Although a causal relationship between the electrification process and income cannot be inferred, a correlation between them can be noticed (IPEA 2013). It is important to mention that after 2003 other governmental social programs were established with the objective of reducing poverty in all dimensions. The main program was **Bolsa Família**, a cash transfer social program. By August 2016, the program had benefited 13.8 million families, with an average cash transfer of US$ 56.00 per month per family (MDS 2016). This will be further explored in section 4.

**Table 3.** Brazilian situation in 2000 and 2010: electrification rate and income per capita by state.

| Brazilian states     | Country region | Households with electricity | Per capita income |
|----------------------|----------------|-----------------------------|-------------------|
|                      |                | 2000 (%) | 2010 (%) | 2000–2010 Growth rate (%) | 2000 (US$) | 2010 (US$) | 2000–2010 Growth rate (%) |
| Brazil               |                | 93.5     | 98.6     | 5.5                        | 182.91     | 245.10     | 34.0                        |
| Acre (AC)            | North          | 75.8     | 91.1     | 20.2                       | 111.34     | 161.21     | 44.8                       |
| Alagoas (AL)         | Northeast      | 89.8     | 99.0     | 10.2                       | 88.08      | 133.55     | 51.6                       |
| Amazonas (AM)        | North          | 82.2     | 92.2     | 12.2                       | 108.56     | 166.66     | 53.5                       |
| Amapá (AP)           | North          | 95.1     | 98.3     | 3.3                        | 131.08     | 184.93     | 41.1                       |
| Bahia (BA)           | Northeast      | 80.9     | 96.5     | 19.2                       | 99.43      | 153.36     | 54.2                       |
| Ceará (CE)           | Northeast      | 88.2     | 99.1     | 12.3                       | 95.77      | 142.21     | 48.5                       |
| Distrito Federal (DF)| North          | 99.7     | 99.9     | 0.2                        | 370.31     | 529.52     | 43.0                       |
| Espírito Santo (ES)  | Northeast      | 98.7     | 99.8     | 1.2                        | 177.27     | 251.75     | 42.0                       |
| Goiás (GO)           | Centre-west    | 97.3     | 99.4     | 2.2                        | 176.44     | 250.38     | 41.9                       |
| Maranhão (MA)        | Northeast      | 78.7     | 96.1     | 22.2                       | 67.39      | 111.25     | 65.1                       |
| Minas Gerais (MG)    | Southeast      | 95.7     | 99.4     | 3.9                        | 169.46     | 241.46     | 36.6                       |
| Mato Grosso do Sul (MS)| Centre-west  | 95.6     | 98.6     | 3.2                        | 177.93     | 246.79     | 38.7                       |
| Mato Grosso (MT)     | Centre-west    | 89.5     | 98.0     | 9.5                        | 179.88     | 235.42     | 30.9                       |
| Pará (PA)            | North          | 76.7     | 91.9     | 19.8                       | 103.66     | 137.93     | 33.1                       |
| Paraíba (PB)         | Northeast      | 94.5     | 99.4     | 5.3                        | 92.34      | 146.63     | 58.8                       |
| Pernambuco (PE)      | Northeast      | 95.5     | 99.5     | 4.2                        | 113.40     | 162.28     | 43.1                       |
| Piauí (PI)           | Northeast      | 74.5     | 93.0     | 24.9                       | 78.66      | 128.72     | 63.6                       |
| Paraná (PR)          | South          | 97.7     | 99.6     | 2.0                        | 197.06     | 275.05     | 39.6                       |
| Rio de Janeiro (RJ)  | Southeast      | 99.5     | 99.9     | 0.4                        | 255.03     | 320.87     | 25.8                       |
| Rio Grande do Norte (RN)| North       | 94.1     | 99.4     | 5.6                        | 108.37     | 168.39     | 55.4                       |
| Rondônia (RO)        | North          | 83.9     | 97.3     | 15.9                       | 144.23     | 207.11     | 43.6                       |
| Roraima (RR)         | North          | 86.0     | 90.7     | 5.3                        | 142.69     | 186.97     | 31.0                       |
| Rio Grande do Sul (RS)| South        | 97.8     | 99.7     | 1.9                        | 218.62     | 296.15     | 35.5                       |
| Santa Catarina (SC)  | South          | 98.6     | 99.8     | 1.2                        | 214.21     | 303.77     | 41.8                       |
| Sergipe (SE)         | Northeast      | 91.8     | 99.2     | 8.1                        | 100.86     | 161.63     | 60.3                       |
| São Paulo (SP)       | Southeast      | 99.6     | 99.9     | 0.3                        | 272.43     | 334.81     | 22.9                       |
| Tocantins (TO)       | North          | 77.2     | 94.7     | 22.7                       | 106.33     | 181.11     | 70.3                       |

Source: IPEA (2013).

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\(^6\) The monthly minimum wage in 2003 was equivalent to US$ 74.10, currently it is US$ 271.70.

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7 Even though no data is available on the electricity consumption rates of households included in the **Bolsa Família**, it is reasonable to assume that they would likely fall in the ‘up to 30 kWh’ bracket, which is entitled to receive a 65% discount (ANEEL 2017).
In the regions included in the LpT program (most of them rural areas), the rise in income levels can be associated with more productive rural activity, as well as the diversification of economic activities. Electrification allows the creation of small businesses, such as bakeries, local markets and drugstores. After LpT, for instance, the presence of local markets, bars and bakeries increased 24%, 22% and 7%, respectively (MME 2013).

Also, according to MME (2013), 462 000 new direct and indirect jobs have been created as a result of the program implementation, and around 244 000 women started in a productive activity (MME 2013). In addition, in another survey made in the state of Tocantins, in the North region, Guimarães (2011) reports the economic improvements triggered by the LpT program. The author presented two case studies on how electrification increased both productivity and family income in rural areas. Guimarães (2011) also reveals that after electrification, communities were able to increase their income and expand their economic activities. For instance, farmers were able to use electrical machinery in farming and processing activities, which increased their productivity considerably. In some cases, households increased their income by 250%.

According to MME (2013), almost all beneficiaries reached by the program have reported improvements in their quality of life, mainly due to comfort and home needs. According to Pereira et al. (2010), what distinguishes a poor household from a better-off one is also the wide range of choices in terms of which fuels to use (more efficient, more convenient, less polluting, etc) and which equipment and appliances to buy. The government appraises that US$ 2.0 billion were injected in the household appliances market due to the LpT program, through electrical appliances bought by beneficiaries of the program. It is estimated that 81% of families purchased new TV sets, 71% refrigerators and 62% cell phones. Considering all the appliances, a total of 14 million new pieces of equipment were bought.

MME (2013) also measured social impacts associated with the electrification process. A survey with program beneficiaries showed an improvement in public services (e.g. education) and welfare. Most of LpT program beneficiaries believe that morning and night shift educational activities were improved. In addition, according to the survey, 309 000 women were enrolled in primary and secondary schools. The survey also evaluated the population opinion about health services. Nearly half of the beneficiaries believed that health care improved given the better access and quality of health centres.

Despite the results, poverty is a complex and multidimensional phenomenon; as so, it cannot be reduced to a single component, as electricity. It is also important to understand the role of other government programs in Brazil. Bolsa Família was the main program at that time, with the goals of reducing poverty, promoting food security, and increasing access to public services, especially health, education, and social assistance. Since it was launched, 5 million people left extreme poverty living conditions, reducing inequalities in Brazil (Fultz and Francis 2013).

As mentioned by Soares (2012), the strategy of the Brazilian government has been based on the complementarity of programs. These include adult education, opportunities for youth, job training, labour intermediation, subsidized electricity, rural electricity grid expansion (LpT), rural extension of microcredit to those who either are or may soon be Bolsa Família beneficiaries. The integration of complementary programs and actions contributes to families’ socio-economic inclusion and their emancipation from the program in a long term perspective (Quinhões and Fava 2010). Bolsa Família can be considered a driver of the social achievements observed, and electrification process is one of the important keys used to give possibilities to many families to alleviate poverty. Therefore, electricity has a role to make the development possible, not by itself, but integrated to other social efforts.

Despite the several evaluations of the results of the LpT program, there is a lack of formal empirical assessments that attempted to quantitatively measure the socio-economic improvements associated with the LpT program. The empirical assessment performed in this paper is an attempt to complement some knowledge gaps on the effects of the LpT program by performing a statistical analysis at the municipality level in Brazil.

4. Empirical assessment of the results of the LpT program

When the program was launched, nearly 90% of the target families that did not have access to electricity had low income—up to three times the minimum wage—and lived in areas with low HDI8 (Eletrobras 2016). It is expected that electricity supply has a large impact on well-being in regions with low HDI by improving health, education and communication services (Gómez and Silveira 2010). Actually, the role of advances in energy services in improving the HDI of a country at early stages of development is demonstrated by some studies (Pasternak 2000, Martinez and
Ebenhack 2008, Jackson 2009, Steinberger and Roberts 2009 and 2010). In this context, the HDI can be one way to analyse the success of a policy.

The Brazilian government uses the HDI as a tool for planning and monitoring development policies, including the LpT program (Gómez and Silveira 2010). Comparing 2000 data on development with observed electrification growth shows that low HDI levels were a reality in areas with the lowest electricity attendance.

According to IPEA (2013), in 2000, North and Northeast regions presented the lowest HDI in Brazil and also the lowest electrification rate at the time, just 87.7% in the Northeast and 81.6% in the North. On the other hand, more developed states, like the Federal District and São Paulo, had high HDI and presented high electrification rates (respectively, 99.7% and 99.6%). Regarding the evolution of the HDI between 2000 and 2010 in each Brazilian state, four states had improvements in electrical coverage higher than 20%: Acre, Maranhão, Piauí and Tocantins. All of them had progress in the HDI levels of around 30%, Maranhão being the state with the highest improvement, 34.2%, with an increase in the HDI from 0.476 to 0.639. According to 2010 data, all Brazilian states left the group of lowest human development regions, and were considered to be medium development regions, with HDI levels higher than 0.600. At the time, the lowest HDI was in the state of Alagoas (0.631). It is worth mentioning, however, that HDI in Alagoas in 2000 was 0.471.

Cunha (2007) shows that correlation between HDI levels and total per capita electricity consumption for 177 countries and 27 Brazilian states are similar to most countries with medium development levels. Also, statistically, there is a significant correlation between residential electricity consumption and HDI, as found by Pasternak (2000), Kanagawa and Nakata (2008), Mazur (2011), Martínez and Ebenhack (2008), Steinberger and Roberts (2009) and Oliveira (2013).

In the Amazon region, Gómez and Silveira (2010) finds evidence about the relationship between per capita residential electricity consumption and HDI. The author concludes that, if electricity access is provided to those with low HDI, a significant improvement in HDI can be achieved. Strong benefits can apparently be achieved in the Amazon region, as electricity helps break isolation and increases opportunity for the socio-economic inclusion of many communities.

Slough et al (2015) examined the correlation between HDI in Brazilian municipalities in 2000 and the improvements in electrification rates between 2000 and 2010, during the LpT program. The study reveals that the improvement in electricity access goes along with an increased HDI and increased per capita income. In each case, the association was strong and suggested that rural electrification and socio-economic development are closely linked. The study also found that electrification efforts made by the LpT program seems to have achieved more success in municipalities that had a low electricity access rate but a relatively high HDI, implying that the drive to bring electricity to the countryside brought the most benefits to municipalities that were already doing relatively well in other development-relevant measures. In contrast, municipalities that previously had both low electrification rates and a low level of socio-economic development appear to have fallen further behind in relative, if not in absolute terms.

In that way, to Slough et al (2015) the strong correlations found cannot tell us whether electrification drives development or development drives electrification. The study concluded that the LpT program targeting poor communities is important for reducing inequality of electricity access, but not sufficient to drive transformational development effects, since the latter depend on the government’s ability to promote economic growth and social development. Complementary interventions are necessary to allow local communities to exploit rural electrification for productive uses, not limiting electricity access for the provision of basic household services. In fact, it is equally possible that LpT actually targeted the most advanced municipalities and did not contribute much to development itself. Despite the correlation observed in the studies, HDI evolution cannot be inferred as a result of the electrification process. However, the latter is unarguably a pre-condition for high HDI levels. The social benefits regarding electrification access can only be achieved if other actions are executed jointly with the electrification process.

An empirical quantitative assessment of the program’s results based on a panel data regression model is proposed to assess the relationship between HDI and its components and electrification rate and, thereby, provide further insight into the socio-economic impacts of rural electrification in the country.

4.1. Database

The database used in this work was constructed from the concatenation of Brazilian population data from Brazilian Institute of Geography and Statistics (IBGE 2016) and the Atlas of Human Development in Brazil (Atlas Brasil 2016), which provides the Municipal Human Development Index (MHDI) and other 200 indicators for demography, education, income, labour, housing and vulnerability of Brazilian municipalities.

The database was constructed at the municipal level, including observations for the 5565 municipalities from all of the 27 Brazilian states for the years 2000 and 2010. The period was selected according to the availability of information.

Descriptive statistics of all variables, as well as the correlation matrix, were calculated. The results are...
found in the Appendix. The correlation matrix seeks to contribute to the verification of correlation between the explanatory variables. Variables used in the estimations, as well as their theoretical and empirical references are described below (Atlas Brasil 2016).

The dependent variables used by this study are the human development index and its three basic dimensions—income, education and health—as described below.

a. MHDI: Municipal Human Development Index. Geometric mean of the indices for the Income, Education and Longevity dimensions, described below.

b. Municipal Human Development Index—Education Dimension (MHDI_E): is obtained by the geometric mean of the frequency of children and young people at school, with weight of 2/3, and the education of the adult population, weighing 1/3.

c. Municipal Human Development Index—Longevity Dimension (MHDI_L): is obtained from the indicator of life expectancy at birth, using the formula:

$$\frac{O - Min}{Max - Min}$$

Where: $O$ is the observed value of the indicator; $Min$ is the minimum value; $Max$ is the maximum value and the minimum and maximum values are 25 and 85 years, respectively.

d. Municipal Human Development Index—Income Dimension (MHDI_Y): is obtained from the per capita income indicator, using the formula:

$$\frac{ln(O) - ln(Min)}{ln(Max) - ln(Min)}$$

Where: $O$ is the observed value of the indicator; $Min$ is the minimum value; $Max$ is the maximum value and the minimum and maximum values are R$ 8.00 and R$ 4033.00 (at August 2010 prices).

The explanatory variables used in the study were as follows:

a. Share of the population living in households with electric power ($I_{LIGHT}$): the ratio of the population living in permanent private households with electricity access to the total population living in permanent private households, multiplied by 100.

b. Bolsa Família control variable ($V_{BF}$): financial amount passed on to municipalities for the management of the Bolsa Família family grant program (in Brazilian reais).

### 4.2. Methodological approach

#### 4.2.1. Municipality selection

There are no official data about the actual municipalities that took part in the LpT program. Therefore, it was necessary to identify and filter the municipalities that were served by the program based on the variation of the rate of electrification: all municipalities that had an increase above 40% in the period were considered in the analysis. By applying this selection criteria, 805 municipalities were selected, comprising 12 million people in 2010, the approximate number of people served by the program according to MME (2017).

#### 4.2.2. Panel data regression model

A panel data regression model was used to assess the relationship between the HDI and its components and electrification rate, in particular, the estimates assuming random and fixed effects will be presented, as well as the robustness tests to choose the best econometric model.

The regression models with panel data combine time series and cross-sectional observations. Therefore, there are more observations and additional degrees of freedom compared to the specific use of cross-sectional or time series analysis (Baltagi 2001, Hsiao 2003).

For modelling the unobserved effects there are two possibilities, both of which were tested: the fixed effects and the random effects. The fixed effects model considers that the specific intercept of each individual can be correlated with one or more regressors. As for the random effects model, it assumes that the (random) intercept of an individual unit is not correlated to the explanatory variables (Wooldridge 2002). In this case, when considering that the variables are not correlated, the random effects method is more appropriate. On the other hand, if the unobserved effects are correlated to some explanatory variable, the estimation by fixed effects would be more appropriate. For the selecting the method—fixed or random effects—the Hausman test will be performed (Wooldridge 2002).

The econometric model adopted is represented by the equation (3):

$$Y_{i,t} = \alpha + \beta_1*I_{LIGHT\_i,t} + \beta_2*V_{BF\_i,t} + \epsilon_{i,t}$$

Where: $Y_{i,t}$ represents the dependent variable for municipality $i$ in period $t$ (MHDI, MHDI_E, MHDI_L, MHDI_Y); $\alpha$ is the intercept; $\beta_1$ and $\beta_2$ are the parameters to be estimated; $I_{LIGHT\_i,t}$ and $V_{BF\_i,t}$ are the explanatory variables; and $\epsilon_{i,t}$ represents the error term.

#### 4.3. Results

The results for the random effects and the fixed effects regression models were sequentially estimated using equation (3). The Hausman test rejected the null hypothesis that the random effects are consistent, pointing out that the best selection is the fixed effects estimation.
modelling. The estimation results and the test performed are shown in Table 4.

Results show that the MHDI is positively related to both explanatory variables, which is expected. Namely, the higher the level of electrification, the higher the MHDI is expected to be. The coefficient for electrification rate (T\_LIGHT) is positive for all models and it is statistically significant at the 1% level. The results show that the electricity access sector is relevant for human development.

When assessing each HDI component separately, results show that the education component is the most affected by electrification, indicating that electricity plays a fundamental role in the indexes related to schooling. In other words, electricity access in the Brazilian rural area was closely related to the increase in the population's access to the education system. Although parallel educational policies are needed to increase MHDIL\_E, and it is not safe to say that electrification is the cause for this, electricity access is a major requirement to improve education. The assessment conducted by Kanagawa and Nakata (2008) confirm this influence. According to the study, which aimed to reveal quantitative relations between access to electricity and advancements in socioeconomic condition in rural Assam state, India, it is estimated that the literacy rate could rise to 74% from 63% with the electrification in the area.

The other two components of HDI—health and income—are statistically explained but not strongly influenced by the increase in the municipal electrification rate. Other explanatory variables may be more relevant in influencing these factors and should be tested. Or even, in the case of income, there should be a delay between electrification and income growth, being education perhaps the transmission channel for that. This means that labour productivity rises, due to education, to then cause income growth in the Brazilian poorest municipalities.

The Bolsa Família value variable coefficient (V\_BF) is also positive for all models and it is statistically significant at the 1% level of significance. The results show that the program, which transfers income to families living in poverty and extreme poverty, does not have a large influence on the HDI. When analysing the monthly values transferred per capita, the results can be better understood. On average each family served by the program received around R$ 26 per month. Thus, the program is more associated with the relief of hunger than with later stages of human development. It helps the extreme poor but has a small influence on HDI, since other factors need to be developed to increase the Municipal Human Development Index (MHDIL), especially in its health and education components.

5. Final remarks

In 2003, Brazil launched the LpT program aiming to universalize access to electricity. The program focused on rural and isolated areas, also targeting to bring development to the region along with electrification. With an initial target of reaching 10 million rural people until 2008, nowadays and after four phases, the program has reached almost 15.8 million people. The program is expected to continue until 2018.

LpT is considered the first electrification governmental policy that focused not only in guaranteeing electricity access to communities, but also in reducing social inequality in rural communities. The LpT program created a priority level based on social welfare parameters, such as HDI and electricity access inequality. Also, the program’s execution along with other initiatives allowed electrification actions to be integrated to other governmental programs like Brazil Without Misery (Brasil sem Miseria, in Portuguese), Water for All (Água para Todos, in Portuguese), National Program for the Strengthening of Family Farming (Programa Nacional de Fortalecimento da Agricultura Familiar—PRONAF, in Portuguese), National Technical Assistance and Rural Extension

Table 4. Panel regression model results.

| Dependent Variable: MHDI | Random effect | Fixed effects |
|--------------------------|---------------|--------------|
| T\_LIGHT                 | 0.2286        | 0.2054***    |
| V\_BF                    | 0.0245        | 0.0258***    |
| R²                       | 0.90          | 0.95***      |
| Hausman test             | 0.008956      |              |
| Dependent Variable: MHDL\_E | 0.2286        | 0.5210***    |
| V\_BF                    | 0.0245        | 0.0543***    |
| R²                       | 0.90          | 0.94***      |
| Hausman test             | 2.2e-16       |              |
| Dependent Variable: MHDL\_L | 0.2286        | 0.0425***    |
| V\_BF                    | 0.02456       | 0.0112***    |
| R²                       | 0.90          | 0.94***      |
| Hausman test             | 2.2e-16       |              |
| Dependent Variable: MHDL\_Y | 0.0819        | 0.0526***    |
| V\_BF                    | 0.0105        | 0.0121***    |
| R²                       | 0.64          | 0.78***      |
| Hausman test             | 5.06e-05      |              |

a ***: Significant at 1%.

9 Around US$ 8 at current rates.
10 One of LpT’s priorities in its later phases was to reach Brasil sem Miseria beneficiaries (MME2011). Brasil sem Miseria program was launched in 2011 with the objective of reducing extreme poverty through a cash transfer program, access to basic public services and families’ productivity inclusion. Infrastructure programs, as LpT and Water for All (Água para Todos, in Portuguese) were key to rural productive inclusion, given that they provide the necessary infrastructure for farming families in Brazil’s semi-arid region, thus enhancing the productive structure needed to strengthen families’ autonomy. Up to June 2014 a total of 369,000 families were connected to electric power from the outset of Brasil sem Miseria plan, with 267,000 of them being Bolsa Família beneficiaries. Of these, 262,000 were in a situation of extreme poverty before the plan (MDS 2015).
Program (Programa Nacional de Assistência Técnica e Extensão Rural—PRONATER, in Portuguese), National Rural Housing Program (Programa Nacional de Habitação Rural, in Portuguese), My House My Life (Minha Casa Minha Vida, in Portuguese) and University for All (Universidade para Todos, in Portuguese). In that way, the program could reach communities that were not covered by previous programs and foster sustainable development in those regions.

Regarding the achievements of LpT, it is important to evaluate the role of electrification in development goals. Electrification is expected to provide the means through which new jobs and income can be generated and welfare can be improved. The presence of electricity can be correlated with HDI, income improvement, educational and health access and with household’s electrical appliances use. But, these benefits can only be reached if other complementary actions are executed alongside the electrification process. Electricity is key to development, but is not in itself a sufficient condition for achieving social development. The empirical results of this study showed that the education component of HDI was the one most influenced by electrification. Chances are that labour productivity growth (hopefully caused by education) will later generate income. But the analysis using the existing database is not able to indicate that yet. Also, development is a complex and multi-dimensional phenomenon, as such it requires a concerted, holistic approach based on complementary programs. These findings are very much in line with those from Slough et al. (2015), who also found that electrification efforts made by the LpT program were apparently more successful in higher HDI regions, implying that electricity access is more effective when accompanied by, or in addition to, other development-relevant policies and measures.

Despite the results achieved by the program, Brazil still has people with no access to electricity. Brazil is a continental country with areas that are hard to access due to the presence of large rivers and dense forests. Part of the population living in those areas are sparse, therefore, supplying electricity to these isolated communities is a challenge for the program. Another challenge is maintaining the affordability of electricity for low-income households benefitted by LpT after the end of the Program, which depend on cross-subsidies provided by the Brazilian interconnected electricity system, guaranteed only until 2018.

**Appendix**

**Table A1.** Descriptive statistics of all the variables inserted in the model.

| Variables | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|-----------|------|--------|--------|------|---------|------|
| MHDI      | 0.20 | 0.39   | 0.49   | 0.48 | 0.57    | 0.71 |
| MHDI_E    | 0.04 | 0.19   | 0.31   | 0.32 | 0.45    | 0.61 |
| MHDI_L    | 0.55 | 0.65   | 0.71   | 0.71 | 0.76    | 0.85 |
| MHDI_Y    | 0.33 | 0.46   | 0.51   | 0.51 | 0.55    | 0.70 |
| T_LGITH   | 10.30| 54.50  | 68.68  | 70.87| 92.74   | 100.00|
| V_BF      | 2864 | 23 960 | 39 940 | 51 390| 65 680  | 316 900|

**Table A2.** Correlation matrix of the model variables.

|          | IDHM | IDHM_E | IDHM_L | IDHM_Y | T_LGITH | V_BF |
|----------|------|--------|--------|--------|---------|------|
| IDHM     | 1    |        |        |        |         |      |
| IDHM_E   | 0.9764982 | 1      |        |        |         |      |
| IDHM_L   | 0.8731050 | 0.8052615 | 1      |        |         |      |
| IDHM_Y   | 0.7972315 | 0.6735330 | 0.7399156 | 1      |         |      |
| T_LGITH  | 0.8568461 | 0.8720774 | 0.7178276 | 0.5736068 | 1      |      |
| V_BF     | 0.5473096 | 0.3758726 | 0.4751958 | 0.3130929 | 0.5838101 | 1    |

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**ORCID iDs**

Roberto Schaeffer [https://orcid.org/0000-0002-3709-7323](https://orcid.org/0000-0002-3709-7323)

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