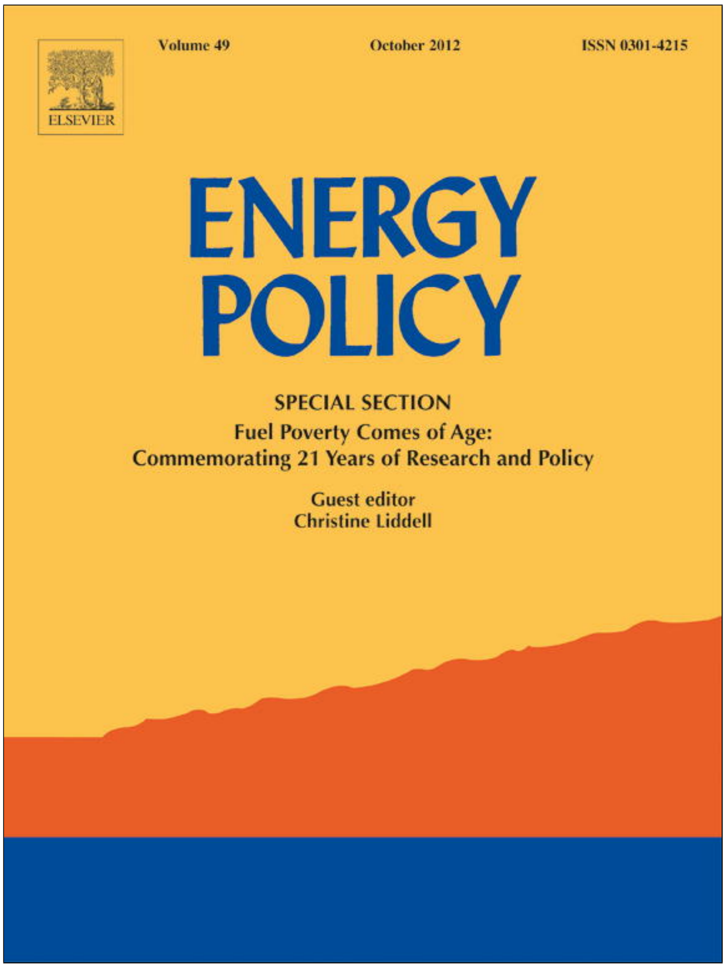
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An assessment of electricity and income distributional trends following rural electrification in poor northeast Brazil

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HIGHLIGHTS

- ► Comprehensive analysis of Brazil's recent rural electrification efforts.
- ► New methodology to analyze energy and income equity trends *ex post* electrification.
- ► Analysis indicates immediate social benefits for electrified households.
- ► We cannot establish a direct link between electricity use and income in the short-run.
- ► Electrification thus should be integrated in long-term rural development strategies.

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ABSTRACT

Rural electrification is considered to be a key strategy for poverty alleviation and sustainable development. It should therefore include (1) *expanding electricity access* and (2) *enable new consumers to increase their electricity consumption*. In this paper we ask how Brazil's recent rural electrification efforts have managed to reach these objectives. A new method to measure energy and income equity is presented which uses estimations of non-parametric density curves for the analysis of energy and income distributional trends following electrification. By applying our method to a panel data set from two Brazilian states situated in the country's poor northeast region we find that (1) rural consumers take up electricity consumption after electrification, and that (2) low consumption levels give way to higher electricity consumption levels after only a few years. This indicates immediate social benefits for households through consumption of electricity services. However, our analysis cannot verify a direct link between electricity use and rural income generation in the short term. The results emphasize the need for government and other actors to integrate rural electrification into broader rural development strategies in order to enable long-term welfare increases through electricity use.

1. Introduction

Rural electrification is a key strategy for poverty alleviation and sustainable development. Due to its versatility and perceived benefits, as well as universal access in most industrialized countries, many individual governments, international donor agencies, and NGOs have since long actively promoted electricity access programs in the developing world (ESMAP, 2000; Karekezi and Kithyoma, 2002; Martinot et al., 2002; Pre Dakar Position Paper, 2008; Niez, 2010).

However, while there is a consensus that electricity access is an essential ingredient for rural development, electric energy itself is not a commodity which can solely alleviate poverty or improve rural living conditions. Instead, the demand for electricity is only derived from the demand for the goods or services it provides or makes possible (Foley, 1995; Wilhite et al., 2000; ESMAP, 2008). Therefore, successful rural electrification programs must simultaneously tackle the issues of (1) *expanding electricity access* and (2) *enable new consumers to increase their electricity consumption*. This latter point integrates concerns to facilitate productive uses of electricity and thus rural development (Munasinghe, 1987; Ranganathan, 1993) as well as social demands for electricity services (including comfort and convenience) and their evolution (Wilhite et al., 2000). It is particularly relevant point as electricity consumption in many developing countries continues to be at extremely low levels even when electrification has reached rural villages (Heltberg, 2004; Fugimoto, 2005; IEA, 2009).

In this context, Brazil has made considerable progress in advancing rural electricity access, and the country is currently near universalization of rural electrification (Goldemberg et al., 2004;

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Obermaier, 2005; Rosa et al., 2006; Niez, 2010; MME, 2011). Importantly, the Brazilian electricity sector regulations integrate the provision of affordable electricity to low-income consumers so that rural electrification can indeed promote development and satisfy social demands.

However, little empirical work has been carried out in Brazil that could verify these relationships. Aggregate studies at the national level have found electricity consumption to positively influence GDP growth (Obermaier, 2006; Yoo and Kwak, 2010), but it is unclear how this translates into local benefits.[1] Recent studies have discussed electrification efforts in Brazil focusing on broader energy poverty concepts (Pereira et al., 2011) or electricity affordability through a more theoretic lens (Winkler et al., 2011). While these studies affirm an important role for electricity regarding rural development and social benefits, there continues to be a lack of detailed case studies that analyze how electricity consumption progresses following rural electrification (that is "*are new consumers enabled to increase their electricity consumption*"?). Furthermore, few studies have yet analyzed how electricity consumption can be related to welfare gains in rural communities. In this paper we thus specifically ask:

1. How does rural electricity consumption evolve following rural electrification, and does it generate measurable impacts on rural income generation or social benefits among the connected households?
2. How can we measure these trends among rural consumers?

These questions are addressed from an energy equity perspective (Schaeffer et al., 2003; Jacobson et al., 2005; Obermaier, 2009) recognizing that rural electrification is only successful if the poor and excluded can benefit from the connections. The analysis is based on a comparison of electricity consumption and income trends following electrification of over 400 rural households in two Brazilian states, Bahia and Ceará. Both lie in the country's poor northeast region (Silveira et al., 2007; IBGE, 2009) and thus make up for an appropriate case regarding our research questions. Non-parametrical density curves are introduced as a statistical tool to identify electricity and income distributional trends *ex post* electrification. These methods have been previously applied in studies on global income distribution (Sala-i-Martin, 2002; Dikhanov, 2005; Edward, 2006), but have also recently been used in a study on energy equity analysis in the state of Bahia (Obermaier, 2009). In general, these papers show that the estimation of non-parametrical density curves can provide more details and allow for a more refined analysis of distributional trends than would be possible under the use of conventional equity metrics such as the Gini coefficients and Lorenz curves. The original analysis of Obermaier (2009) is enhanced here by including a second case study (Ceará) and a control group in order to analyze the impacts of rural electricity consumption on income generation more clearly.

Accordingly, the remainder of this paper is organized as follows: Section 2 presents an overview on the Brazilian rural electrification efforts and development strategies in the poor northeast region. In the following, we describe the methodology and data. Section 3 then presents the estimations and results on electricity and income distributional trends. Section 4 discusses the findings in light of the recent progress in Brazilian electrification as well as the potential limitations of our methodological approach. Some final in Section 5 remarks conclude this paper.

[1] Recent studies show increasing rural family incomes and a significant reduction in rural income inequality. However, much of this evolution seems to be explained by cash transfer programs and old age pensions (Helfand et al., 2009; Araújo and Lima, 2009).

2. Context and methodology

2.1. Overview on Brazilian rural electrification efforts

Governments have often made rural electrification a governmental agenda. This is also the case for Brazil, where as early as during the 1960s the possibility of financial assistance for rural electrification initiatives was discussed, thus marking the beginning of public sector engagement for rural electrification in Brazil. A first national rural electrification program was implemented in 1970, with other initiatives following soon after (Fugimoto, 2005). Despite the fact that significant progress was made during the following years in supplying rural families with electric energy access – including those in lower income classes – connection rates remained on a low level (Beltrão and Sugahara, 2005). Up into the 1990s, rural electrification policies continued to be predominantly implemented at state level through concessionaires using state treasury resources (ESMAP, 2005; Instituto Acende Brasil, 2007a). Other electrification efforts were handled by a number of international donors as well as NGOs that supported or implemented several non-sectorial and decentralized electrification projects. Institutional set-ups and responsibilities varied considerably between these different programs (Goldemberg et al., 2004; ESMAP, 2005; Zerriffi, 2007).

A marked change was introduced with the Brazilian Constitution of 1988 that recognized the distribution of electricity as an essential public service for which the federal government would have to assume full responsibility. Accordingly, electrification works would either have to be carried out directly by state actors or through designated concessions or permits (Goldemberg et al., 2004).[2] Under these new regulations two large federal-led rural electrification programs were soon started: the Energy Development Program of States and Municipalities (PRODEEM) and the Light in the Countryside (Luz no Campo, or short LNC) — were established in 1994 and 2000, respectively. Both programs displayed strong differences from prior rural electrification initiatives in terms of their magnitude and in the technologies applied (Correia et al., 2002). PRODEEM and LNC were coordinated by similar actors: LNC by Eletrobrás[3] under coordination of the Ministry of Mines and Energy (MME),[4] and PRODEEM directly by the MME. Both programs drew from different funding sources: PRODEEM relied on National Treasury Funds and LNC on Global Reversion Reserve (Reserva Global de Reversão, or RGR) loans for utilities (Goldemberg et al., 2004; ESMAP, 2005) that set aside by law about one-fourth of the available resources for low-income consumers in rural areas (ESMAP, 2005).

PRODEEM was started by presidential decree and was to promote off-grid electrification of rural villages. The program was especially set up to provide solar photovoltaic (PV) panels free of charge upon demand from schools, health centers, and other community installations, but excluded rural households. Between 1996 and 2000, the program provided equipment for 3050 villages, and benefited an estimated 604,000 people (ESMAP, 2005). Five years later, in 1999, the LNC program was implemented with the aim of bringing electricity to 4.4 million people (about 930,000 households) by 2002. Unlike PRODEEM,

[2] Service providers are mainly concessionaires and permissionaires (permit-holders) authorized by ANEEL. Generally speaking, permit-holders are independent operators that work inside a concession area. Rural electrification cooperatives can become permit-holders if they provide a public service (ESMAP, 2005).

[3] The federal-owned holding company for electricity assets, controlling a large part of electric power generation and transmission systems mainly through six subsidiary companies, as well as some distribution capacity in the Amazon area.

[4] The MME oversees the whole power sector and is responsible for policy setting.

the program was to supply mainly grid electrification, with a geographic focus on the poor northeast region. Consumers were generally expected to pay the full cost of the connections to be spread over several years, but, depending on each state, significant financial assistance was given (ESMAP, 2005). In several states such as in Bahia consumers eventually ended up not having to pay for the connection at all (Obermaier, 2009). Both programs had in common that they had no clearly defined targets for reaching universal access in rural areas. However, state-owned utilities with soft budget constrains should supply electricity to low-income or rural consumers at extremely low tariffs (or free of charge), independently of cost recovery issues (Goldemberg et al., 2004; Zerriffi, 2007).

Despite the progress being made regarding the expansion of electricity services, both programs have been criticized on various grounds. Regarding PRODEEM, this included the missing integration of cost-recovery concerns and lack of funding, which resulted in insufficient maintenance activities, and consequently unstable services. Furthermore, lack of responsibility within the communities for the equipment led to malfunctioning of the systems. An evaluation in ten states consequently found that only 56% of the systems continued to operate (Goldemberg et al., 2004). Major problems identified in LNC were the lack of incentives for utilities to provide low-cost connections, as well as to undertake off-grid electrification (Goldemberg et al., 2004). As a result, connection costs for dispersed consumers rose beyond US$4000, that is, well above any international benchmarks (ESMAP, 2005).

An electricity sector privatization started in 1996 and led to a new Power Sector model in 2004, which resulted in 65% of electricity distribution being privatized, but major electricity generation assets remaining under government control, including Eletrobrás and most electricity transmission networks (EIA (Energy Administration Agency), 2012).[5] Under this new model the expansion of rural electricity services continues to be based primarily on federal power sector funds, but includes also state government resources, contributions from the concessionaires, and a greater focus on cross-subsidy polices benefitting low-income consumers (Goldemberg et al., 2004; Zerriffi, 2007). As such, low income consumers (not limited to rural areas) often pay discounted consumer tariffs (35% or 60%) due to their low consumption level (below 30 kW h and 80 kW h, respectively). It the states of the poor northeast region 62% of the consumer base falls within these reduced tariff classes, the highest rate within Brazil (Instituto Acende Brasil, 2007b).

It is worth noting that, despite the country's ongoing privatization efforts, in 2003 the Brazilian government proposed a new attempt with the *Luz para Todos* (Light for All, short LPT) program that would universalize rural electrification by 2008 (now 2014). The program target is to connect an estimated 12 million inhabitants in 2.5 million households in Brazil. Nearly half of these connections (1.1 million households or 44%) were identified to lie in the mostly poor rural northeast region (Niez, 2010). Then Minister of the MME, Dilma Rousseff, defined the program as a "proposal for the reduction of poverty and hunger, using electricity as a vector for development" (MME, 2003), and newly connected consumers would receive this services without paying financial compensation tariffs, next to already reduced consumer tariffs.[6] This underlines that rural electrification continues to be prioritized as a key element in Brazil's overall poverty alleviation strategy (Goldemberg et al., 2004; ESMAP, 2005).

In fact, the Brazilian government has shown a strong interest on promoting development in poor regions in the last decade, including the rural northeast. These approaches include social programs (old age pensions or, conditional cash transfer programs for extremely poor families through the Family Fund program, short PBF), agricultural policies (including the National Program on Biodiesel Production and Use that focuses on the social inclusion of family farmers in the northeast), food and nutrition security or microfinance (Helfand et al., 2009; Araújo and Lima, 2009; CONSEA, 2009; Obermaier, 2011).

It is under this context that rural electrification efforts in the northeast need to be analyzed. Two particular examples are the states of Bahia and Ceará. Both states display below Brazilian average living standards and are home to a significant rural population (see Table 1). They also accounted for a large number of non-electrified households in the time period on which our case study is based (Brasil, 2007, IBGE, 2009). Indeed, according to official estimates, 420 thousand households in Bahia and 190 thousand households in Ceará had been without electricity access in 2000 (Rodrigues, 2006). This number was equal to about half of all electrification works to be carried out by LPT in the northeast (Niez, 2010)[7] and justifies their inclusion as case studies for the present paper.

2.2. Methods and data

To analyze income and electricity consumption trends Gini and Lorenz metrics – whose definition is analogous to their standard application in income distributive analysis – have become more frequently used.[8] For example, Jacobson et al. (2005) use electricity Gini coefficients together with Lorenz metrics to show that differences in electricity consumption levels among different income classes are far less important in developed countries (Norway and United States) than in developing countries (El Salvador, Thailand, and Kenya). In another study (Schaeffer et al., 2003) show that access to electricity is most unequally distributed in Brazil's poor northeast region by using energy Gini coefficients.

Equity metrics such as Gini coefficients provide a good starting point for analyzing distributional trends. However, one and the same Gini coefficient may coincide with considerably different distributions. While Jacobson et al. (2005) thus call for a complementary analysis with Lorenz curves, we estimate here density functions, as discussed by Sala-i-Martin (2002), Dikhanov (2005) and Edward (2006).

Density curves can be interpreted as refinements of histograms, with the advantage that smooth and continuous functions are estimated. Furthermore, their form does not depend on the end points of histogram bins, a frequent problem when computing histograms. To prevent over- or undersmoothing of the bandwidth,[9] the estimations minimize the asymptotic mean integrated square error. By using this technique all important

[5] Brazil's power sector is now fully deregulated. Generators (mostly large government-controlled companies, but also several private power producers) sell their electricity to distributors via auctions. Electricity distribution is mainly operated by the private sector, whereas transmission is both publicly and privately owned. The provision of electricity services relies on government concessions, and all of the country is fully covered by either private or state-owned concession areas. Smaller regions are sometimes covered by authorized rural electrification cooperatives (ESMAP, 2005).

[6] In practice, LpT amounts to a partnership between the federal government, the state governments, and the concessionaires, with the federal government being responsible for the major share of the expenses (about 75%) and concessionaires and state governments sharing about equal parts of the remaining costs (Niez, 2010).

[7] Unofficial estimates pointed even at lower electrification levels by that time (Rodrigues, 2006).

[8] The Lorenz curve is the graphical representation of a cumulative distribution function. The Gini coefficient compares the Lorenz curve with the line of perfect equality, and ranges between 0 (perfect equality) and 1 (perfect inequality or concentration).

[9] The bandwidth is basically the equivalent to the binwidth of a histogram.

Table 1
Selected socioeconomic data on case study regions.
Sources: IBGE (2009, 2012).

	Bahia	Ceará	Brazil
Average household income (2000, in R$)	655.31	655.00	1,117.95
Households accessing PBF (2006, in %)	28.62	35.44	14.86
Illiterate population (2001, in %)	24.25	26.34	14.50
Migration (2000)*	−0.35	−0.06	n/a
Child mortality rate (2000, in %)	49.45	54.21	35.26
Food insecurity (2004, in %)	55.79	61.28	39.69

* Note: Migration index that varies between −1 and 1. Negative values imply net emigration.

features of the data are retained,[10] while smoothness of the function is maintained.

In this paper non-parametric density curves are applied due to several properties. First, unlike Gini coefficients every distribution has a unique density curve, implying that every distribution has a singular form. Second, density curves allow the researcher to insert limit values into their graphical representation. For example, the distribution of income among households can be put into context with minimum wage targets implemented by government, thus allowing a more complex analysis of distributional trends.[11]

Before starting the analysis a few words should be stressed on the data: in the first months of 2003 and 2004 several hundred rural families in Bahia and Ceará were asked to fill out survey forms that included questions related to rural electrification. These families had received access to rural electricity through the LNC program mainly in 2001,[12] and the research teams conducting the interviews were interested in gathering information that could be used to study the long-term impacts of rural electrification. This data has been published since in CEPEL (2006).[13]

A reduced sample of this survey is used in this paper which includes only those households that participated in both the 2003 and 2004 surveys (see Fig. 1 for main survey locations). This gives 270 observations for the state of Bahia, and 131 observations for the state of Ceará. In the following, both years are denoted as $t=1$ (2003) and $t=2$ (2004). In the case of Bahia a smaller sample is available for analysis of income trends over a longer time, dating back to the moment when electrification works were begun (2000–2001). This year is named $t=0$ and contains only 92 observations due to the fact that few families in Bahia participated at all three stages of the survey ($t=0$, $t=1$ and $t=2$). Yet, the smaller sample size comes at the benefit of having at hand a true panel set over a time frame of nearly four years which is quite rare in *ex post* electrification analysis.

Furthermore, a control group ($n=74$) is available for $t=1$ and $t=2$ for the state of Bahia, that is households that did not receive electricity access throughout the study period.[14] By using the control group data it is possible to infer on the impact of rural electrification on rural income generation even although no aim is made in this paper to establish a causal relationship between both variables, as would be possible, for example, through application of an econometric model.

Both original per household data as well as per capita adjusted household data[15] are used, because household size varies considerably *among* families as well as *within* families over the survey period which has strong impacts on the discussion of equity for both electricity and income variables.

3. Results

3.1. Data analysis

As a first step Tables 2–4 summarize the data from the Ceará and Bahia samples (CEPEL, 2006).[16] They show that the average electricity consumption as well as family and per capita income increased between $t=1$ and $t=2$, with average household size decreasing slightly during the same period. This could lead to the conclusion that the new rural consumers take up electricity and even increase their income, but such a judgment is premature as the average values hide information about the distribution of income and electricity consumption in the sample. In fact, looking at the Bahia sample it is found that income is actually higher at $t=0$ where there was no electricity yet available than at $t=1$, although little below that at $t=2$ (but only if by family income, in terms of per capita income values are almost equal). Furthermore, income increases between $t=1$ and $t=2$ are not limited to regions where households have been connected, but are most expressive in the control group sample. This indicates that rural electrification alone has had little direct impact in increasing rural incomes.

Beyond looking at average values it is necessary to take a closer look at the changes of the electricity and income Gini coefficients to understand the distributional trends of these variables. For the Bahia sample (Table 1), at $t=1$, both the household electricity and the per capita electricity Gini coefficients are near 0.5. By $t=2$, electricity inequality has decreased considerably, though at different rates when depending on whether one looks at household or per capita data (to 0.34 and 0.42, respectively).[17] A similar observation can be made for the Ceará sample (Table 2), although both distributions seems to be more equal than in the case of Bahia.

A surprising result can be found for the income Gini coefficient in the Bahia sample, which takes on different signs, depending on whether one regards the household or per capita data. While both coefficients are again approximately the same at $t=1$ (0.33 and 0.34, respectively), they have moved to opposite directions by $t=2$. The per household income distribution coefficient decreases by three digits to 0.30 (i.e., household income becomes more equally distributed)[18] whereas the per capita income coefficient increases (i.e., the per capita income distribution has become less equal).

From the information above it is therefore clear that the use of electricity or income Gini metrics alone, though providing for a good starting point of the analysis, is not sufficient to understand the trends of both variables following electrification. To mitigate

[10] That is neither obscuring data information nor creating data artifices.

[11] There is a third possible advantage: activity effects over time can be incorporated by normalizing the curves at $t=1$ and then scaling the curves at $t=2$ with regard to $t=1$ accordingly. This additional visualization effect is not available when, for example, using Lorenz and Gini metrics. This option is not used in this paper as it skews our analysis which focuses strongly on median values.

[12] The electrification works were primarily carried out by the two states' concessionaires COELBA (Bahia) and COELCE (Ceará).

[13] While this data is not based on the current LpT electrification program but its predecessor LnC, it is still possible to use this data for our analysis given the similar program benefits for rural consumers in both programs.

[14] This information is not available in the case of the Ceará sample.

[15] Per capita adjusted means that the original per household data was divided by the number of residents, assuming that intra-household electricity consumption or income is evenly distributed among its members.

[16] All calculations were carried out using R: A language and environment for statistical computing (R Development Core Team, 2010).

[17] This is, of course, due to the different household sizes between and within families at $t=1$ and $t=2$.

[18] This observation does not imply that the families in the data set are well off. In fact, many families in the sample display a monthly income below the R$300 minimum salary of that time.

Fig. 1. Main locations of electrified households analyzed in this study. Note: every star denotes a municipality with more than 21 observations in the panel data set. Locations are approximate.
Source: adapted from ANA/MIN (accessed at: http://www.asabrasil.org.br/UserFiles/Image/mapa%20Semirido.jpg).

Table 2
Bahia.

Time	Sample size	Household size	Average electricity use (kW h)		Average income (R$)		Electricity Gini		Income Gini	
			Family	Per capita	Family	Per capita	Family	Per capita	Family	Per capita
$t=0$	92	3.01			320.36	132.91			0.28	0.35
$t=1$	270	3.44	34.88	12.16	290.76	99.93	0.51	0.53	0.33	0.34
$t=2$		3.37	42.41	16.02	354.77	133.44	0.34	0.42	0.30	0.37

Table 3
Ceará.

		Household size	Average electricity use (kW h)		Average income (R$)		Electricity Gini		Income Gini	
			Family	Per capita	Family	Per capita	Family	Per capita	Family	Per capita
$t=1$	131	3.47	54.51	18.50	437.51	146.41	0.35	0.40	0.30	0.37
$t=2$		3.40	63.01	22.10	446.50	156.27	0.28	0.34	0.22	0.28

Table 4
Bahia control group.

		Household size	Average income (R$)		Income Gini	
			Family	Per capita	Family	Per capita
$t=1$	74	3.47	262.37	87.81	0.38	0.41
$t=2$		3.68	363.02	124.35	0.28	0.37

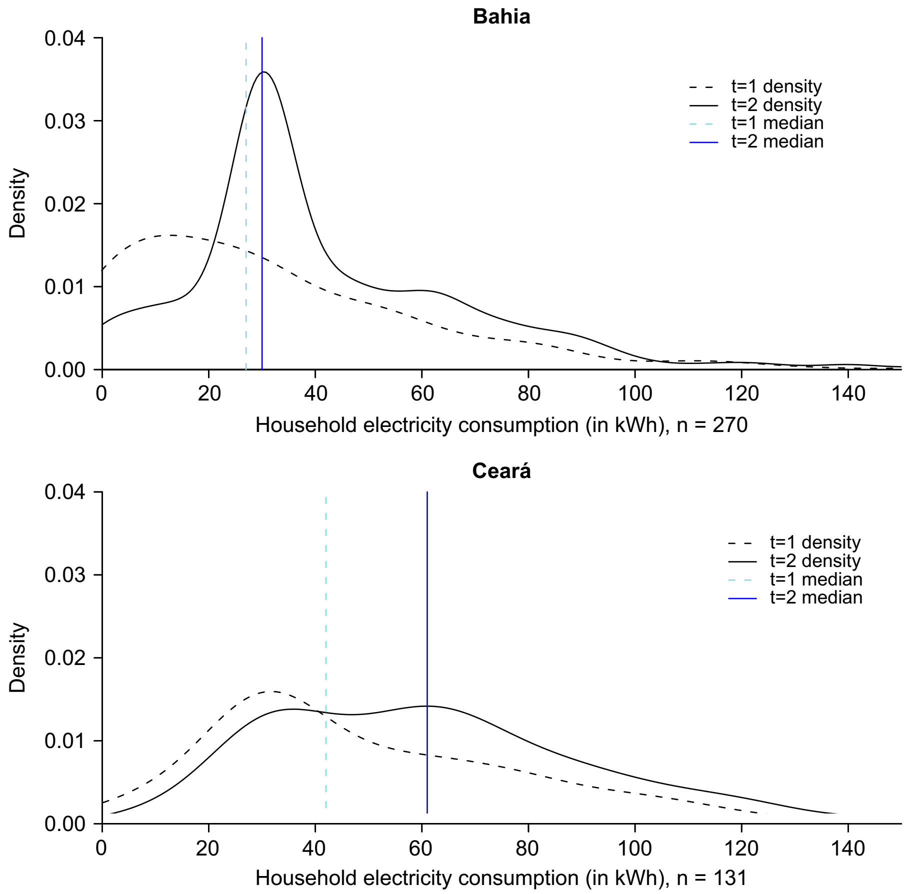

Fig. 2. Household electricity consumption density, Bahia and Ceará.

these shortcomings, electricity and income density curves are estimated in the following two sections. Both provide a more complex picture of the dataset as well as a better visualization of the distributional trends.

3.2. Electricity density curves

This section starts with a short description of how density curves can be read. Fig. 2 shows the density curves of per household electricity consumption for both Bahia and Ceará in time $t=1$ and $t=2$. Any curve displays the level of electricity consumption per household along the *x*-axis, where the height of the curve represents the respective share of the population living at that particular consumption level. Therefore, at any particular point on the *x*-axis a different number of households fall below under a singular electricity consumption level, which is represented by the area below the curve and to the left of that particular level. For example, the area left of 30 kW h per household could be characterized as that part of the population that still has problems filling basic electricity consumption needs, a point we discuss further below. Similarly, the area left of the median line represents the levels of electricity consumption of the first 50% of the sample population.[19]

It is now useful to explain in more detail how it is possible to interpret equity and distributional trends in the density curves. The following four examples are most plausible: first, under little inequality, the density curve would display a single peak near the 50% or median consumption level, and the curve area would remain inside relatively narrow limits to the left and to the right side of that particular consumption on the *x*-axis. Second, under these premises, a shift of the density curve to the right would mean a stronger uptake of electricity consumption, and in the case of rent, higher per capita or family income, providing thus positive evidence on rural electricity and development trends. Third, several discrete peaks in a density curve can be interpreted as inequality where income levels or electricity consumption levels actually becomes so divided between richer and poorer consumers that distinct peaks form.[20] Fourth, and related, relatively broad limits of the density curve also suggest an unequal distribution.

Using the sample from Bahia, the figure on per household electricity consumption above can be interpreted as follows: first, a clear rightward shift of peak electricity consumption of about 10 kW h can be observed between $t=1$ and $t=2$, giving evidence that more families use more electricity in $t=2$. As we know that the incremental benefit of one additional kW h unit at a very low consumption level is larger than when starting from a higher consumption level, this observation is even more important. In addition, the distribution of electricity consumption can also be interpreted as being more equal because the peak of the density function at $t=2$ is now near the median value of household electricity consumption which was not the case at $t=1$, as well as it is more confined (or not as broadly spread) than in $t=1$.

[19] We omitted a part to the right of the sample (the density curve shows consumption up to 280 kW h a month) as to better visualize the development among families with little electricity consumption.

[20] See also Edward (2006, 1675–1677) for a similar discussion.

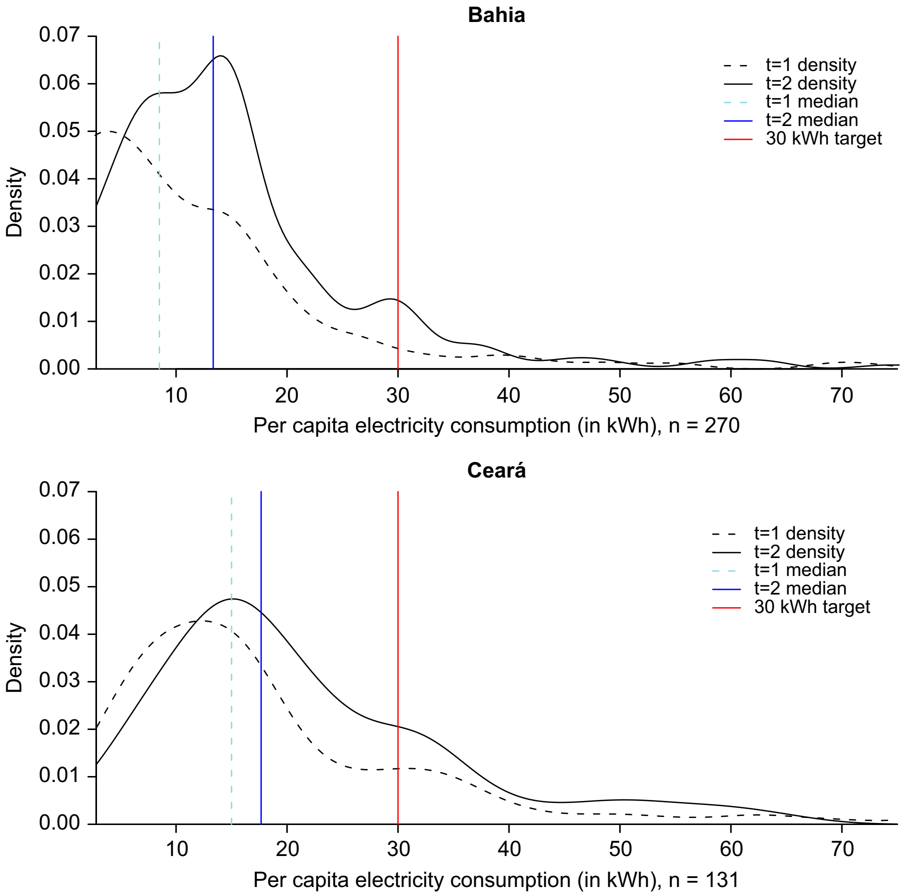

Fig. 3. Per capita electricity consumption density, Bahia and Ceará.

In the case of Ceará, progress seems more noticeable given the strong rightward move of the electricity median (households consume more electricity). However, electricity consumption continues to be broadly spread, implying that while there are many users with higher electric energy use, there are also quite a few continuing with low consumption levels. This clearly shows the multifaceted problem of equity analysis.

While improvements in the distribution of electricity use are thus visible, they occur on a small scale. This becomes more evident when analyzing per capita electricity use (Fig. 3). The courses of both density curves are approximately similar to those in Fig. 2, but it is now possible to derive how close those electrified are below or above minimum electricity per capita targets. For example, the World Energy Council (WEC) proposed that immediate annual per capita electricity consumption should be 300 kW h (which should further increase to 500 kW h by 2020) in order to meet minimum energy demands by the poorest of the poor (WEC, 2000).

Using 30 kW h per month (i.e., 360 kW h per annum) as limit value—which is the actual consumption level up to which Brazilian households receive a strongly subsidized electricity social tariff—enhances the analysis considerably. In Bahia, three to four years after electrification per capita electricity consumption is still concentrated at little below 10 kW h per month and thus far to the left of the 30 kW h target. Indeed, even at $t=2$ only around 10% of the sample observations consume more than 30 kW h on a per capita basis. Converting the original WEC targets into monthly data, it is possible to find little changes when adopting a 25 kW h per month target (or 300 kW h per annum), and, of course, even less when using a 40 kW h limit value (of 500 kW h per annum). The majority of new consumers uses far less than proposed as immediate minimum threshold by the WEC. For Ceará, although consumption is concentrated at higher levels, the results do not differ considerably:[21] only few households come near or use more than 30 kW h a month.

However, it should be acknowledged that 30 kW h per month can still allow for some lighting, refrigeration, and television viewing or other information/leisure activities, especially as these uses are often not exclusive for household members. Therefore, most of the times all family members can be expected draw benefits from the use of an appliance, and not only one member. Going back to Fig. 2, it is now interesting to show an example of household electricity consumption presented by Foley (1995): accordingly, two 40 W incandescent lamps used for 4 to 5 h a night use about 10 to 12 kW h per month. A small radio-cassette player and table fan for 10 h each day increase the consumption by about 10 to 15 kW h. Adding a small colour TV used for 6 h a day, a family might lie within a consumption range of little above 30 kW h per month.[22] While this may not be enough to facilitate many productive activities or fulfil basic needs, this consumption level may nevertheless provide some benefits at least for the rural family. If we would establish the 30 kW h limit value for households (see Fig. 2), it is possible to see that the number of families below this limit value is small compared to the per capita

[21] It is interesting to see that the per capita density curve is more similar in its shape to that of the Bahia sample than if taken by household level (especially at $t=2$). This might support a more general theory of electricity consumption trends following electrification, but this would require more data from cross-sectional studies.

[22] Due to increases in end-use efficiency the electricity required for these services may be even lower.

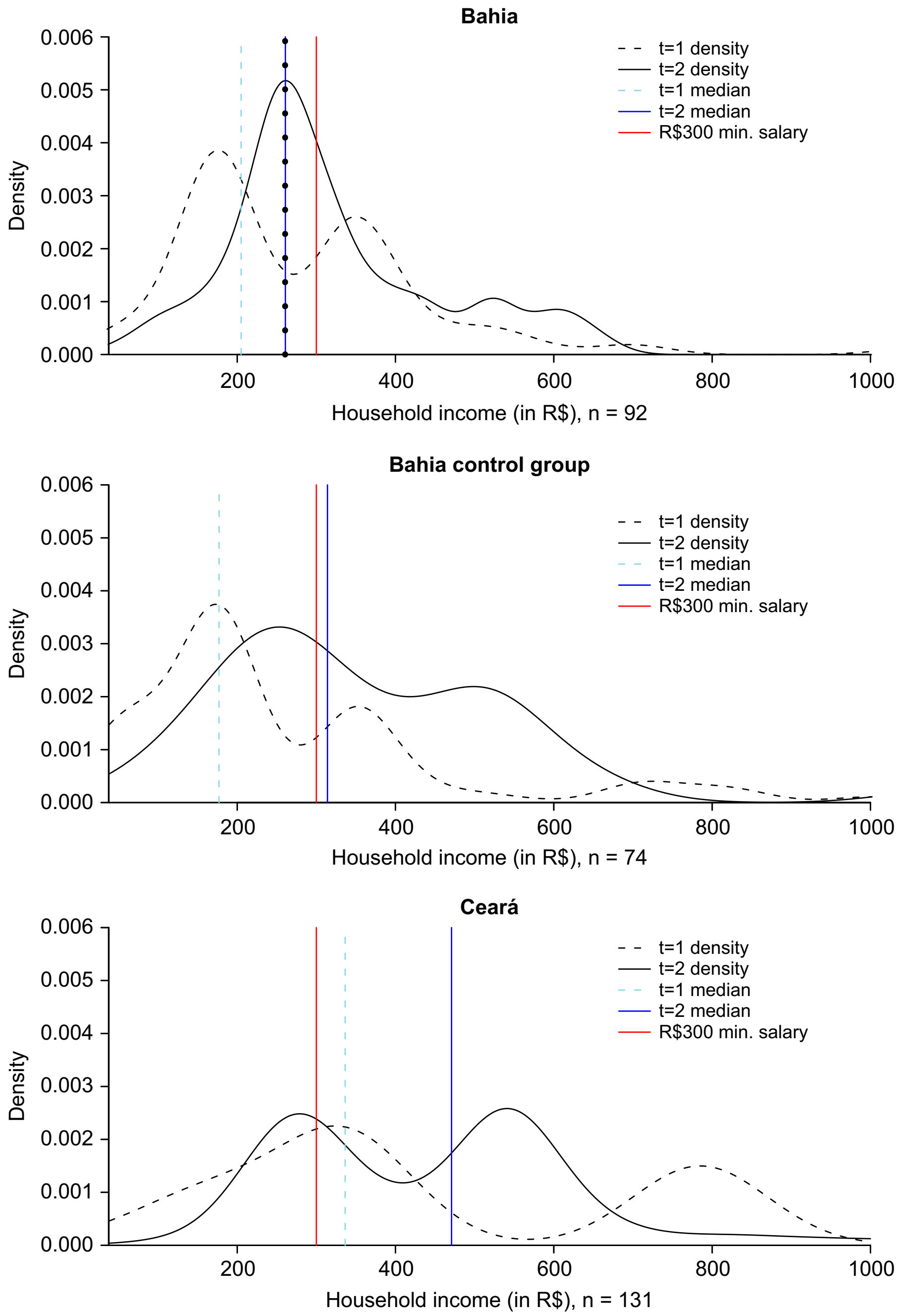

Fig. 4. Household income density, Bahia, Ceará and control group.

analysis, where, in the case of Bahia, at $t=2$ already around 30% of the sample families use 30 kW h or above on a monthly basis, and for Ceará even more families. As a substantial number of households consume more than 30 kW h (especially in the case of Ceará) the actual benefits derived from electric energy use are even higher.

3.3. *Income density curves*

Fig. 4 shows the density curves for household income in $t=1$ and $t=2$, including the control group sample. In order to keep the figure in the case of Bahia clearly arranged—which now includes values for $t=0$ or three years before electrification—a simple median household income was inserted instead of a third density curve.

Based on the estimations, it is easy to see that the distributions of incomes are highly instable along time, at least for the three samples. In the case of Bahia, there are two distinct peaks found in the density curve in $t=1$, the tendency one year later is that this sharp division weakens considerably. There is furthermore evidence that more households earn higher incomes as evidenced by a higher median consumption, however, a considerable share of households in $t=2$ continue to rely on very low incomes. In the case of Ceará, two persistent peaks can be observed at both $t=1$ and $t=2$ with median income also having moved to the right. However, the peak to the right has moved leftward in $t=2$, implying that households with high incomes now concentrate at a lower income level than before. Finally, there are very few changes at low income levels. This means that a similar number as before continues to rely on very low incomes.

Compared to this, the control group sample shows (as measured by median income) much higher income gains, although households did not receive electricity during the time of the study. Again, this questions a direct relationship between electricity consumption and income generation, at least in a shorter term.[23]

As a final exercise, it is interesting to put the curves into context with the Brazilian minimum wage, which at the time of the survey was R$300 (about US$100 at $t=1$ and $t=2$). As Fig. 4 shows, considerable changes occurred between $t=1$ (2003) and $t=2$ (2004) which vary strongly among the sample sets. In Bahia, changes occur on a very small scale as the vast majority continues to earn far less than the minimum wage. A larger number of observations in $t=2$ is concentrated at the only peak of the curve, implying that income distribution seems more just with regard to $t=1$. Contrary to this, in both the Ceará and control sample median incomes at $t=2$ are to the right of the median income, giving evidence that the interactions between electricity consumption and rural income growth are quite complex and at least in the short time not as relevant.

4. Discussion

In the previous section we analyzed the equity trends in electricity consumption and income following rural electrification. The analysis was based on a sample of over 400 rural households in two Brazilian states, Bahia and Ceará, both in the country's poor northeast region. Furthermore, a control group ($n=74$) was included in order to understand if rural income generation can be related to electricity consumption in households in the short-term. For the analysis non-parametrical density curves were estimated in order to get a more detailed picture of energy and income distributional trends.

Accordingly, our analysis of equity trends in electricity consumption and income following rural electrification found that (1) rural consumers tend to take up electricity consumption after electrification, and that (2) low consumption levels give way to higher electricity consumption levels after only a few years.

In general, however, electricity consumption as measured by median consumption remains limited: 30 to 50 kW h at household level, and 14 to 18 kW h on a per capita basis—although tariffs for low-income consumers (principally below 80 kW h) were subsidized throughout the survey period (Tavares, 2004; Instituto Acende Brasil, 2007b). This also implies that consumption levels for many families continued to remain considerably below international benchmarks such as the 30 kW h per capita target (WEC, 2000) that should allow to meet minimum energy demands by the poorest of the poor.

Furthermore, our analysis could not verify a direct link between electricity use and rural income generation for short-term periods following electrification as highest income gains (as measured by median income) are found for the control group that did not receive electricity in the survey period. This, in fact, may indicate that productive uses of electricity are not as relevant in early *ex post* electrification phases (due to their lack of impact on incomes). On the contrary, household benefits linked to electrification are likely concentrated in the realization of social benefits derived from electricity services, including those related to comfort and convenience.

The estimation of density curves in this paper gives additional insights into rural electrification and income dynamics. The methodological approach allows to analyze in greater detail the (sometimes opposing) distributive trends following household connections which would have otherwise gone unnoticed if relying only on more simple equity metrics such as Gini coefficients or Lorenz curves. Nevertheless, in the short term it was not possible to establish a causal relationship between electricity consumption and income generation based on non-parametrical approaches, despite the inclusion of a control group to control for changes in electricity consumption and income. In our study, however, the problem is not limited to the methodological approach, but is affected by the lack of detail regarding the composition of income (e.g., what role do conditional cash transfers, family remittances, public jobs or old age pensions play?) or socioenvironmental events (e.g., migration due to drought, or farmer income losses due to extreme rainfalls). In absence of this information it is difficult to link income growth to a specific variable (electricity consumption).

Given Brazil's considerable income concentration, a more equitable distribution of electricity consumption may have considerable relevance for a more just development. Existing welfare and development policies in Brazil seem to have reduced rural-urban inequality, however largely through other incomes sources, including old age pensions and access to Brazil's conditional cash transfer program for extremely poor families (Helfand et al., 2009).

This emphasizes the well-known need to integrate electricity beyond pure commodity or social benefits as a production input or development infrastructure and promote such uses in order to contribute to real rural welfare increases and electrification sustainability (Munasinghe, 1987, Ranganathan, 1993), acknowledging also that such efforts can only be successful if social policies and development strategies are in place that allow rural inhabitants to stay in the rural regions and to actively develop productive uses, including in small-scale commerce, family agriculture, food processing or even biodiesel production. These initiatives would thus not need to occur within electricity sector-specific programs led by sector agents, but can also be integrated in conventional development programs with local partners in order to maximize benefits.

5. Final remarks

In spite of the limitations of the methodology developed and applied, the results of this study regarding energy and income equity trends remain important in the context of Brazil's recent development efforts. While aggregate studies at national level have found electricity consumption to positively influence GDP growth, it remains unclear how this translates into local or regional benefits, at least in the short term. Rural electrification access in Ceará and Bahia seems to provide limited impacts which may seem disappointing given the high costs of bringing electricity access to the rural poor. However, at low levels of consumption or income incremental benefits of one additional unit of either electricity or income are considerable, and immediate social benefits of rural electrification are usually high, especially for poor rural households. That little time has passed between the interviews further explains why trends may have been minor, and an analysis using an extended panel dataset covering a larger time period in the nearer future would likely provide further insights. This emphasizes the need to continuously monitor and measure the impacts of rural electrification in emerging countries, such as Brazil. Furthermore, the need for government and other actors to integrate rural electrification into broader rural development strategies in order to enable long-term welfare increases through electricity use is highlighted.

[23] Actually, income increases may be due to government transfer programs rather than economic activities. Throughout the past years low income classes in the northeast region have become the most important beneficiaries of federal income transfer programs, including the Brazilian *Bolsa Família* program which provides direct cash transfer to families living poverty or extreme poverty (Araújo and Lima, 2009). Other strategies such as the seeking of old age pensions or procuring of public jobs have also been found to have considerable impact on the rural salary mass (Maia Gomes, 2001; Araújo and Lima, 2009).

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