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Abstract

Providing access to electricity is widely considered a precondition for socio-economic improvement in rural areas of developing countries. While electrification interventions are often expected to reduce poverty through their application in income generating purposes (business), the reality of rural usage patterns suggests a different actuality, with electricity being used for lighting and entertainment devices only. It is particularly lighting, with its implications for security and convenience, which explains the importance assigned to electrification. This paper investigates the effects of Solar Home System (SHS) electricity usage on lighting consumption and activities after nightfall, applying cross-sectional household-level data from rural Senegal. We apply a new matching algorithm to control for a possible self-selection into SHS ownership and find substantially higher lighting usage and study time for school children after nightfall. We also find some indication for improvements in perceived security.

Keywords: Electricification; Senegal; socio-economic impacts; attitude, perception

> I am a man who walks alone
>
> And when I'm walking a dark road
>
> At night or strolling through the park
>
> When the light begins to change
>
> I sometimes feel a little strange
>
> A little anxious when it's dark
>
> (Iron Maiden, *Fear of the Dark*, 1992).

1.0 Introduction

In his 1940 Rural Sociology article, John Kerr Rose emphasized the potential for rural electrification activities in the United States of America (US) as a field of social research. At that time, approximately 600,000 farms were non-electrified. The reason for Rose's interest in rural electrification was the expectation that such an infrastructural leap would substantially change people's lives: "Opinion at its optimistic limits credits rural electrification with being the long sought equalizer of city and country, a significant step in economic and social justice, and the force which will cause prompt regurgitation of population and industry into the countryside" (Rose, 1940, p. 412).

Today some 70 years later, the issues raised by Rose are increasingly relevant, with 1.3 billion people in developing countries lacking access to electricity. Some 600 million of them are living in Africa (IEA, 2011) where the rural electrification rate is particularly low at only 11% (UNDP/WHO, 2009). What Rose referred to in the aforementioned quote as *optimistic limits* is at the heart of the international community's expectations: Providing access to electricity is seen as a precondition for sustainable development. Policy papers highlight the relevance of electricity, notably in the achievement of the Millennium Development Goals (MDGs). Besides health and educational benefits that are expected to be triggered via improvements in public services, other impact expectations are related to income-generating uses of electricity (UN, 2005, 2010). Based on such assumptions the United Nations have proclaimed the year 2012 as the *International Year of Sustainable Energy for All*, calling for electricity provision to all households worldwide by 2030.

While the investment requirements of electrification projects are enormous, with the IEA (2011) estimating approximately 650 billion USD if full access to electricity is to be achieved by 2030[1], the social research Rose called for in 1940 has rarely happened and the impact of electrification remains grossly under-researched. There is indication in the literature that the reality of electricity usage patterns in many remote villages of rural Africa is different from what is expected in most policy papers; for instance, electricity up-take among micro-enterprises is often low and does not necessarily lead to higher incomes or better overall performance (Neelsen & Peters, 2011; Peters et al., 2011), while among households electricity is primarily used for lighting and entertainment devices (see Acker & Kammen, 1996; Bensch et al., 2011; Harsdorff & Peters, 2010; Wamukonya & Davis, 2001).[2] It therefore appears that electrification in rural Africa may not bring along the prompt revolutionary changes that Rose and its contemporaries expected in the US.

The observation that electricity is mostly used for consumptive purposes in households is often regarded as a disappointment or even a failure of electrification

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[1] This calculation only refers to what are considered "additional" investments required in IEA's so called *New Policy Scenario*, which assumes certain electrification activities as typical versus atypical; therefore, the total costs to connect today's 1.3 billion non-electrified people can be expected to be even higher.

[2] Further recent studies that try to determine welfare gains caused by electrification taking selection and program-placement biases into account are Dinkelman (2011), Barham et al. (2012), Rud (2012), Grogan & Sadanand (2012), and Khandker et al. (2012a, 2012b).

projects; on the other hand, Rose's *optimistic limits* not only include hard economic expectations about electrification as fuel for productive uses, but also considers softer impacts such as a different time allocation, a "shift in the farmers' psychology", or "nonfinancial contributions to welfare" (Rose, 1940, p.418f). In spite of the lack of substantial productive electricity use, personal discussions with people in non-electrified rural areas reveal that it is one of their most urgent needs because of the desire for electric lighting. In closing the gap between social and economic benefits, Fouquet and Pearson (2006) emphasize the importance of improved lighting for the economic development of industrialized countries. The authors claim that improvements in access to high quality lighting "may have also changed the way we think about and sense the world – less dependent on the sun and moon, less afraid of the dark and distancing ourselves from the communal fire" (Fouquet & Pearson, 2006, p.173); furthermore, they claim that "our ability to live and work in a well-illuminated environment has radically transformed the economy and society of industrialized countries" (Fouquet & Pearson, 2006, p.173). This is in-line with what rural dwellers in Africa frequently report in qualitative interviews: The much brighter electric lighting increases both the perceived and the objective security in its impact on the perception of life and society as well as economic decision-making.

This paper presents our attempt to probe into the less tangible effects of access to electricity, beyond the narrow focus on the MDGs. Based on a household survey conducted at the end of 2009 in the rural Casamance region of southern Senegal, we assessed the impact of electricity usage on lighting consumption and activities after nightfall. The households surveyed were all electrified via Solar Home Systems (SHS) promoted by *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ). In cooperation with *Agence Sénégalaise d'électrification rurale* (ASER), the GIZ project *Electrification rurale pour le Sénégal* (ERSEN)[3] supported the dissemination of SHS in 56 villages during the first phase of the project (ERSEN 1), and was completed in 2009. During the second phase (ERSEN 2), SHS were to become available in another 105 villages. The sample used in this study consisted of 218 households from 13 villages: 114 ERSEN 1 SHS owners and 104 ERSEN 2 households that had not yet benefitted from electricity.

The remainder of this paper introduces the country and project background (Section 2.0), describes the survey and data collection design (Section 3.0), and presents the identification strategy and results (Section 4.0). Section 5.0 concludes the study.

2.0 The Senegalese Energy Sector and Project Background

Power production in Senegal is almost entirely based on thermal power plants that run primarily on oil and natural gas. Countrywide, approximately 42% of the population has access to electricity. While this is a significant percentage, as compared to other African nations, most "electrified" people and households live in urban and more densely populated areas, as indicated by an urban electrification rate of nearly 75%. Roughly half of Senegal's population lives in rural areas where only 18% have access to the electrical grid (AfDB, 2010; UNDP/WHO, 2009).

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[3] ERSEN is part of the outcome-oriented Dutch-German Energy Partnership Energising Development (EnDev), which is financed by the German Federal Ministry for Economic Cooperation and Development (BMZ) and the Netherlands' Directorate General for International Cooperation (DGIS) and implemented by GIZ.

ASER is the body responsible for Senegal's electricity division and, following institutional reform in 1998, aimed to liberalized and partially privatized the sector. In the last ten years, efforts to improve access to electricity in Senegal were bundled within the ambitious *Programme prioritaire d'électrification rurale* (PPER). Through PPER, ASER subdivided the Senegalese territory into ten regions for the provision of rural electrification concessions awarded to private operators following the international Call for Tenders. The concessionaires are responsible for infrastructure as well as the operation of the grids. Although the operator is free to choose the electrification technology, it can be expected that most regions will be developed via grid extension. In areas not electrified by the concessions, local initiatives can apply for support to be electrified through an approach called *Électrification rurale d'initiative locale* (ERIL*)*. ERIL projects are, in principle, free to choose the applied technology; however, since the encompassed areas do not fall under any concession and tend to be more remote, decentralized solutions like mini-grids or SHS are likely to represent the least-cost approach.

The Senegalese-German energy program PERACOD (*Programme pour la promotion des énergies renouvelables, de l'électrification rurale et de l'approvisionnement durable en combustibles domestiques*), implemented by GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), provides technical assistance to the sector reform process in Senegal. One of its components, ERSEN, accompanied ASER in implementing a first wave of projects under the ERIL framework through the provision of electricity access to non-electrified villages. In addition to individual households, ERSEN has connected health stations and schools with two technology options depending on village size: SHS for villages with less than 500 households and solar-diesel hybrid mini-grids for larger villages. The project was implemented in two phases: In the first wave (2005-2009) ERSEN disseminated SHS in 56 villages and installed solar-diesel hybrid mini-grids in 15 villages (ERSEN 1). In a second phase, another 105 villages were planned to be electrified by SHS dissemination and 70 villages through mini-grids by the end of 2012 (ERSEN 2).

The ERSEN program selected villages to be included in the intervention based on an examination of pre-determined criteria. Apart from village population, these criteria comprised the distance between the village and the national grid, and the existence of social infrastructure facilities (schools and health stations); furthermore, pre-electrification rates (i.e. generator and non-ERSEN SHS usage) were to be low (below 20%). The list of villages was assembled in close cooperation with local authorities, and the process was applied in both ERSEN 1 and ERSEN 2 phases. Given that enterprise (home and public business) was by and large absent in the surveyed areas, the applied criteria yielded a homogenous set of both ERSEN 1 and ERSEN 2 villages.

At the time of this study (the end of 2009) the ERSEN 1 mini-grids had only just initiated operation, whereas the ERSEN 1 SHS had already been up and running for two years. In the dissemination of the SHS, ERSEN pursued a fee-for-service approach. The disseminated units consist of a 12-volt photovoltaic (PV) panel with a 55 watt peak capacity, a battery and charge controller, four energy saver lamps, and hardware. Within ERSEN 1, parties interested in receiving an SHS paid a connection fee of 20,000 FCFA (30 EUR). During the first year after connection the monthly fee amounted to 6,500 FCFA (10 EUR), which included installments of 2,500 FCFA for the in-house set-up. Households then paid a continuous fee of 4,000 FCFA (6 EUR)

thereafter. In an average ERSEN 1 village, more than half of the households rented an SHS under these conditions, presenting a take-up rate of more than 50%. Apart from pilot solar-powered mills introduced by the project in a few ERSEN 1 villages, almost no micro-enterprise could be found among the ERSEN SHS clients simply because virtually no such enterprises existed locally. A primary school was typically located in every ERSEN 1 village and was also equipped with an SHS, while the number of villages with health facilities was far fewer.

Figure 1. ERSEN intervention areas

ERSEN had two target regions: the Bassin Arachidier and the Casamance (see Figure 1). The analysis for this paper is restricted to SHS dissemination in the Casamance region. With regard to geographic conditions, the Casamance is largely separated from the rest of the country by The Gambia and the homonymous Casamance River. This isolation has led to both political and economic marginalization of the region; in addition, the Casamance region strongly differs from the rest of Senegal in terms of ethnicity. While the Wolof is the predominant ethnic group across the whole of Senegal, the Casamance is mainly inhabited by the Jola. The Jola's quest for autonomy is associated with the establishment of the separatist Movement of Democratic Forces in the Casamance (MDFC) that has fought a guerrilla war since 1990.

Another difference between the Casamance and the rest of Senegal is the predominantly subtropical vegetation in the region. In part due to its prolific soils, this environment has created excellent conditions for agricultural development. There is a strong tradition of rice growing in addition to other cereals, groundnuts, and vegetables. Despite such longstanding practice, the agricultural sector has suffered from chronic under-investment, trapping the region in a state of underdeveloped infrastructure and low levels of income and education.

3.0 The Data

3.1 Survey Design and Data Collection

The data considered for this analysis was collected between November and December 2009 as part of the monitoring and evaluation of the ERSEN project and within the guidelines described in Bensch et al. (2012). The evaluation pursued two objectives: (1) to provide a baseline for a future *ex-post* evaluation of the ERSEN 2 activities following an end-line survey scheduled for 2013, and (2) to assess the impact of SHS in ERSEN 1 villages of the Casamance. This impact assessment is the focus of the present paper. We applied a cross-sectional comparison of SHS-users and non-users, where non-users were the non-electrified households of ERSEN 2 villages that did not yet have access to electricity at the time of the survey. The survey also covered ERSEN villages in the Bassin Arachidier region as well as villages in the Casamance that were to be electrified by ERSEN mini-grids. While the data from these villages serves as a baseline for future ex-post evaluation, it was not included in the analysis presented in this paper. The mini-grids in the Casamance had not yet been established and for the villages in the Bassin Arachidier region we lacked an appropriate comparison group, rendering a cross-sectional comparison impossible.

We conducted extensive field trips in the preparatory phase of the study to become acquainted with the general conditions of different project villages and areas. Based on these insights, we finalized a structured household questionnaire that would serve as our primary survey tool, in addition to our two-stage sampling procedure. In the first sampling stage, a subset of villages was selected from the total ERSEN villages. For this purpose we determined criteria to stratify the population of villages and to randomly select villages to be included from each stratum. The stratification criteria were set in such a way that villages in each stratum could be considered sufficiently comparable. Field inspections revealed three criteria that would assist in meeting this goal: village population size, distance to the next main road, and type of road access. These criteria captured the main sources of heterogeneity that would potentially affect our research outcomes: Size of the local community and access to markets and information. We ultimately selected 13 villages: seven already electrified ERSEN 1 villages and six ERSEN 2 villages without access to electricity. In the second stage we sampled 218 households within these villages and SHS-users were purposefully visited; that is, all 114 SHS-users in ERSEN 1 villages were interviewed. Households in the still non-electrified ERSEN 2 villages were randomly sampled, resulting in 104 non-electrified control households.

The structured questionnaire covered all relevant socio-economic aspects pertaining to households. In addition to educational, health, and financial characteristics, the questionnaire collected detailed information regarding agricultural revenues (the major source of income) and lighting usage. Taking into account the importance of security issues associated with lighting that surfaced during qualitative pre-survey field interviews, we developed research questions and indicators on these topics as outlined in the following section and included a module with related questions. Qualitative semi-structured interviews and focus group discussions with additional potential beneficiaries and key informants, such as school, health, administrative, and micro-enterprise representatives, complement the quantitative approach.

3.2 Research Questions and Indicators

The United Nations Advisory Group on Energy and Climate Change establishes a direct relationship between electricity and most MDGs (UN, 2005). The majority of electrification projects undertaken by international donors includes these hypotheses within their frameworks and resultant chains, and is based on the assumption that electricity triggers productive activities in individual households and agglomerations as well as quality-enhancing electricity usage in social institutions like schools or health stations. In the case of ERSEN, virtually no enterprise was found to use SHS, and electricity-based income-generating activities at home were non-existent. Only one of the analyzed ERSEN 1 villages possessed a health facility; thus, the project installed an SHS at this location. The primary schools in six ERSEN 1 villages in the Casamance were also equipped with solar systems. In light of these circumstances, the focus of the impact assessment presented in this paper is on SHS usage in individual households.

The research focus of this paper follows up on the insights gained during the qualitative pre-survey interviews during which rural dwellers emphasized that it is mostly the desire for lighting that makes up the attractiveness of electricity accessibility; hence, the research questions concentrated on lighting usage and related activities in SHS-using and non-using households. We also attempted to examine how electric lighting has changed the attitudes and behaviors of people. To achieve this goal, we took into account the qualitative interviews that highlighted the security and comfort issues surrounding lighting. These security issues were in some cases substantiated by "real" problems; for example, the higher risk of being robbed in a non-electrified village. In other cases, they suggested a feeling of discomfort with "living in obscurity".

We initiated our analysis by addressing the relatively straightforward variable of *lighting hours*: the total duration of lighting usage per day across all lighting devices (electric or non-electric). We also attempted to account for the higher quality of electric lighting by assessing the daily consumed *lumen hours* of households. *Lumen* is the unit of luminous flux or a measure of the total "amount" of visible light emitted by a source; therefore, *lumen hours* are *lighting hours* multiplied by the *lumen* values of the different lighting sources. The lumen values relevant for our analysis ranged from 12 for paraffin candles to 1,613 for 40 watt fluorescent tubes (O'Sullivan & Barnes, 2006).

We also attempted to capture how the daily lives of rural people have changed in the wake of electrification, through the examination of nighttime activities. Given the lack of home business activities, the time school children dedicated to study at home was the most MDG-relevant indicator we examined; more specifically, we considered the total hours of *studying after school* and *studying after nightfall* among children. The most ambitious task was our attempt to grasp the security issues of electrification, the most objective dimension of which could be included by examining the frequency of *robberies and pillaging* or *animal attacks*. We incorporated the more subjective dimension of security, the perception of uncomfortableness, by asking whether respondents felt uneasy if their children were outside after nightfall (*fear*) and whether the household members ventured outdoors after nightfall (*leaving the house after nightfall).*

4.0 Impact analysis

4.1 Identification Strategy

Our strategy to identify the impact of electrification, based on the aforementioned indicators, was to compare households that used SHS (treated group) to those who did not (control group). This approach could only provide a valid impact assessment if the two groups (SHS- users and non-users) were comparable. One might reasonably suspect that households with particular characteristics self-selected into SHS ownership, which might then cast doubt on their comparability to non-using households (see Peters, 2009). Self-selection might therefore result from differences such as educational background; that is, better educated households being more aware of advantages related to SHS usage, such as the fact that expenditures for inefficient lighting fuels can be saved, and might also be more capable of grasping this investment-like character of an SHS. As a consequence, these better educated households would be more likely to acquire an SHS while simultaneously expected to dedicate more effort toward motivating their children to study, independent of the presence or absence of electricity. If one then compares study hours of children in SHS-using households (on average better educated) to SHS non-using households, one obtains a difference that is at least partly due to the higher educational level and not solely to the SHS usage status. Not accounting for such differences could have led to significant biases in our impact estimates and would have challenged the aim of our assessment in determining the genuine effects of SHS usage.

In order to increase the likeliness of finding households in the control group that were comparable to households from our treatment group, we adopted Peters' (2009) recommendation of recruiting control households from areas that lacked access to electricity. In our case, these areas were the ERSEN 2 villages. Different from non-users in ERSEN 1 villages where the project had already been active for an extended period, it could be reasonably assumed that some of the households in ERSEN 2 villages would decide to obtain an SHS when electricity became available in the future. It could also be expected that such households would resemble those from the treatment group of SHS-users in ERSEN 1 villages, with the only difference being that they did not currently own an SHS and had not undergone changes potentially ensuing from SHS ownership and usage (e.g. in terms of our impact indicators). Based on these considerations we did not sample non-electrified households in ERSEN 1 villages as the control group, and turned our attentions instead to the inhabitants of yet non-served ERSEN 2 villages who were chosen and served as a reservoir for comparable future control households.

To assure that comparable households were chosen, we drew upon a matching technique. The goal was to identify comparable households to SHS-users from the ERSEN 1 villages among the non-users in ERSEN 2 villages, in terms of level of education, income, wealth, etc. The most frequently applied matching approach is *propensity score matching* (PSM). Through PSM, the treatment status of households was regressed, based on available covariates in a probit model, to reconstruct the selection into the treatment decision. In our case, estimating such a probit model was inexpedient as we did not have information on the SHS non-users in the electrified ERSEN 1 villages and therefore were unable to calibrate the connection decision

with our data. As an alternative, we applied a *stratification matching* approach, as proposed by Iacus et al. (2011, 2012), called *Coarsened Exact Matching* (CEM).[4]

In principle, the CEM approach stratifies both the treatment and the control group according to different covariates. The basic procedure is to recode each covariate in such a way that sufficiently similar values can be grouped together; for example, a continuous variable such as income is transformed into a categorical variable of different income strata, causing the variable to be *coarsened*. These transformed covariates are then used to match treated and non-treated observations based on an *exact* matching algorithm; that is, units from both groups are only assigned to the same subgroup if their coarsened covariates are identical. If once coarsened a variable does not find a matching partner it is excluded from the analysis. The CEM approach, in that it serves a very straightforward means of bridging treated and control units, exposes the pivotal idea of all matching algorithms: in other words, electrified and non-electrified households should be matched in such a way as the imbalance in covariates becomes smaller within this matched subgroup. If successful, the remaining difference between households in one subgroup is the electrification status alone. In contrast to other matching approaches, we actively set the degree of balance ex-ante by deciding on the extent of coarsening.

A crucial decision in applying CEM is the way in which the covariates are effectively coarsened. As Iacus et al. (2012) suggest this can be implemented as easily as drawing a histogram; on the other hand, it represents a complex and deliberative issue in that it is driven by the desired balancing in the covariates. The desired balancing is a trade-off between precision and bias: the smaller the respective groups the more similar matched partners are and the smaller the bias. However, the smaller the respective groups, the more households have to be "pruned" due to the lack of control group counterparts in their exactly matched cell, which increases the standard error.

The extent to which the covariates are coarsened makes up the crucial difference between CEM and PSM; for example, one might consider the education variable for the head of household that exhibits three values, including primary school diploma, secondary school diploma, and university degree. One might further assume that there are a couple of household heads within the treatment group, while no non-treated household has a head with a university degree. If the researcher decides to coarsen the variable into a binary entity, with primary school as one value and secondary school or university degree as the second value, she explicitly allows for the inclusion of university degree holders within the analysis. When adopting propensity score matching such inclusion or exclusion processes are somewhat hidden in the "black box" of the matching algorithm.

4.2 Implementation of the CEM Approach

The selection of covariates follows the same requirements as PSM. Matching builds on the so-called Conditional Independence Assumption (CIA) that dictates that the outcome variables must be independent of the treatment, and are conditional on the observed covariates. The treatment in our case is whether the household has obtained an SHS. The CIA requires that the covariates are non-responsive to the connection status (Rosenbaum, 1984). The covariates to be

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[4] For applications of the CEM approach see Azoulay et al. (2010), Daxecker (2012), Finkel et al. (2012), or Groves & Rogers (2011).

included should also only be those that affect both the decision to connect and the outcome variable (Schmidt & Augurzky, 2001; Caliendo & Kopeinig, 2005). In the optimal case one has pre-treatment observations at hand; for example, household income at the time of electricity provision. Barring such observations, we utilize variables that are observed after the treatment and that we assume to fulfill these two requirements.

Within our data, the following variables affect household decisions to connect and the impact indicators, as well as being non-responsive to the treatment: *head of household's education*, *bank account ownership*, *roofing condition* (i.e. the material of the dwelling), and *income* (standardized by dividing through the number of household members able to work[5]). The inclusion of covariates such as *bank account ownership* and *roofing condition* are in their service as proxies for wealth. Wealth can be expected to affect the household's position to buy an SHS, simply given that richer households are more likely to have already satisfied more pressing needs and to be able to put forward the investment and operation costs. Similar to wealth, we use the household's *income* to capture the self-selection process underlying the decision to obtain an SHS. For income after the electricity connection, one may as well expect a reverse causality and argue that it is affected by electrification; for example, Peters (2009) and Khandker et al. (2012a, 2012b) examined household income as an impact indicator in electrification programs. In the present case, SHS were not used in productivity (income generating activities). It was therefore very unlikely that the installation of SHS approximately twelve months prior to the survey impacted household income.[6] Finally, the education level of the heads of households is included as a covariate (for reasons described in the aforementioned example) when introducing the identification strategy.

In order to coarsen the *income* variable, we set twelve different income levels with the overall boundaries being defined by the lowest and highest income among treated households. The ten deciles of the income distribution among treated households served to define the boundaries between the different income levels. This comparatively fine categorization of income suggested that the self-selection process into the SHS treatment was in fact largely driven by purchasing power. In coarsening *income* into many groups, we intended to achieve a high comparability of observations to be included in the matched impact analysis. For the *head of household's education*, we distinguished solely between no formal education (including alphabetization at informal Quran schools) and primary education (or higher). Excluding or including higher degrees at this point had hardly any effect as very few heads of households had a degree higher than secondary school. The *roofing material* was coarsened into straw only or higher quality material such as zinc and roof slate. The *bank account ownership* variable was binary, so did not require coarsening.

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[5] "Able to work" is defined as being between 15 and 65 years old, neither studying nor being retired.

[6] In order to verify the robustness of our results with regards to the covariate selection, we checked all results in case income is not included as a covariate. The results do not change in signs or significance levels.

Figure 2. The CEM procedure in the stylized case of two covariates
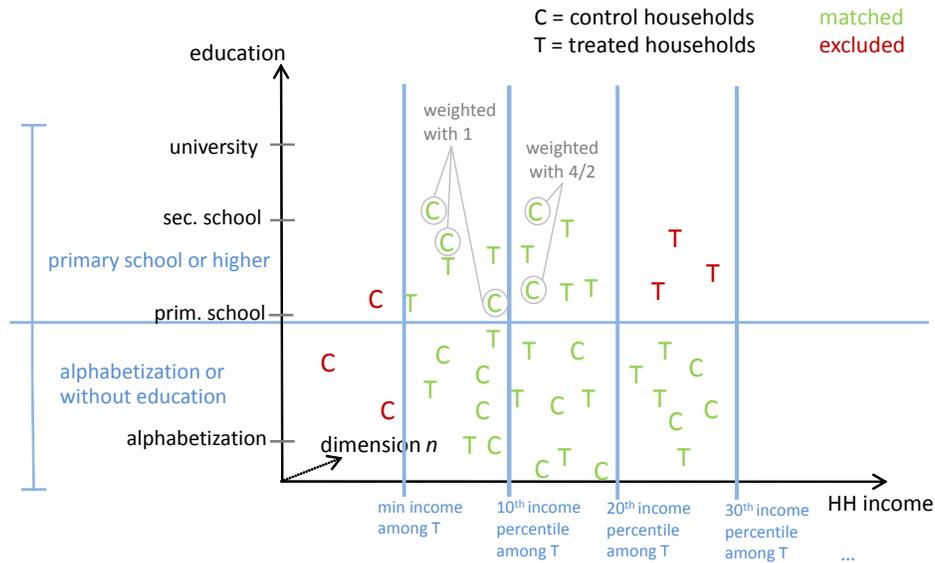
The covariates coarsened in this manner yielded 96 theoretical combinations of covariate characteristics, referred to as "bins" in the following description. Of these 96 possible combinations, 46 contained at least one observation. A treated household observed in the data was only included within the analysis if one or more counterparts could be found in the non-treated group that exhibited the same characteristics in terms of the coarsened covariates; in other words, a treated household was only included if it was allocated to a bin in which a non-treated household could also be found (and vice versa). Within each bin, the relative frequency for treated and control units was recorded and used as a weight for the subsequent analysis. The non-treated control observations were weighted according to the inverse of the relative frequency within a bin. If, for example, a control household was in the same bin as two treated households, the control household was weighted with the factor 2. Figure 2 visualizes the procedure for the two covariates *education* and *income*.

In only 14 of the 46 bins did we find both treatment and control observations (all included in the analysis). The remaining 32 bins contained, in total, 24 control and 32 treatment observations that were subsequently discarded from the analysis. We thereby arrived at a sample of 82 treated and 81 control households (see Table 1).

Table 1. *Basic figures on matching approach*

	Number of Observations		Number of Bins
	treated	control	
total	114	104	46
matched only	82	81	14

The purpose of this entire exercise was to improve the comparability of the included treated and non-treated households. In order to verify whether the matching actually improved the comparability, it was necessary to compare the balancing between the two groups before and after the matching process. Iacus et

al. (2011) propose as the central measure of balance for CEM the so-called *L1*-distance statistic that reflects the difference in the covariate distributions between the treated and the non-treated group. It can be calculated for each covariate separately (univariate balance) and as a balance measure across all covariates (multivariate balance). To obtain the *L1*-distance, the distribution is again grouped into bins in a first step.[7] For the univariate case, the *L1*-distance then sums up the absolute differences in the frequencies of treated and control units for each bin, divided by the number of observations in both groups respectively. In the multivariate case, the *L1*-distance checks for the overall balance by calculating the sum of the differences in frequencies for the multidimensional bins; that is, the different combinations of the covariate characteristics for both the treatment and control group. The *L1*-distance ranges between 0 and 1, with *L1*=0 indicating a perfect balance and *L1*=1 indicating completely non-overlapping distributions (see Figure 3 for a graphical representation of the univariate case).

Figure 3. Graphical representation of the determinants of the univariate *L1*-distance for income
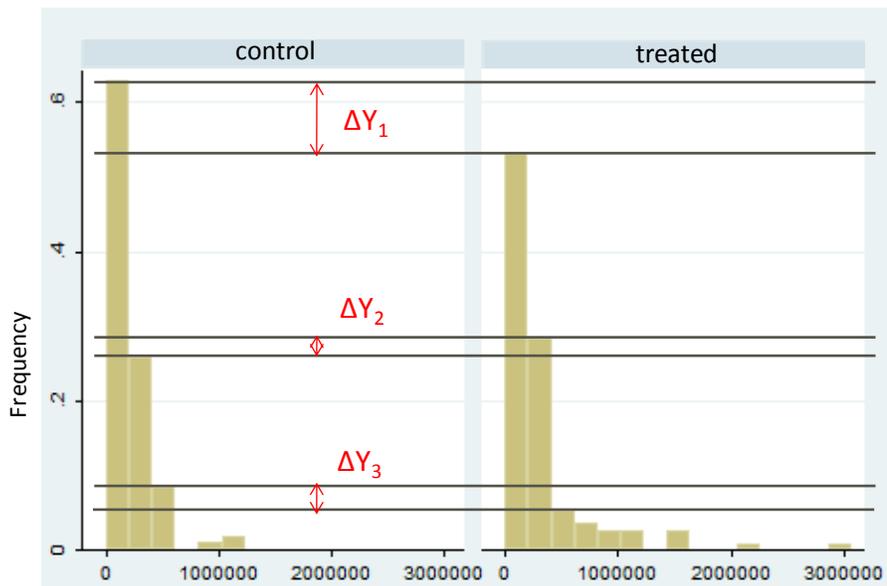
Note. The histograms depict the annual household income per household member able to work before matching. ΔY_i refers to the absolute difference in the frequencies of treated and control units in bin *i*, which is then divided by the number of observations in both groups, respectively, and summed up across all bins.

Table 2 presents the balancing results from our study. The univariate *L1*-distances for all covariates were substantially lower after matching. The multivariate balancing check confirmed the success of the matching process: The multivariate *L1*-distance before matching was 0.328, and was reduced to 0.132. Table 2 also displays the differences in means for each covariate as another more common measure of balancing. This data underpins the success of the matching process:

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7 Iacus et al. (2011) demonstrate that the definition of the bin width, in most cases, is not important for identifying the best matching solution. They propose a conventional algorithm to determine the bin size, which is implemented per default in the CEM tool for the statistical software package STATA.

While we observed a statistically significant difference in means of all covariates before matching at a 1% level, the significance in the differences vanished after matching.

Table 2. *Balancing test before and after matching SHS users and non-users*

Covariate		L1-distance	mean (*p*-value)	min	25%	50%	75%	max
			Absolute difference					
household income (in 1000 FCFA)	before	0.1275	117.790 (0.01)	10.75	16.50	36.00	100.00	1,800
	after	0.0707	50.646 (0.53)	10.75	2.11	-1.45	-40.24	1,800
roofing material	before	0.2242	0.641 (0.00)	0	1	0	0	0
	after	0.0469	0.041 (0.45)	0	0	0	0	-1
bank account ownership	before	0.1481	0.148 (0.00)	0	0	0	0	0
	after	0.0000	-0.000 (1.00)	0	0	-1	0	0
head of household's education	before	0.1835	0.184 (0.00)	0	0	0	0	0
	after	0.0000	-0.000 (1.00)	0	0	0	0	0
Multivariate L1 distance	before	0.328						
	after	0.132						

Note. The *p*-value refers a *t*-test of statistical significance for the difference in means between SHS users and non-users. *p*-values lower than 0.05, this is five percent, can be considered as indicating statistical significance. Min and max represent the minimum and maximum value, respectively, whereas 25%, 50% and 75% refer to the 25th, 50th, and 75th percentile of the respective univariate distribution.

4.3 Results

4.3.1 Appliances usage

We began our analysis with descriptive statistics on appliance usage as the primary instruments by which change could be detected. Generally, the number of energy-using appliances was rather low among the surveyed households. Most of the appliances used by the households were entertainment and information devices (Table 3). The most common appliances were radios, yet they were all powered through dry-cell batteries, as was also true of cassette recorders. None of the SHS-users operated line-powered radios. While a high percentage among both groups used irons, all were charcoal operated. The principal reason for a lack of electric irons was that the capacity of the SHS was too low for their operation. Beyond electric lighting, the only line-powered electric appliances that were used by several households were television (TV) sets. Only one SHS-using household ran an electric sewing machine.

Table 3. *Percentage of households using appliances that run on non-human energy*

		SHS users	SHS non-users
Radio	battery-driven	69%	65%
	line-powered	0%	0%
	bivalent	0%	0%
Irons	charcoal	50%	33%
	electric	0%	0%
Cassette recorders	battery-driven	23%	18%
	electric	0%	0%
TV Sets	electric	19%	3%
Sewing machine	mechanical	0%	1%
	electric	1%	0%

We have present lighting sources among SHS-users and non-users in more detail in order to emphasize the lighting usage patterns of the two comparison groups. All households that owned an SHS in ERSEN 1 villages used compact fluorescent lamps (*energy savers*); however, in 21% of the observed households this was complemented by the use of candles, while in only one household were ordinary incandescent light bulbs employed. No additional lighting source was used in more than 10% of the electrified households (see Table 4). The reason for this was that the energy savers were included in the SHS service package purchased by the households. A striking result concerning non-electrified households in ERSEN 2 villages was that the vast majority had already replaced candles or kerosene with fixed torches that were battery operated and installed permanently on walls inside the houses. While candles were still used by 45% of households, tin lamps and hurricane lanterns also played a subordinate role.

Table 4. *Percentage of households using lighting sources*

	Lumen	SHS users	SHS non-users
Candles	12	21%	45%
Hurricane lanterns	32	3%	13%
Tin lamps	11	0%	1%
Fixed torches	100	8%	75%
Incandescent light bulbs	600	1%	-
Fluorescent tube	1,613	0%	-
Compact fluorescent lamp	600	99%	-

Note. The table also presents the lumen values for the different lighting sources. For the electric lighting sources, the lumen values refer to the most common types in the surveyed areas, which are 60 watt incandescent light bulbs, 40 watt fluorescent tubes and 11 watt compact fluorescent lamp (see O'Sullivan & Barnes, 2006).

4.3.2 Impact indicators

In considering our impact indicators, Table 5 shows the demand for lighting in ERSEN 1 and ERSEN 2 households. First, we addressed the amount of *lighting hours* consumed by the households. This indicator was lower for SHS-users as compared to SHS non-users, mainly due to the widespread use of fixed torches that were considerably cheaper in a total cost analysis. However, the quality in lighting (brightness) differed substantially between SHS-users and non-users. We also examined the indicator of *lumen hours*, accounting for the lumen emitted by the different lighting sources (see Table 4). In spite of the slightly lower consumption of lighting hours, the SHS-users consumed around five times more lumen hours as compared to the SHS non-users. We also consulted the results for matched comparison groups to mitigate a potential selection bias. The matched results appeared not to differ substantially from those that were unmatched (Table 5).

Table 5. *Lighting consumption*

Outcome Indicator	Unmatched			Matched		
	SHS users	SHS non-users	Difference in means	SHS users	SHS non-users	Difference in means
Lighting hours	19.96	21.47	-1.52	21.41	23.89	-2.48
Lumen hours	10,762	1,584	9,178***	11,301	1,862	9,439***

Note. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

The usage of SHS obviously pushed the consumption of lighting to new levels, in particular when the lighting quality was considered. Our analysis therefore required us to probe deeper into the question of purpose with regard to the use of high-quality lighting. A frequently mentioned impact of better lighting availability was the improved studying conditions for children at home and, as consequence, increased studying time among school children. Children in electrified households were found to dedicate more time to studying than their non-electrified counterparts. As presented in Table 6, this difference was fully driven by a higher studying time after nightfall.

Table 6. *Study time (in minutes per day and child)*

Outcome Indicator	Unmatched			Matched		
	SHS users	SHS non-users	Difference in means	SHS users	SHS non-users	Difference in means
Total studying after school	134	108	26***	134	113	21***
Studying after nightfall	108	74	33***	106	76	30***

Note. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

In considering the potential security impacts of electrification we first assessed frequency of *robberies and pillaging* as well as *animal attacks*. This was considered against the backdrop of the ongoing conflict between separatist forces in the Casamance and the Senegalese army, which has destabilized the Casamance region

and made it a more insecure zone as compared to other regions in Senegal. Some of the separatist forces that were initially politically motivated have refocused their activity on simple pillaging and robbery. Our data confirmed substantially more robberies or pillaging activity in the Casamance region than in the Bassin Arachidier region. Within the sample considered in this study, we also observed significantly more incidents among SHS-using households. This could be explained by the fact that electrified households tended to be relatively wealthier; therefore, were more likely to be robbed than non-electrified households. The statistical significance disappeared if the matching algorithm was applied, comparing electrified households to better-off non-electrified households. While it could not be concluded that electrification increased the probability of being robbed, nor was there evidence that the usage of electricity (notably of electric outdoor lighting at night) protected the households in any way from robberies and pillaging activity.

Many interviewees stated that attacks by snakes and scorpions could be reduced by improved lighting. According to such statements, victims in unlit areas simply did not see the animals and were then bitten. They also claimed that such animals are scared by lighting and, consequently, no longer approach the houses. In considering SHS-using and non-using households there was no clear interpretation, as people in SHS-using households were no less frequently attacked.

Within our study we also attempted to understand the more subjective feelings of security by incorporating questions on nighttime behavior and perceptions of darkness within the structured questionnaire; for example, in qualitative interviews people stated that they would have liked to leave their houses more frequently at night but they did not do so because they were afraid of the darkness. We analyzed the frequency of *leaving the house after nightfall* for SHS-users and non-users and did detect an indication for more activity among households with electricity, but the significance of this difference disappeared in the matched comparison for men and only remained significant for children under the age of twelve years.

Table 7. Out-of-home activity after sunset

Number of times per week … leaves home after 8 pm	Unmatched			Matched		
	SHS users	SHS non-users	Difference in means	SHS users	SHS non-users	Difference in means
Man	4.50	3.59	0.90*	4.32	3.74	0.57
Woman	1.29	0.97	0.32	1.46	0.94	0.52
Boys (12-17 years)	4.19	4.75	-0.56	3.93	5.20	-1.27
Girls (12-17 years)	2.19	1.55	0.64	2.25	1.84	0.41
Children <12 years	1.54	0.74	0.80**	1.70	0.74	0.96**

Note. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

We also elicited information on different perceptions of darkness and nighttime. Interviewed persons were asked if they were afraid when they were outdoors after nightfall (8 pm in the study areas at the time of the survey) and when their children were outdoors after nightfall. As is illustrated by Table 8, some indication could be

found to suggest that electrified households were less afraid of the night. A significantly lower percentage of people were afraid if their children were outside after 8 pm, while only a minority of adults were afraid when outside themselves at night (percentages being equal in SHS-using and non-using households).

Table 8. *Nighttime fears*

Afraid when…	Unmatched			Matched		
	SHS users	SHS non-users	Difference	SHS users	SHS non-users	Difference
…being outdoors after 8 pm	25%	31%	0.10	26%	27%	0.02
…children are outdoor after 8 pm	41%	71%	0.31***	40%	69%	0.30***

Note. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

5.0 Conclusion

Based on household survey data from rural Senegal, we analyzed the change of lighting demand and related activities and perceptions after electrification by Solar Home Systems (SHS). In so doing we accounted for a potential self-selection bias by identifying SHS non-users that were most comparable to the SHS-users by applying a matching approach. Our initial results have allowed us to outline clear effects of the SHS treatment on lighting usage, provided that lighting quality is accounted for in terms of lumen hours. Electrified households consumed around five times more lumen hours than comparable non-electrified households. The total usage time of artificial lighting sources, irrespective of their quality, did not significantly differ between the two groups. This was to do with the fact that a variety of low-cost battery-run lighting devices have greatly impacted rural lighting programs in Senegal: a development that is gathering momentum across the African continent.

We then probed into the changes that were potentially induced by the availability of improved lighting and found a significantly higher study time after nightfall for school children. This suggests that lighting improves educational conditions and associated outcomes for children. We dedicated particular attention to qualitative findings gained during focus group discussions and open household interviews prior to the formal survey. In almost all cases, people claimed that their perceived feelings of security were increased in large part due to electricity access. We made an attempt to assess these softer impacts by isolating indicators that could be included in a structured questionnaire: frequency of animal attacks, thefts, and robberies, as well as subjective questions on anxiety after nightfall. No evidence could be found for a reduction of animal attacks or thefts and robberies in electrified households. By contrast we did find some indication for increased outdoor activities of rural dwellers (in particular small children) after nightfall and that people felt more comfortable at night.

While the impacts on indicators for lighting consumption and children studying at home are quite robust, the approach toward capturing security issues, convenience, and well-being can only be considered preliminary. Although some insight can be derived from the findings presented in this paper, we also reveal the limits of

quantitative studies using relatively small sample sizes. Our basic recommendation echoes the concerns raised by Rose in 1940 that further research is required. In addition to the "careful and intelligent sampling" highlighted (Rose, 1940, p.426), other methods have evolved in the last decades that could serve to shed more light on the softer impacts of electrification. Willingness-to-pay approaches could serve to capture the overall value that households assign to electricity in accounting for all monetary (kerosene savings) and non-monetary (higher convenience) benefits. Such approaches might also capture other soft benefits such as psychological effects of being part of a modern, urban-type life. Security issues must also be examined on the village level as spillover to non-connected households is likely to occur; therefore, a larger sample of surveyed villages is required. Likewise, a larger sample size of interviewed households might help to detect changes on the level of convenience and can be combined with the willingness-to-pay approaches and qualitative methods.

6.0 Acknowledgements

7.0 References

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