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Gunther Bensch, Jörg Peters, and Maximiliane Sievert[1]

Fear of the Dark? – How Access to Electric Lighting Affects Security Attitudes and Nighttime Activities in Rural Senegal

Abstract

Providing access to electricity is widely considered as a precondition for socio-economic development in rural areas of developing countries. While electrification interventions are often expected to reduce poverty through productive uses for income generating purposes, the reality in rural usage patterns looks different: Electricity is often used for lighting and entertainment devices only. It is particularly lighting with its implications for security and convenience that explains the high importance beneficiaries assign to electrification. Against this background, this paper probes into the effects of Solar Home System electricity usage on lighting consumption and activities after nightfall using cross-sectional household-level data from rural Senegal. We apply a new matching algorithm to control for a possible self-selection into Solar Home System ownership and find substantially higher lighting usage and study time after nightfall of school children. We also find some indication for improvements in perceived security.

JEL Classification: O12, O13, O18, O22

Keywords: Rural electrification; energy access; impact evaluation; matching

September 2012

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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. Introduction

In his 1940 *Rural Sociology* article John Kerr Rose emphasized the potentials of rural electrification activities in the US as a field for social research. Back then, around 600,000 farms were non-electrified. The reason for Rose's interest in rural electrification was the expectation that this infrastructural leapfrog would substantially change people's life: "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: 412).

Today, some 70 years later, the issues raised by Rose are even more relevant than before 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 as *optimistic limits* in the quote above is at the bottom of the international community's expectation: Providing access to electricity is seen as a precondition for sustainable development. Policy papers highlight the relevance of electricity notably for 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 – IEA (2011) quantifies the needs to some 650 billion US Dollars if full access to electricity should be achieved by 2030[1] – the social research Rose called for in 1940 has rarely happened. In other words, the impacts of electrification remained widely under-researched.

However, there is some indication in the literature that the reality of electricity usage patterns in many remote villages in rural Africa is different from what is expected in most policy papers: Electricity take-up among micro-enterprises is often low and does not necessarily lead to higher incomes or better firm performance (NEELSEN AND PETERS 2011; PETERS, VANCE, AND HARSDORFF 2011). In households, electricity is mainly used for lighting and entertainment devices (see ACKER AND KAMMEN 1996, BENSCH, KLUVE, AND PETERS 2011; HARSDORFF AND PETERS 2010; WAMUKONYA AND DAVIS 2001).[2]

Hence, it seems 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 seen as a disappointment or even a failure of electrification projects. On the other hand, already Rose's *optimistic limits* not only include hard economic expectations about electrification as fuel for productive uses, but also softer ones, such as a different time allocation, a "shift in the farmers' psychology", or "nonfinancial contributions to welfare" (ROSE 1940: 418f). In fact, 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 – most importantly because of electric lighting. Closing the gap between social and economic benefits, FOUQUET AND

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[1] This calculation only refers to what counts as "additional" investment required in IEA's so called *New Policy Scenario*, which assumes certain electrification activities that would happen anyhow in the business-as-usual-scenario. So, 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, LIPSCOMB AND MOBARAK (2012), RUD (2012), GROGAN AND SADANAND (2012) and KHANDKER ET AL. (2012a, b).

PEARSON (2006) emphasize the importance of improved lighting for the economic development of industrialized countries. The authors claim that the 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 AND PEARSON 2006: 173). They furthermore claim that "our ability to live and work in a well-illuminated environment has radically transformed the economy and society of industrialized countries" (FOUQUET AND PEARSON 2006: 173). This is perfectly 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. It appears straightforward that this also changes the perception of life and social as well as economic decision-making.

This paper is an attempt to probe into such less tangible effects of electrification going beyond the narrow focus on the MDGs. Based on a household survey conducted at the end of 2009 in the rural Casamance in the South of Senegal, we assess the impacts of electricity usage on lighting consumption and activities after nightfall. The households are 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] has supported the dissemination of SHS in around 56 villages in a first phase of the project, which ended in 2009 (ERSEN 1). In a second phase, SHS are planned to become available in another 105 villages (ERSEN 2). The sample of 218 households from 13 villages used for this analysis includes 114 ERSEN 1 SHS owners and 104 ERSEN 2 households that do not yet benefit from electricity.

The remainder of the paper is organized as follows: Section 2 introduces the country and project background. Section 3 describes the survey design and the data collection

[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.

work. In Section 4, the identification strategy is outlined and the results are presented. Section 5 concludes.

2. The Senegalese energy sector and project background

Power production in Senegal is almost entirely based on thermal power plants, which mostly run on oil and natural gas. Countrywide, about 42% of the population have access to electricity. While this is a decent share for African comparison, most of these electrified people live in urban and more densely populated areas – as indicated by an urban electrification rate of nearly 75%. Yet, about half of Senegal's population lives in rural areas where only 18% have access to the electricity grid (AfDB 2010; UNDP/WHO 2009).

ASER is the responsible body in Senegal's electricity sector. It has emerged after an institutional reform aiming at a liberalized and partially privatized sector in 1998. In the last ten years, efforts to improve access to electricity in Senegal have been bundled in the ambitious *Programme prioritaire d'électrification rurale* (PPER). Within PPER, ASER has subdivided the Senegalese territory into ten regions for the provision of rural electrification concessions to be awarded to private operators after international Call for Tenders. The concessionaires will be responsible for the construction works 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 that will not be electrified by the concessions, local initiatives can apply for support to get electrified through an approach called *Électrification rurale d'initiative locale* (ERIL). ERIL projects are, in principle, as well free to choose the technology. Since these areas that do not fall under any concession tend to be more remote areas, decentralized solutions like mini-grids or SHS are likely to be the least-cost approach here.

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, called ERSEN, accompanies ASER in implementing a first wave of projects under the ERIL framework by providing electricity access to so far non-electrified villages. In addition to individual households, ERSEN connects 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 villages larger than that. The project is implemented in two phases: In a first wave between 2005 and 2009, ERSEN disseminated SHS in 56 villages and installed solar-diesel hybrid mini-grids in around 15 villages (ERSEN 1). In a second phase, another 105 villages are 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 by examining pre-determined selection criteria: Apart from village population, these criteria comprise 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, should be low (below 20%). The lists of villages have been assembled in close cooperation with local authorities. This process was applied in the same way for ERSEN 1 and ERSEN 2. Also given that enterprises are by and large absent in the surveyed areas, the applied criteria turned out to yield a homogenous set of both ERSEN 1 and ERSEN 2 villages.

At the time of the implementation of this study at the end of 2009, the ERSEN 1 mini-grids only progressively started their operations, whereas the ERSEN 1 SHS had already been disseminated for up to two years. For the dissemination of these SHS, ERSEN pursues a fee-for-service approach. The disseminated SHS 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, people 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 installation. Thereafter, households only paid a continuous fee of 4,000 FCFA (6 EUR). In an average ERSEN 1 village, more than half of the households have rented an SHS under these conditions, implying 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 can be found among the ERSEN SHS clients simply because virtually no such enterprises exist locally. In addition, a primary school is typically located in every ERSEN 1 village, which ERSEN also equipped with an SHS. The number of villages with health facilities is far lower.

Figure 1: ERSEN intervention areas

ERSEN has two target regions: the Bassin Arachidier and the Casamance (see Figure 1). The analysis in this paper is restricted to SHS dissemination in the Casamance region. Concerning the geographical conditions, the Casamance is largely separated from the rest of the country by The Gambia and the homonymous Casamance River. This isolation led to both political and economic marginalization. In addition, the

Casamance region strongly differs from remaining Senegal in terms of ethnicity. While the Wolof is the predominant ethnic group across whole Senegal, the Casamance is mainly inhabited by the Jola. The Jola's quest for autonomy can be associated with the establishment of the separatist Movement of Democratic Forces in the Casamance (MDFC) that fights a guerrilla war since 1990.

The other main difference to the rest of Senegal is the predominantly subtropical vegetation in the Casamance. Along with prolific soils, these create excellent conditions for agricultural development. There is a strong tradition of growing rice and other cereals as well as groundnuts and vegetables. However, like in other parts of the regional economy, the agricultural sector suffers from chronic underinvestments, trapping the region in a status of underdeveloped infrastructure and low levels of income and education.

3. The data

3.1. Survey design and data collection

The data used for the analysis in this paper was collected between November and December 2009 as part of the monitoring and evaluation of the ERSEN project and along the lines described in BENSCH, PETERS, AND SCHMIDT (2012). The evaluation pursues two objectives: The first is to provide a baseline for a future ex-post evaluation of the ERSEN 2 activities after an end-line survey scheduled for 2013. A second objective is to assess the impacts of SHS in ERSEN 1 villages in the Casamance. This impact assessment is the focus of the present paper. We use a cross-sectional comparison of SHS users and non-users, where non-users are yet non-electrified households in ERSEN 2 villages, which did not 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 to be electrified by ERSEN mini-grids. While the data from these villages will serve as a baseline in a future ex-post evaluation, it is not included in the present analysis. The mini-grids in the

Casamance had not yet been established and for the villages in the Bassin Arachidier region we are lacking an appropriate comparison group. Hence, in both cases, a cross-sectional comparison is not possible.

We conducted extensive field trips in the preparatory phase of the study implementation to become acquainted with the general conditions in the different project villages and areas. Based on these insights, we finalized a structured household questionnaire, which is our major survey tool, and our two-stage sampling procedure.

In the first sampling stage, a subset of villages was selected from the totality of ERSEN villages. For this purpose, we determined criteria to stratify the population of villages and selected villages to be included in the survey randomly from each stratum. The stratification criteria were set in such a way that the villages in each stratum can be considered as sufficiently comparable. The field inspections revealed that three criteria help to meet this goal: Village population size, distance to the next main road, and type of the roads that accesses the village. These criteria capture the main sources of heterogeneity that potentially affect our research outcomes: Size of the local community and access to markets and to information. We thereby selected 13 villages; seven already electrified ERSEN 1 villages and six ERSEN 2 villages without electricity access. In the second stage, we sampled 218 households within these villages. SHS users were purposefully visited, this is, all 114 SHS users in ERSEN 1 villages were interviewed. Households in the yet non-electrified ERSEN 2 villages were randomly sampled, resulting in 104 non-electrified control households.

The structured questionnaire covers all relevant socio-economic household aspects. In addition to educational, health, and financial characteristics, the questionnaire collects detailed information on agricultural revenues as the major source of income and lighting usage. Taking into account the importance of security issues associated with lighting that came out of the 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 accordingly.

Qualitative semi-structured interviews and focus group discussions with other (potential) beneficiaries and key informants such as schools, health stations, administrative units, and micro-enterprises complement the quantitative approach.

3.2. Research questions and indicators

The United Nations Advisory Group on Energy and Climate Change establishes linkages between electricity and most MDGs (UN 2005). Most electrification projects by international donors include these hypotheses in their logical frameworks and results chains. These linkages are often 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 ERSEN case, virtually no enterprise uses SHS and electricity-based income-generating activities at home are inexistent. Only one of the analyzed ERSEN 1 villages disposes of a health facility at all; the project installed an SHS there. The primary schools in six ERSEN 1 villages in the Casamance are also all equipped with a solar system. 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 to the insights we gained during the qualitative pre-survey interviews in which rural dwellers emphasized that it is mostly lighting that makes up the attractiveness of electricity. Hence, the research questions concentrate on lighting usage and related activities in SHS using and non-using households. In a further step, we try to examine how electric lighting changes the attitudes and behavior of people. In doing so, we particularly take into account that qualitative interview partners highlighted security and comfort issues of lighting. These security issues were in some cases substantiated by "real" problems like for example the higher risk of being robbed in a non-electrified village. In other cases, they uttered a vaguer feeling of uncomfortableness of "living in obscurity".

We start out the analysis by looking at the very straightforward indicator *lighting hours*, which refers to the total duration of lighting usage per day across all lighting devices – be they electric or non-electric. In addition, we account for the higher quality of electric lighting by assessing the daily consumed *lumen hours* of households. Lumen is the unit of luminous flux and thereby a measure of the total "amount" of visible light emitted by a source. *Lumen hours* are, hence, *lighting hours* multiplied by the lumen values of the different lighting sources. The lumen values relevant for our analysis range from 12 for paraffin candles to 1,613 for 40 watt fluorescent tubes (O'SULLIVAN AND BARNES 2006).

We furthermore try to capture how the daily life of rural people changes in the wake of electrification by looking at nighttime activities. Given the lack of home business activities, the time school kids dedicate to study at home is the most MDG-relevant indicator we look at. More specifically we look at the *total studying after school* among school children and their *studying after nightfall*. The most ambitious task is the attempt to grasp the security issues of electrification: The more objective dimension can be included by looking at *robberies and pillages* or *animal attacks*. We incorporate the more subjective dimension of security, the perception of uncomfortableness, by asking for whether respondents feel uneasy if their children are outside after nightfall (*fear*) and whether the household members go out after nightfall (*leaving the house after nightfall)*.

4. Impact analysis

4.1. Identification strategy

Our strategy to identify impacts of electrification on the indicators outlined in the previous section is to compare households that use SHS and thereby received the treatment to those that do not, who represent the control group. This approach only provides for a valid impact assessment if the two groups – SHS users and non-users – are comparable. However, one might reasonably suspect that households with particular characteristics self-select into SHS ownership, which casts doubts on their comparability to non-using households (see PETERS 2009). The self-selection might result, for example, from differences in the educational background: Better educated households might be more aware of advantages related to SHS usage like the fact that expenditures for inefficient lighting fuels can be saved and might as well be more capable to grasp this investment-like character of an SHS.

As a consequence, these better educated households are more likely to acquire an SHS. At the same time, they can be expected to dedicate more effort to motivating their kids to study – independently of electricity. If one then compares study hours of kids in SHS using households (which are, 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 only to the SHS usage status. Not accounting for such differences will lead to biased impact estimates that challenge the aim of our impact assessment to determine the genuine effect of SHS usage.

In order to increase the likeliness of finding households in the control group that are comparable to households from our treatment group, PETERS (2009) recommends recruiting the control households from areas that, in principle, lack electricity access. In our case, these areas are the ERSEN 2 villages. Different from non-users in ERSEN 1 villages where the project is already active for longer time, it can reasonably be expected that part of the households in ERSEN 2 villages will decide to obtain an SHS in case electricity becomes available in the future. Accordingly, it can be expected that they resemble households from the treatment group of SHS users in ERSEN 1 villages with the only difference that they do not own an SHS and did not undergo changes potentially ensuing from this 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 control group but rather the inhabitants of yet non-served ERSEN 2 villages, which serve as a reservoir to find comparable control households in a next step.

To assure that comparable households are compared, we draw on a matching technique. In principle, the idea is to identify households among the non-users in ERSEN 2 villages exhibiting the same characteristics (e.g. in terms of education, income, wealth etc.) as SHS users from the ERSEN 1 villages in order to then match the two. The most frequently applied matching approach is *propensity score matching* (PSM). With PSM, the treatment status of households is regressed on available covariates in a probit model to reconstruct the selection into treatment decision. In our case, estimating such a probit model is inexpedient, since we do not have information on the SHS non-users in the electrified ERSEN 1 villages and, hence, we are unable to calibrate the connection decision with our data. As an alternative that works without estimating a selection model first, we apply a stratification matching approach proposed by IACUS, KING, AND PORRO (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 like income is transformed into a categorical variable of different income strata. In other words, the variable is *coarsened*. These transformed covariates are then used to match treated and non-treated observations based on an *exact* matching algorithm, this is, units from both groups are only assigned to the same subgroup if their coarsened covariates are identical. In case they do not find any matching partner, they are excluded from the analysis. The CEM approach, as a very straightforward way of bringing together treated and control units, exposes the pivotal idea of all matching algorithms: electrified and non-electrified households should be matched in such a way that the imbalance in covariates becomes smaller within this matched subgroup. If done successfully, the only remaining difference between the households in one subgroup is the electrification status. In contrast to

[4] For applications of the CEM approach see for example AZOULAY, ZIVIN, AND WANG (2010), DAXECKER (2012), FINKEL, HOROWITZ, AND ROJO-MENDOZA (2012), or GROVES AND ROGERS (2011).

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, KING, AND PORRO (2012) suggest, this can be on the one hand implemented as easily as drawing a histogram, but is on the other hand a complex and deliberative issue as it should be driven by the desired balancing in the covariates. In a nutshell, 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 is the bias. However, the smaller the respective groups, the more treated households have to be pruned due to the lack of control group counterparts in their exactly matched cell, which increases the standard error.

The definition of the extent to which the covariates are coarsened makes up the crucial difference between CEM and PSM. To point this out, one may take the stylized example of an education variable for the head of household that exhibits three values: primary school diploma, secondary school diploma, and university degree. One may further assume that there are a couple of household heads within the treatment group, while no non-treated household has a head with university degree. If the researcher decides to coarsen the variable into a binary one with primary school as one value and secondary school or university degree as the second value, she explicitly allows for including the university degree holders into the analysis. When using 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 for PSM. First, matching builds on the so-called conditional independence assumption (CIA): The outcome variables must in the end be independent of the treatment 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). Furthermore, only covariates should be included that affect both the decision to connect and the outcome variable (SCHMIDT AND AUGURZKY 2001; CALIENDO AND KOPEINIG 2005). In the optimal case, one has pre-treatment observations at hand, for example household income at the time of electricity provision. Lacking these, we utilize variables that we observe after the treatment, but for which we nevertheless assume that they fulfill these two requirements.

In our data, the following variables meet the requirements of affecting both the decision 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* in terms of the material of the dwelling, and *income*, which we standardize by dividing through the number of household members able to work[5].

The reasons for including these covariates are as follows: *Bank account ownership* and *roofing condition* are proxies for wealth. Wealth can be expected to affect the household's tendency to buy an SHS, simply since richer households are more likely to already have satisfied more pressing needs and to bring up 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. PETERS (2009) and KHANDKER ET AL. (2012a, b), for example, look at household income as an impact indicator in electrification programs. In the present case, though, SHS are not used for productive and, hence, income generating activities. It is therefore very unlikely in our case that the installation of SHS approximately twelve months prior to the survey has triggered impacts on income.[6] Finally, the educational level of the head of household is

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

[6] In order to check 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.

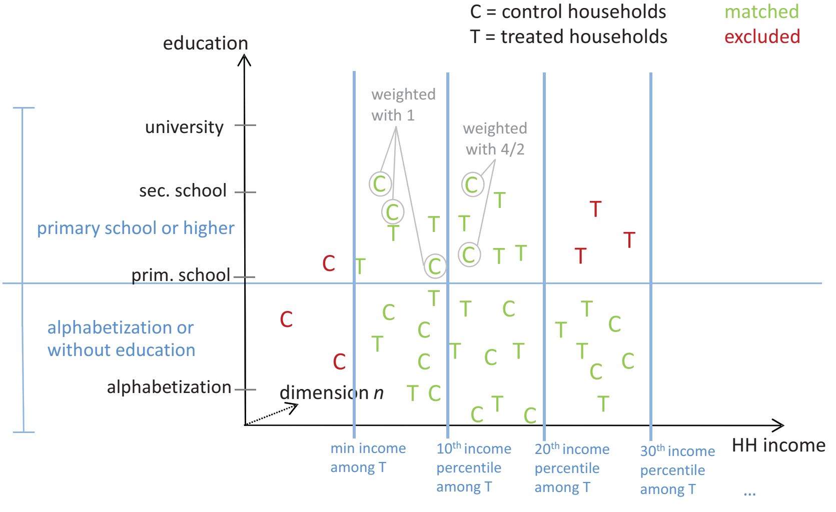
included as covariate for reasons described in the example above when introducing the identification strategy.

In order to coarsen the variable *income*, 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 then define the boundaries between the different income levels. This comparatively fine categorization of income is a tribute to the suspicion that the self-selection process into the SHS treatment is in fact largely driven by purchasing power. In coarsening *income* into many groups we intend to achieve a high comparability of observations to be included in the matched impact analysis. For the *head of household's education*, we only distinguish between no formal education, which includes alphabetization at informal Quran schools, and primary education or higher. Excluding or including higher degrees here does hardly have any effect, since only very few heads of household have a degree higher than secondary school. The *roofing material* is coarsened into straw only and higher quality material such as zinc and roof slate. The *bank account ownership* variable is a binary one and, hence, does not need to be coarsened.

The covariates coarsened in this way yield 96 theoretical combinations of covariate characteristics, to which we refer as bins in the following. Out of these 96 possible combinations, 46 contain at least one observation. A treated household observed in the data is only included into the analysis if one or more counterparts can be found in the non-treated group that exhibit the same characteristics in terms of the coarsened covariates. In other words, a treated household is only included if it is allocated to a bin in which a non-treated household can also be found – and vice versa of course. In each bin, the relative frequency for treated and control units is recorded and is used as a weight for the subsequent analysis. The non-treated control observations are weighted according to the inverse of the relative frequency within a bin. If, for example, a control household is in the same bin as two treated households, the control household is weighted with the factor 2.

Figure 2 visualizes the procedure for the stylized example of two covariates, *education* and *income*.

Figure 2: The CEM procedure in the stylized case of two covariates



Only in 14 out of the 46 bins, we find both treatment and control observations, which are all included in the analysis. The remaining 32 bins contain in total 24 control and 32 treatment observations that are consequently discarded from the analysis. We thereby arrive at a sample of 82 treated and 81 control households (see Table 1).

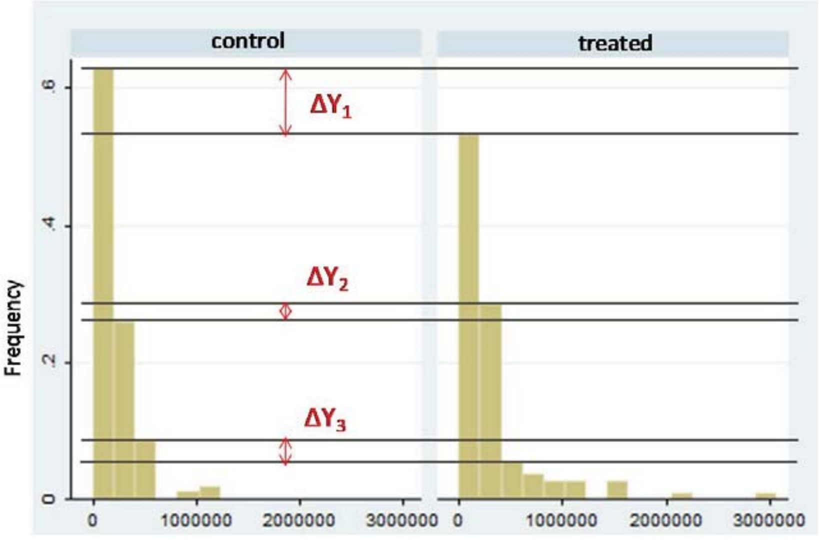
Table 1: Basic figures on matching approach

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

The purpose of this whole exercise is to improve the comparability of the included treated and non-treated households. In order to verify whether the matching has actually improved this comparability, one has to compare the balancing between the two groups before and after the matching process. IACUS, KING, AND PORRO (2011) propose as the central measure of balance for CEM the so-called *L1*-distance statistic, which basically reflects the differences 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 in 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, this 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.

[7] IACUS, KING, AND PORRO (2011) show that the definition of the bin width in most cases is not important for identifying the best matching solution. Therefore, 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.

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 present the balancing results. The univariate *L1*-distances for all covariates are substantially lower after matching. The multivariate balancing check confirms the success of the matching process: The multivariate *L1*-distance before matching is 0.328 and is reduced to 0.132. The table furthermore displays the differences in means for each covariate as another, more common measure of balancing. This data underpins the success of the matching process: While we observe a statistically significant difference in means of all covariates before matching at a 1% level, the significance in the differences vanishes after matching.

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

Covariate		*L1*-distance	Absolute difference						
			mean (*p*-value)		min	25%	50%	75%	max
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 begin our analysis with descriptive statistics on appliance usage as the primary instruments by which change will be effected. Generally, the number of energy-using appliances is rather low among the surveyed households. Most of the appliances used by the households are entertainment and information devices (Table 3). The most common appliances are radios. Yet, all of them are driven by dry-cell batteries. None of the SHS users operates a line-powered radio. The same applies to cassette recorders. While an important share among both groups has irons, all of them are operated with charcoal. The principal reason for a lack of electric irons is that the capacity of the SHS is too low for operating them. Beyond electric lighting, the only line-powered electric appliance that is used by several households are TV sets. Only one SHS using household runs an electric sewing machine.

Table 3: Share 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%

Furthermore, we present lighting sources among SHS users and non-users in more detail in order to get an idea of the lighting usage patterns of the two comparison groups. All households that own an SHS in ERSEN 1 villages use compact fluorescent lamps (*energy savers*), in 21% of the observed households complemented by candles. Only one household uses ordinary incandescent light bulbs. No other lighting source is used by more than 10% of the electrified households (see Table 4). The reason for this is that the energy savers are included in the SHS service package paid by the households. A striking result concerning non-electrified households in ERSEN 2 villages is that the vast majority of them has already replaced candles or kerosene by fixed torches, which are battery driven torches that are installed permanently at walls inside the houses. While candles are still used by 45%, tin lamps and hurricane lanterns play a subordinated role.

Table 4: Share 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 AND BARNES 2006).

4.3.2 Impact Indicators

Coming to our impact indicators, Table 5 shows the demand for lighting in ERSEN 1 and ERSEN 2 households. First, we look at the amount of *lighting hours* consumed by the households. In fact, this indicator is lower for SHS users than for SHS non-users, mainly due to the widespread use of fixed torches, which are considerably cheaper in a total cost analysis. However, the quality in lighting, the brightness, differs substantially between SHS users and non-users. We therefore additionally examine the indicator *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 consume around five times as much lumen hours as the SHS non-users. We also present the results for matched comparison groups to mitigate a potential selection bias. The matched results turn out to not differ substantially from the unmatched ones (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.

Obviously, the usage of SHS pushes the consumption of lighting to new levels – if one accounts for the lighting quality. In the following, we try to probe deeper into the question for which purposes the high-quality lighting is used. A frequently mentioned impact of better lighting availability are the improved studying conditions of children at home and, as a consequence, increased studying time among school children. In fact, children in electrified households dedicate more time to studying than their non-electrified counterparts. As can be seen from Table 6, this difference is 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.

Turning to the potential security impacts of electrification we first assess *robberies and pillages* as well as *animal attacks*. This has to be seen against the background of the ongoing conflict between separatist forces in the Casamance and the Senegalese army, which has destabilized the Casamance region and makes it a more unsecure place than other regions in Senegal. Some of the separatist forces, which in the beginning were politically motivated, have changed their activities to simple pillages and robberies. In fact, the data confirm substantially more robberies or pillages in the Casamance region than in the Bassin Arachidier region. Within the sample used for this paper, we observe significantly more incidents among SHS using households. This can be explained by the fact that electrified households tend to be relatively richer and, hence, are more likely to be robbed than the non-electrified households. In fact, the statistical significance disappears if the matching algorithm is applied, and, thereby, electrified households are compared to better-off non-electrified ones. While one, hence, cannot conclude that electrification increases the probability of being robbed, there is neither indication in the data that the usage of electricity (notably of electric outdoor lighting at night) protects the households in any way from robberies and pillages.

Many people stated that in particular attacks by snakes and scorpions can be reduced by improved lighting. According to these statements, people in many cases simply do not see the animals and are then bitten. Additionally, they claimed that these animals are scared by lighting and, consequently, do not approach the houses anymore. When looking at SHS using and non-using households, there is no clear tendency perceivable, though. People in SHS using households are not attacked less.

We furthermore try to grasp the more subjective feeling of security in the structured questionnaire by incorporating questions on behavior during nighttime and perceptions on darkness. In qualitative interviews, people stated, for example, that they would like to leave their houses more frequently at night – but they do not do so because they are afraid of the darkness. Accordingly, we analyze the frequency of *leaving the house after nightfall* for SHS users and non-users. In fact, we see some indication for more activity among households with electricity. The significance of these differences in nighttime activity, though, disappears in the matched comparison for men and only stays significant for children smaller than 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.

Furthermore, we elicited information on different perceptions on darkness and nighttime. Interviewed persons were asked if they are afraid, first, when they are outdoors after nightfall (8 pm in the study areas at the time of the survey) and, second, when their children are outdoors after nightfall. As can be seen in Table 8, some indication can be found that electrified households are less afraid of the night. A significantly lower share of people is afraid if their kids are outside after 8 pm. Only a minority of adults is afraid when being outside at night – with these shares 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. 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 doing so, we accounted for a potential self-selection bias by identifying SHS non-users that are most comparable to the SHS users by applying a matching approach. Our first result is that we find clear effects of the SHS treatment on lighting usage – if lighting quality is accounted for in terms of lumen hours. Electrified households consume around five times more lumen hours than comparable non-electrified households. The total usage time of artificial lighting sources irrespective of their quality does, instead, not significantly differ between the two groups. This has to do with the fact that a variety of low-cost battery-run lighting devices has vastly penetrated the rural areas in Senegal – a development that progressively gathers momentum across the African continent.

We then probed into the changes that are potentially induced by the availability of improved lighting and find a significantly higher study time after nightfall of school children. This indicates that, in fact, educational conditions for children improve and that better educational outcomes can be expected. Furthermore, we dedicated particular attention to qualitative findings gained during focus group discussions and open household interviews before the survey was launched. People claimed in almost all interviews that their perceived feeling of security has increased thanks to electricity access. We made an attempt to assess these softer impacts by indicators that can be included in a structured questionnaire. We asked for animal attacks, thefts and robberies as well as subjective questions on anxiety after nightfall. No evidence can be found for a reduction of animal attacks or thefts and robberies in electrified households. In contrast, we find some indication for increased outdoor activities of rural dwellers (in particular small children) after nightfall and that people feel more comfortable at night.

Altogether, while impacts on indicators for lighting consumption and kids studying at home are quite robust, the approach towards capturing security issues, convenience and, eventually, well-being can only be considered as a first step. Although some indicative insights can be derived from the findings presented in this paper, they also reveal the limits of quantitative studies using relatively small sample sizes. Therefore, our basic recommendation picks up again the call raised by Rose in 1940: further research is needed. In addition to the “careful and intelligent sampling” (ROSE 1940: 426) that he highlights, 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 household assign to electricity – accounting for all monetary (kerosene savings) and non-monetary (higher convenience) benefits. These approaches might also capture other soft benefits such as psychological effects of being part of a modern, urban-type life. In addition, security issues have to be examined on the village level as well, because spillovers to non-connected households are likely. For this purpose, 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.

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