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Impacts of Rural Electrification Revisited – The African Context

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Jörg Peters and Maximiliane Sievert[1]

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Abstract

The investment requirements to achieve the United Nations' universal electricity access goal by 2030 are estimated at 640 billion US Dollars. The assumption underlying this goal is that electrification contributes to poverty alleviation in many regards. In recent years, a body of literature has emerged that widely confirms this positive poverty impact assumption. Most of these studies, however, are based on data from Asia and Latin America. This paper challenges the transferability of impact findings in the literature to the African context. Using a unique data set that we collected in various African countries we show that impact expectations on income, education, and health should be discounted considerably for Africa, at least in the shorter run. In many cases, the low levels of electricity consumption can also be served by low-cost solar alternatives. To ensure cost-efficient usage of public investments into rural electrification, we call for careful cost-benefit comparisons of on-grid and off-grid solutions.

JEL Classification: O33, P46, Q41

Keywords: Energy access; on-grid electrification; off-grid electrification; Africa

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1. Introduction

The lack of access to electricity is frequently said to hamper economic development and the provision of public services like health care and schooling. Based on this assessment, the United Nations aim for universal access to electricity by 2030 via their initiative *Sustainable Energy for All* (SE4All, see also UN 2010). That will be no easy matter: More than 1.3 billion people in developing countries lack access to electricity today; some 590 million live in Africa (IEA 2012), where the rural electrification rate is only 14% (SE4All 2013). As a consequence, the investment requirements of electrification are enormous: IEA (2011) quantifies the needs to 640 billion US Dollars if universal access to electricity should be achieved by 2030.

The existing literature on socio-economic effects of electrification underpins the hopes for benefits on various dimensions, mostly based on evidence from Asia and Latin America. Three types of impacts stand out: educational benefits because of increases in study time, improvements in income because of increased non-agricultural activities, and a decrease in respiratory diseases because of decreases in kerosene usage. In this paper, we complement the existing literature in two ways: First, we present evidence from Africa showing that the impact findings in the literature cannot be readily transferred to the African context. Second, we discuss implications on costs, service provision, and user preferences of on-grid and off-grid technologies.

In the first part of the paper, we present findings from our own research spanning rural areas in Benin, Burkina Faso, Indonesia, Senegal, Rwanda, Uganda, and Zambia. Our data is hence predominantly coming from rural Sub-Sahara Africa, where electrification rates are the most deprived. Our data indicates that impact potentials in Africa are different. Possibilities to reduce respiratory diseases are lapsed to a great extent, because dry-cell battery driven lamps have made inroads into African households, even in remote rural areas. This phenomenon cannot be observed to a comparable degree in non-electrified Latin America and Asia.

We furthermore provide evidence for an increase in flexibility that electrification induces for households, but we cannot confirm positive consequences for ultimate poverty indicators which are based on income, education, and health. For example, while kids in fact increase their study time after nightfall, this comes at the expense of study time during daytime. Likewise, daily activity schemes of household members change after electrification, but the number of working hours or employment patterns are not affected. Yet, there is little indication for an effect on households' income, also because potentials for rural micro-enterprises to expand production are hampered in most places due to limitations to market access.

In the second part of this paper, we extend the scope of the literature's findings to a discussion on the appropriate technology to provide access. Using data on typical consumption patterns in regions that have been electrified via grid extension, village-grids and individual solar systems, we show that consumption levels of rural households in Africa can easily be supplied by solar home systems. In addition, we present cost estimates of on-grid connections from grid extension programs as well as different types of solar home systems. While the cost spread is huge, rural households have a clear preference for grid connections over solar home systems. We underpin this conventional wisdom by willingness-to-pay evidence for different service levels that we elicited in different countries. This measure of stated preference suggests that the access technology, on-grid vs. solar, matters more to rural beneficiaries than the revealed preference indicated by the realized consumption levels. Another issue that advocates in favour of on-grid electrification are maintenance and thus sustainability requirements that are more difficult to accomplish if electricity is provided by solar home systems or village-grids.

The remainder of this paper is organized as follows: in Section 2 we present a review of the seminal papers that have been published in recent years on the nexus between electrification and human development. Section 3 presents the complementary impact evidence from our studies. Section 4 compares on-grid and off-grid electrification interventions, and Section 5 concludes.

2. Impacts of rural electrification: The Literature

In 2008, the World Bank Independent Evaluation Group published a report on the state of affairs in terms of knowledge about the impacts of electrification and noted that "the evidence remains weak for many of the claimed benefits of rural electrification". In this section, we provide a brief review of the growing body of literature, represented by the seminal papers that have been published in recent years and that are frequently cited as empirical substance to justify investments in rural electrification.

One of the most influential papers is the one by Taryn DINKELMAN (2011). She examines mid-term effects of electricity network roll-out on rural employment growth and particularly female labor market participation in South Africa. She observes positive effects on female labor supply in the wake of electrification. The mechanism at work, Dinkelman argues, is a shift away from cooking with wood, which releases female time from home work for market work. In addition, she expects home business activities to increase. Dinkelman does not find evidence for an increase in labor demand. As a consequence, female wages do not increase in her data. One issue with this study is that South Africa is a very particular country with post-apartheid electrification being a very particular policy intervention. Hence, transferring these findings to other settings in Sub-Sahara Africa is only possible to a limited extent.

Two recent studies examine the long-term effects of electrification, both using data from India. RUD (2012) uses a 20-years-panel of Indian states, of which many receive access to the electricity network in the course of the observed period. He uses groundwater availability as predictor for network expansion (since water pumps played an important role in the green revolution) and hence as source of exogenous variation. He finds considerable positive effects of electricity access on the states' manufacturing output. Rud ascribes this result to an increase of business activities of existing firms, but also to the creation of new firms.

VAN DE WALLE et al. (2013) examine long-run effects at both regional and household level for the Indian grid roll-out program. Using data sets from 1982 and 1999 on a study population in which the connection status increased substantially in between these two surveys, they find long-term effects on both connected households and positive spillover effects on non-connected households in connected communities. Consumption increases as well as school enrolment rates and years of schooling improve for girls. Moreover, both men and women supply more labor. According to Van de Walle et al., men shift leisure time from daytime to evening hours and offer more regular work during daytime. Women, in contrast, offer more casual work, which might as well include unpaid domestic work. Wages do not increase significantly in their sample.

LIPSCOMB et al. (2012) investigate the long-run effects of the expansion of the electricity network in Brazil on economic development on the county level between 1960 and 2000. Similar to DINKELMAN (2011), they use an exogenous program placement instrument to identify the impacts. They find large effects on the counties' Human Development Index and average housing value as a proxy for improvements in living and working condition in a county. As the relevant mechanism behind this they identify positive effects of electricity access on employment and income as well as literacy and school enrolment.

Using household data from Nicaragua and an instrumental variables approach, GROGAN AND SADANAND (2012) explore rural electrification's effect on labor market participation. They find that agricultural activities decrease significantly, whereas non-farm salary work increases. In particular, women in rural areas are more likely to take up work outside their homes.

KHANDKER et al. (2013) study a World Bank rural electrification program in Vietnam implemented between 2000 and 2005. Using a two-period household panel data set with an electrification intervention that affected parts of the sample in between the two surveys, they examine income-related and educational outcomes with a fixed effects model. They find that various income measures are positively affected: farm and non-farm income, wages, and expenditures. For both boys and girls, school enrolment and total years of schooling increase. The latter comes as a surprise given the short period the newly connected communities have been using electricity. The authors themselves emphasize the particularity of Vietnam as a very fast growing country that might bear better potentials for economic development following to electrification than others.

KHANDKER et al. (2012) use a large cross-sectional household survey in Bangladesh and an instrumental variables approach to study effects of electricity access on income, expenditures and investments into education. They observe a quite substantial increase in income and expenditures as well as completed schooling years for both boys and girls. Another indicator they examine is the study time of school kids at home, which is frequently mentioned as an early indicator for investments into education triggered by electrification. The transmission channel is the facilitation of reading after nightfall through improved lighting. In fact, they find that school boys study around 22 minutes more and girls around 12 minutes more per day.

School kids' home study time is also investigated in BARRON AND TORERO (2014), who exploit exogenous variation introduced by randomly assigned vouchers on connection fees in El Salvador. They find an increase in total study time per day for both school boys and girls of around 10 minutes. For adults, they observe an increased engagement of males in non-agricultural activities leading to a substantial increase in income (34 percent more than at baseline). Barron and Torero also analyze the effect of electrification on respiratory diseases. The transmission channel here is that, in the absence of electricity, most households in El Salvador use kerosene for their lighting needs, which in turn leads to emissions of soot that is harmful for the exposed people.[1] In fact, in their sample the electrification treatment leads to a

[1] The electricity-health nexus via kerosene usage is also emphasized in van de Walle et al. (2013) and IEG (2008), although it is not examined in these studies.

concentration of harmful pollutants that is 63 percent lower than in the control group, which furthermore translates into a reduction of respiratory infections.

Somewhat comparable impact indicators are studied in SAMAD et al. (2013) who evaluate Solar Home System Usage in Bangladesh. They find effects on kids studying after nightfall and health because of a reduction in kerosene usage as well as an increase in expenditures.

Table 1: Overview seminal papers on rural electrification

Study	Country	Impact categories			
		Income generation/labor market	School enrolment / years of schooling	Study time	Health
DINKELMAN (2011)	South Africa	+			
RUD (2012)	India	+			
VAN DE WALLE et al (2013)	India	+	+		
LIPSCOMB et al. (2012)	Brazil	+	+		
GROGAN AND SADANAND (2012)	Nicaragua	+			
KHANDKER et al. (2013)	Vietnam	+	+		
KHANDKER et al. (2012)	Bangladesh	+	+	+	
BARRON AND TORERO (2014)	El Salvador	+		+	+
SAMAD et al. (2013)	Bangladesh	+		+	+

In conclusion, it stands out that all papers find – often substantial – effects on income or income related indicators such as labor supply (see Table 1). The second impact indicator most papers look at is investment into education, i.e. school enrolment, years of schooling, and kids' daily study time. Again, substantial positive effects are observed. Health indicators are less often analyzed, mostly due to a lack of data. Those papers that examine kerosene usage find important reductions in consumption after electrification as well as a reduction in exposure to harmful pollutants or even an effective reduction of respiratory infections. Only one study comes from the African continent, from South Africa – which for obvious reasons is a very particular case and thus transferability of findings to other Sub-Saharan countries is probably limited.

3. Impacts of rural electrification: the African context

3.1. Data used in this section

The evidence presented in this section stems from original data sets that we collected as part of evaluation studies on different rural electrification projects. The virtue of this data is the detailed information on lighting devices used in households, the purposes lighting is used for (including study time and business activities), and agricultural and non-agricultural activities of household members. In addition, we use data on the productive use of electricity in enterprises.

Table 2 summarizes the key features of the different data sets. For further information, we refer to the full reports and academic papers listed in Table A1 of the annex. The covered technologies span the spectrum from Pico-PV, solar home systems, village-grids to on-grid electrification.

Table 2: Studies and surveys used in this paper

Study[2]	Year of collection	Sample Size	Study set-up	Survey Focus	Technology
Benin 2009	2009	367	cross-sectional	Enterprises	Grid
Burkina Faso 2012	2010, 2012	896	DiD, cross-sectional	Households	SHS
Indonesia 2013	2010, 2013	442	DiD, before-after	Households	Village-grids
Rwanda Periphery 2012	2011, 2012	300	RCT	Households	Pico-PV
Rwanda 2013	2011, 2013	974	DiD	Households	Grid
Senegal 2009	2009	218	cross-sectional	Households	SHS
Senegal 2011	2011	482	baseline survey	Households	SHS
Senegal 2014	2014	205	baseline survey	Households	Village-grids
Uganda 2009	2009	223	cross-sectional	Enterprises	Grid
Zambia 2011	2011	180	baseline survey	Households	Grid

Note: DID and RCT refer to Difference-in-Difference and Randomized Controlled Trial evaluation approaches, respectively.

3.2. Lighting

BARRON AND TORERO (2014) state that "improvements in indoor air quality are expected to be present in most settings, but in most cases impact will depend heavily on household and context characteristics." The authors are right in emphasizing the harmful effect of kerosene that is considered being widely used for lighting purposes

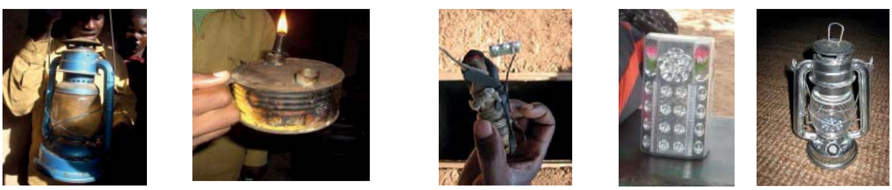
[2] Complete references of reports and papers presenting findings of these studies can be found in the Annex.

throughout the developing world. FULLERTON et al. (2009), LAM et al. (2012), POKHREL et al. (2010) and SCHARE AND SMITH (1995) provide evidence on the kerosene-health nexus. Kerosene usage for lighting has for long been neglected because of the apparently small contribution to household air pollution compared to firewood and charcoal usage for cooking. It is the immediate exposure of people sitting next to a wick lamp for a specific task (e.g. studying), that makes kerosene a substantial health threat. Hence, as found by BARRON AND TORERO (2014), it is true that electrification can yield substantial health benefits for households, even if it is not used for cooking purposes, as found

In recent years, however, the situation in rural Africa has changed rapidly. Even without any external intervention, people in non-electrified regions use kerosene and candles less and less, as dry-cell battery driven LED-lamps have become available in almost every rural shop. Among the most common lamps are small LED torches and mobile LED lamps that exist in various shaping, for example a battery driven hurricane lamp (see Figure 1).

Figure 1: Lighting devices used in non-electrified areas

hurricane lamp	traditional tin lamp	hand-crafted LED lamp	Ready-made LED lamps



Source: Own illustration

In addition, many rural households use hand-crafted LED lamps, i.e. diodes that are removed from LED torches and installed somewhere in the house or on a stick that can be carried around. Among many other advantages, the LED technology perfectly fits to the financing capacities of the poor, as it can be scaled almost continuously. People with very limited financial capacities use hand-crafted lamps with only one or two diodes. As capacity to pay increases, households use multi-diode lamps or even solar systems. Pictures of these lighting devices are depicted in Figure 1.

As can be seen in Table 3, the LED technology has widely made inroads into households in Africa and, as a consequence, kerosene usage is on the decline. The depicted numbers refer to the share of households that use either dry-cell batteries or kerosene as the major lighting source. It bears noting that we only included areas in this analysis in which no electricity-oriented intervention was going on. LED usage reported in Table 3 reflects technology uptake, which has not been initiated by any deliberate policy intervention.

Table 3: Kerosene and dry-cell battery usage as major lighting source

Survey	Survey Year	Share of non-electrified HH using […] for lighting		Annual decrease of kerosene consumption in percentage points per year (if panel data)
		kerosene	Batteries	
Burkina Faso 2012	2010	0.29	0.99	
	2012	0.10	0.99	0.11
Indonesia 2013	2010	0.97	0.23	
Rwanda 2013	2011	0.64	0.24	
	2013	0.36	0.47	0.12
Rwanda Periphery 2012	2011	0.56	0.48	
	2012	0.51	0.46	0.09
Senegal 2009	2009	0.20	0.99	
Senegal 2011	2011	0.20	0.99	
Senegal 2014	2014	0.01	0.90	
Zambia 2011*	2011	0.19	0.41	

*Note: Households with electricity sources are excluded from the analysis. * In Zambia, due to unreliability of usage data on kerosene and battery, we report ownership of the respective lamps, i.e. at most 19 percent and 41 percent of households use kerosene and batteries respectively.*

In particular, the two Western African countries Burkina Faso and Senegal reveal dry-cell battery usage rates in rural areas close to 100 percent and, consequently, kerosene usage that is already very low and further decreasing. In Rwanda, LED usage rates are much lower, but increasing at a rapid pace. The Rwanda Periphery survey was conducted in areas clearly beyond the direct and indirect reach of the expanding Rwandan grid. Even in these remote places, half of the surveyed population is mainly using dry-cell batteries, mostly one or two diode hand-crafted lamps. Likewise, a considerable share of households is still using kerosene, but given the trends in battery usage rates, this can be expected to decrease further. While we only have cross-sectional data for Zambia, the level of battery usage was already remarkably high at the time of the survey. In contrast, households in remote localities in Indonesia, the only Asian country in our portfolio, report kerosene usage rates close to 100 percent.

3.3. Study time

BARRON AND TORERO (2014) and KHANDKER et al. (2012) find positive effects for another important indicator, the study time of school kids at home, that is also frequently emphasized by rural electrification donors (see for example IEG 2008, SACHS et al. 2004, UN 2005). Since traditional lighting sources like kerosene and candles, but also hand-crafted torches emit very little lighting, studying after nightfall is facilitated considerably after electrification[3]. In line with this assumption, Barron and Torero in El Salvador as well as Khandker et al. in Bangladesh find positive effects on the time kids dedicate to studying at home.

For our data set, we collected detailed time-usage data for all household members including school kids. In contrast to Barron and Torero and Khandker et al. we differentiated between study time *before* and *after* nightfall. Using this information,

[3] Candles and wick lamps emit around 10-12 lumens, two diode hand-crafted torches around 10 lumens, while compact florescent lamps (energy savers) emit 240-1,000 lumens (O'SULLIVAN et al., 2006; GRIMM et al. 2014)

we observe that, in fact, the time kids study after nightfall increases significantly in three countries. However, if additionally also study time before nightfall is examined, it becomes visible in two countries that study time before nightfall decreases. This indicates that kids shift study time from daytime to night-time. Only in Senegal, we are able to detect a significantly positive effect on total study time (see Table 4). This shift in study time from day- to night-time is clearly associated with convenience benefits for the newly electrified households, but the investments into education that Torero (and others) observes can be confirmed only for one country.

Table 4: Daily study time of children between 6 and 17 years old (in minutes)

Study	Increase in study time before and after nightfall (total study time)	Increase in study time after nightfall
Burkina Faso 2012	No effect	No effect+
Indonesia 2013	No effect	No effect+
Rwanda Periphery 2012	No effect	19 min.#
Rwanda 2013	No effect	25 min.+
Senegal 2009	21 min.§	30 min.§

Note: Aggregated values based on information on daily routine of children in four groups distinguished by age and sex (older vs. younger than 12 years; male vs. female). Increases are identified using DiD-estimation (+), cross-sectional comparison in an RCT (#) or cross-sectional comparison in an observational study (§). If increases are reported the estimated differences are statistically significant at least at the 5 percent level.

In line with our findings, neither FURUKAWA (2012) nor BENSCH et al. (2011) detect positive effects on the time kids dedicate to studying at home for Uganda and Rwanda, respectively.

3.4. Income and productive use of electricity

A straightforward expectation related to rural electrification is an increase in people's income. In many cases, rural electrification interventions by the international community are motivated based on these expectations (see, for example, IEG, 2008 and UN, 2005). Indeed, there are various ways in which rural electrification might affect the income of newly connected households ranging from direct effects via home business activities to better job opportunities in now connected enterprises in the community. TORERO (2015) has brought the debate considerably forward by formulating a useful theoretical framework for the channels through which income may be affected by access to electricity.

First, changes of labor allocation across activities might occur and lead to higher productivity and hence income. Here, it is particularly the shift from agricultural to non-agricultural activities that is associated with productivity increases. Second, electrification might affect the household's total working hours. Third, wages might increase, also leading to increases in purchasing power. The literature review in Section 2 has shown that for Latin American and Asian countries there is a good substance of evidence for the first channel in particular. In the following, we examine our data sets in order to identify parts of the transmission channels in Torero's model.

For the first mechanism, shifts in labor from agricultural to non-agricultural activities, we examine productive appliance usage, changes in the main occupation and firm creation after electrification. It is important to emphasize that the vast majority of households in rural Africa are farmers and do not pursue any non-agricultural activity. Communities are characterized by only little entrepreneurial activity in the non-agricultural sector. The regions we surveyed represent this typical pattern.

Across our portfolio of surveys, households hardly use electricity for income generation purposes at all. As can be seen in Table 5, this is also reflected in the share of households that use appliance productively, which is close to zero in all cases. For the few cases in which appliances are used by households to earn income, the produced goods and services are oriented towards the local population (mobile phone charging, television "cinemas", or mills). Also, electrification does not lead to a change in occupation of household members. This finding can be corroborated by only little effects of electrification on firm creation and firm development – which would be the major driver for job opportunities in the non-agricultural sector.[4]

Table 5: Productive appliance usage and labor shifts to non-agricultural activities

Labor / productivity	1. Mechanism: *Shifts in labor devoted to agricultural and non-agricultural activities*			
	Productive use of electric appliances [Share of HH in electrified areas using respective appliance]		Changes in main occupation of HH members	Firm creation on village level; firm development
Benin 2009	Not applicable		Not applicable	Some very successful new enterprises, but existing firms do not benefit
Burkina Faso 2012	Video-TV-system Electric sewing machine	<1% <1%	Not applicable	Not applicable
Indonesia 2013	Rice cooker Electric carpentry equipment Electric brush Grinder Blender	<1% <1% <1% <1% <1%	No effect	Very low – virtually only kiosks
Rwanda 2013	TV DVD Electric sewing machine Electric mill	1% 2% 2% 2%	No effect	Modest firm creation and firm development, only in well-connected business centers
Senegal 2009	TV Electric sewing machine	1% 1%	Not applicable	Not applicable
Uganda	Not applicable		Not applicable	Very little evidence for positive effects on firm development; no firm creation

If one general statement can be derived in this regard from our different studies in various countries with different research foci it is the fact that market access is the limiting factor in wide parts of rural Africa and generally in remote areas. This lacking access to markets is much more important for the development of non-agricultural activities than electrification and it consequently cannot be overcome in the short or mid-term by the provision of electricity.

As for the second mechanism, a potential increase in household's total working

[4] See also NEELSEN AND PETERS (2011) and PETERS et al. (2011).

hours, we meticulously elicit information on the daily routine of household members. In none of our studies a shift in time use towards income generation could be observed. Changes in the daily routines mostly relate to how people spend their leisure time and to some extent to studying (see Section 2.3.). Against this background, it is also difficult to investigate the third mechanism, a potential increase in wages as a result of an increasing productivity, simply because local non-agricultural labor markets are virtually inexistent and hence no wages can be observed. In surveys that concentrated on firms, though, we find some weak indication for increasing wages in enterprises once they are electrified (NEELSEN AND PETERS 2011, PETERS et al. 2013).

These findings suggest that at least for very rural and remote areas – which is where the vast majority of non-electrified Africans live – impact expectations for income dimensions should be kept at modest levels. It is the difficult access to markets that is hampering the rise of new enterprises or the growth of existing ones, which in turn is the necessary condition for the changes predicted by Torero's model. It has to be emphasized, though, that our data sets are unable to observe what happens in the long run. The period between connection and our follow-up survey is between one and seven years. Long-term studies in non-African countries find more positive or even substantial effects (see RUD 2012, VAN DE WALLE et al. 2013, and LIPSCOMB et al. 2013).

4. On-grid vs. off-grid electrification

So far we have not distinguished between the different technologies by which access to electricity is provided. While most studies in the literature examine on-grid electrification interventions[5], the technologies that we studied cover the range of electricity sources from Pico-PV kits and solar home systems to village-grids and extension of the national grid. The differences in capacity potentials of these

[5] SAMAD et al. (2013) is a prominent exception.

technologies are obvious: a Pico-PV kit only provides enough electricity to feed maybe one or two lamps and a radio; on-grid connections allow for usage of refrigeration and even heavier machinery, for which three-phase electric power is required.

Table 6: Retail prices of solar systems on local markets

Country	Year	Capacity/Quality	Price	Source
Burkina Faso	2010-12	No quality certification; Wp not specified	135 USD	Burkina Faso 2012[1]
Mongolia	~2010	50 Wp; High quality certificate[2]	350 USD	EWSA 2012
Rwanda	2013	30-50 Wp; High quality certificate[2]	200-300 USD	EWSA 2012; Interviews with key resource persons (2013)
Senegal	2010 -14	No quality certification; Wp not specified	440 USD	Senegal 2014[1]
Worldwide	2014	Lighting Africa certified Solar Portable lights <10 Wp	10-40 USD	GOGLA and A.T. Kearney 2014
Worldwide	2014	Lighting Africa certified Pico-PV kits to power a radio or small TVs	50-100 USD	GOGLA and A.T. Kearney 2014

[1] In the Burkina Faso and Senegal survey, already at the baseline stage, a considerable share of households were using solar systems that they obtained at non-subsidized prices on local markets. The Wp was unknown for users and could thus not be elicited. [2] Includes aftersales services.

These advantages come at a price, since investment requirements for grid extensions are enormous. WORLD BANK (2009) estimates a cost range for on-grid electrification in rural areas of 730 to 1450 USD per connection. Recent experience from the large Rwandan Electricity Access Roll-Out Program confirms these numbers. Costs of individual solar systems, in contrast, are much lower, but vary considerably depending on the quality and the capacity of the system. Table 6 shows prices of different individual solar systems in a set of countries, based on different sources. Solar lamps are available from 10 USD, Pico-PV kits lie between 50 and 100 USD and for 50 Wp solar home systems most sources state prices between 200 and 350 USD.

Even if the numbers in Table 6 can only be taken as rough estimates, it becomes evident that the cost spread between on-grid electrification and individual solar systems is considerable. In a next step, we therefore examine whether higher capacities are actually needed in rural areas. Table 7 shows a set of descriptive statistics about electricity consumption in our data sets. As can be seen from the low mean and median values for both kWh consumption and peak watt demand, the majority of connected households consume very little electricity only and do not use appliances that require high watt power. For these households, the provision of regular 50 Wp (or less) solar home systems would be sufficient to meet their demands. Few connected households consume an amount of electricity and require peak loads that cannot be provided by off-grid technologies. However, these outliers only justify higher investment costs if they generate corresponding spill-overs, which is very questionable.

Table 7: Consumption levels of different technologies

Country (Year)	Technology	Average electricity consumption in kWh per month			Peak demand (Watt)*		
		Mean	Median	Max	Mean	Median	Max
Rwanda (2013)	Grid rural	11.1	6.6	180	202	12	4093
Indonesia (2010)	Village-grid	22	14	322	473	80	5204
Burkina (2013)	SHS	6.4	5.4	59	54	26	1213
Senegal (2009)	SHS	4.6	4.2	12	31	9	152

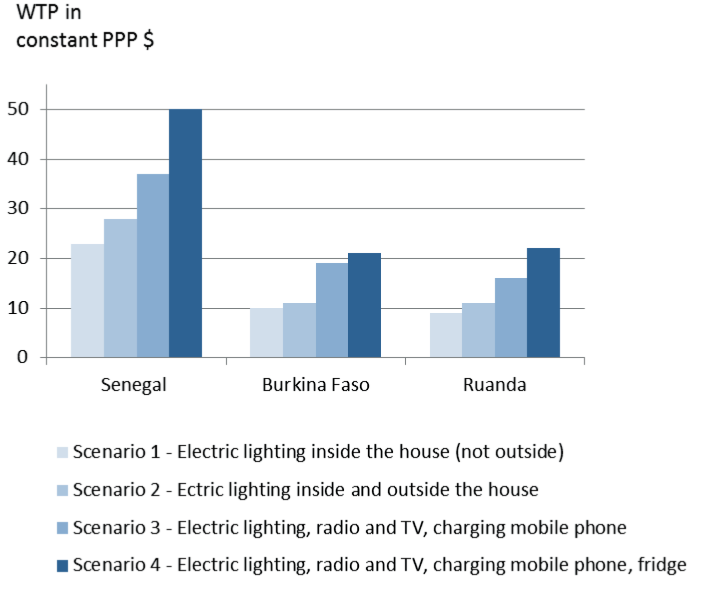
*Peak demand has been calculated by summing up the wattage of all electric appliances used in the household.

If these consumption levels are representative for many rural areas in which electrification interventions are planned this would call for a stronger consideration of low-cost and lower-capacity technologies in the design of these interventions. These cost and consumption considerations are contrasted frequently with the common wisdom that rural dwellers have a clear preference for on-grid electricity over decentralized options. We could confirm this preference in many open interviews and focus group discussions across our studies. To make an attempt to quantify this preference, we included simple willingness-to-pay questions in our questionnaires for different service packages before electrification. The service packages roughly reflect the capacity potentials of the different technologies.

It is certainly hasty to take the stated WTP at face value, but the hierarchy of preferences can clearly be found in the WTP patterns depicted in Figure 2. People augment their WTP considerably if the service package contains a TV set (which would require a larger solar system) and again if a fridge is included (which would require a grid connection). For future research, it would be recommendable to probe deeper into household's preferences by explicitly disclosing the opportunity costs of a grid connection. For example, service packages can be offered in WTP studies that contrast a grid connection or to a cost-equivalent service package of a solar home system and other services such as piped water access or improved cooking devices.

Another issue that forms part of the discussion on the different electrification technologies is the organization of after sales service and maintenance, which has clear implications for the sustainability of electrification interventions. Ensuring sustainability is much more difficult in off-grid approaches. While national utilities have longstanding experience in managing and extending the national grid (or large stand-alone grids), they are mostly lacking these skills in managing solar dissemination programs. This is why for solar home system dissemination programs in most cases private sector companies are included who take over the after-sales service. While the concept behind this is straightforward in theory – users either pay on a fee-for-service basis or the private company offers a warranty – in many cases these approaches have failed. Likewise, village-grids are in most cases operated by private operators or village committees. Again, this has proven to be more difficult in practice than it is in theory.

Figure 2: Willingness-to-pay for different service levels (monthly fees)



5. Conclusion

The United Nations' endeavor to provide modern energy to everybody by 2030 (see UN 2010, SE4All 2013) is based on the assumption that rural electrification contributes to various dimensions of human development. In fact, the academic literature underpins these expectations. However, the seminal studies in this area are based on findings from Asia and Latin America. The present paper has challenged the transferability of these findings to Africa, where half of the currently 1.3 billion people without electricity access live. We provided evidence on three important categories of socio-economic impacts of rural electrification: potential positive health effects through a reduction in kerosene consumption, investments into education related to lighting usage for studying and income increase potentials.

Based on original data sets from different African countries and Indonesia, we have shown that expectations related to these impact dimensions should not be too high. Thus, electrification should not be motivated by hopes for short- and mid-term impacts on classical poverty indicators alone. Yet, if the scope is extended beyond the mere definition of poverty along MDG-like indicators towards direct measures of well-being, electrification for sure has its merits. Electricity has an extremely high importance for the rural population and softer impacts on perceived convenience and people's flexibility are considerable. VAN DE WALLE et al. (2013) present a model that captures the channels through which household's welfare is affected directly.

In addition, the analysis in this paper applies to the short- and mid-term effects of electrification and long-term effects might differ. Although for non-African countries the existing evidence in the literature is promising, the bottlenecks for rural development after electrification we observed in our studies – lack of market access and hence very limited labor demand – will likely not vanish after a few more years without a further exogenous development impetus. Nonetheless, in the long term electrification might lead to a higher development trajectory by enabling improved provision of public goods, most notably health and education. Also, the long term impacts of psychological dimensions should not be underestimated, as emphasized by FOUQUET AND PEARSON (2006) in there analysis of seven centuries of lighting usage in the UK.

Whether such long-term benefits justify today's high investment costs for on-grid electrification is an open question and eventually one of social discount rates. The focus of the international endeavor to fight poverty is more on short-term achievements of basic needs as it is reflected in the MDGs. This would rather call for a quick dissemination of low cost solar systems that meet the basic energy needs, but obviously lack the capacity to enable industrialization-like developments.

In fact, modern energy is not a binary situation. Rather, there are several steps between a candle and an incandescent light bulb or even a situation in which lighting can hardly be considered a scarce good (like in industrialized countries). A regular connection to the national electricity grid is of course much more powerful and hence allows for usage of more appliances than a connection to a village-grid or an individual solar home system. The SE4All Global Tracking Framework (GTF) accounts for this by defining four tiers of electricity access (see SE4All 2013).

The analysis in this paper has shown that in rural Africa, where most of the so-far non-electrified households live, demand is very low. Even if the provided electricity connection allows for Tier 4 consumption in the GTF, large parts of the target group reveal extremely low demand patterns that qualify for Tier 1 or 2 at best. This calls for intensifying the discussion about whether to focus electrification investments on grid extension programs or off-grid dissemination programs.

This discussion should also encompass sustainability considerations and potential repercussions on higher technical assistance costs. It should furthermore account for the fact that people have a clear preference for on-grid connections over decentralized technologies. On this note, the academic side might contribute by intensified research to improve the understanding of these preferences.

References

Bensch, Gunther, Jochen Kluve, and Jörg Peters. 2011. "Impacts of rural electrification in Rwanda." *Journal of Development Effectiveness*, 3(4): 567–88. http://ideas.repec.org/a/taf/jdevef/v3y2011i4p567-588.html.

Dinkelman, Taryn. 2011. "The Effects of Rural Electrification on Employment: New Evidence from South Africa." *American Economic Review*, 101(7): 3078–108.

EWSA, 2012. Rwanda Electricity Access Roll Out Program. Mid-term review. Final report.

Fouquet, R. and P.J.G. Pearson, 2006**. "**Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300-2000)." *The Energy Journal*, 27 (1), pp. 139-177.

Fullerton, D. G., Jere, K., Jambo, K., Kulkarni, N. S., Zijlstra, E. E., Grigg J., French, N., Molyneux, M. E., and S.B. Gordon, 2009. "Domestic smoke exposure is associated with alveolar macrophage particulate load" *Tropical Medicine & International Health* 14(3): 349–354.

Furukawa, Chishio. 2013. "Do Solar Lamps Help Children Study? Contrary Evidence from a Pilot Study in Uganda." *The Journal of Development Studies*, 50(2): 319–41. http://dx.doi.org/10.1080/00220388.2013.833320.

GOGLA and A.T. Kearney, 2014. "Investment and Finance Study for Off-Grid Lighting." Global Off-Grid Lighting Association, A.T. Kearney. Available at [http://global-off-grid-lighting-association.org/wp-content/uploads/2013/09/A-T-Kearney-GOGLA.pdf].

Grimm, Michael., Anicet Munyehirwe, Jörg Peters and Maximiliane Sievert ,2014. "A First Step up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda." *IZA Discussion Paper Series*. No. 8594. IZA, Bonn.

IEA. 2011. *World Energy Outlook 2011*. Paris.

IEA. 2012. *World Energy Outlook 2012*. Paris.

IEG, 2008. The Welfare Impacts of Rural Electrification – An IEG Impact Evaluation. Independent Evaluation Group, World Bank.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. 2012. "The Welfare Impacts of Rural Electrification in Bangladesh." *The Energy Journal*, 33(1). http://ideas.repec.org/a/aen/journl/33-1-a07.html.

Lam, Nicholas L., Smith, Kirk R., Alison Gauthier, and Bates, Michael N. 2012. "Kerosene: A Review of Household Uses and their Hazards in Low- and Middle-Income Countries." *Journal of Toxicology and Environmental Health, Part B*, 15(6): 396–432.

Lipscomb, Molly; A.Mushfiqu Mobarak and Tania Barham, 2013. Development Effects of Electrification: Evidence from Topographic Placement of Hydropower Plants in Brazil." American Economic Journal: Applied Economics, 5 (2): 200-231.

Neelsen, Sven and Jörg Peters. 2011. "Electricity usage in micro-enterprises — Evidence from Lake Victoria, Uganda." *Energy for Sustainable Development*, 15(1): 21–31. http://www.sciencedirect.com/science/article/pii/S0973082610000712.

O'Sullivan, Kyran and Douglas F. Barnes. 2006. "Energy Policies and Multitopic Household Surveys. Guidelines for Questionnaire Design in Living Standards Measurement Studies." *ENERGY AND MINING SECTOR BOARD DISCUSSION PAPER*(17).

Peters, Jörg, Colin Vance, and Marek Harsdorff. 2011. "Grid Extension in Rural Benin: Micro-Manufacturers and the Electrification Trap." *World Development*, 39(5): 773–83.

Peters, J., C. Vance and M. Harsdorff (2013), Electrification and Firm-Performance in Rural Benin: An Ex-Ante Impact Assessment. Energy Sector Management Assistance Program (ESMAP), the Africa Electrification Initiative (AEI), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). http://produse.org/imglib/downloads/PRODUSE_study/PRODUSE%20Study_Case%20Study%20Benin.pdf

Pokhrel, A. K., Bates, M. N., Verma, S. C., Joshi, H. S., Sreeramareddy, C. T. , and K. R. Smith, 2010. "Tuberculosis and Indoor Biomass and Kerosene Use in Nepal: A Case–Control Study." *Environmental Health Perspectives* 118(4): 558-564.

Rud, Juan P. 2012. "Electricity provision and industrial development: Evidence from India." *Journal of Development Economics*, 97(2): 352–67.

Sachs, J.D., J.W. McArthur, G .Schmidt-Traub, M. Kruk, C. Bahadur, M. Faye, and G. McCord. 2004. "Ending Africa's Poverty Trap" *Brooking Papers on Economic Activity*, (1) 2004: 117-240.

Samad, Hussain A., Shahidur R. Khandker, M. Asaduzzaman, and Mohammad Yunusd. 2013. "The Benefits of Solar Home Systems:. An Analysis from Bangladesh." *World Bank Policy Research Working Paper*(6724).

Schare, S. and Kirk.R. Smith, 1995. "Particulate emission rates of simple kerosene lamps." *Energy for Sustainable Development* **2** (2): 32-35.

Sustainable Energy for All (SE4All). 2013. Sustainable Energy for All Global Trecking Framework Consultation Document. http://www.se4all.org/tracking-progress/ (accessed September 10, 2014).

United Nations. 2005. *The Energy Challenge for Achieving the Millenium Development Goals*. New York.

United Nations. 2010. *Energy for a Sustainable Future. Report and Recommendations*. New York.

van de Walle, Dominique, Martin Ravallion, Vibhuti Mendiratta, and Gayatri Koolwal. 2013. "Long-term impacts of household electrification in rural India." *World Bank Policy Research Working Paper*(6527). http://ideas.repec.org/p/wbk/wbrwps/6527.html.

World Bank. 2009. "Unit Costs of Infrastructure Projects in Sub-Saharan Africa." *Africa Infrastructure Country Diagnostic, Background Paper*(11).

Annex: Evaluation Studies and Related Publications

Study	Publications
Benin 2009	Peters, J., C. Vance und M. Harsdorff (2011), Grid Extension in Rural Benin: Micro-Manufacturers and the Electrification Trap. *World Development* 39 (5): 773-783. Peters, J., C. Vance and M. Harsdorff (2013), Electrification and Firm-Performance in Rural Benin: An Ex-Ante Impact Assessment. Energy Sector Management Assistance Program (ESMAP), the Africa Electrification Initiative (AEI), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Available at [http://produse.org/imglib/downloads/PRODUSE_study/PRODUSE%20Study_Case%20Study%20Benin.pdf]
Burkina Faso 2012	Bensch, G., M. Grimm, J. Langbein, and J. Peters (2013), The provision of solar energy to rural households through a fee-for service system. Public Private partnership GDIS-NUON. Implemented by FRES and the local company Yeelen Ba. Final Report on behalf of the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs.
Indonesia 2013	Peters, J., M. Sievert (2014), The provision of electricity to rural communities through Micro-Hydro Power. Micro Hydro Power pilot programme within the National Programme for Community Development (PNPM) supported by the Netherlands through Energising Development. Final Report on behalf of the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs.
Rwanda Periphery 2012	Grimm, M., A. Munyehirwe, J. Peters, M. Sievert (2014) A First Step up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda. IZA Discussion Paper Series. IZA DP No. 8594. IZA, Bonn. Available at [http://ftp.iza.org/dp8594.pdf] Grimm, M., J. Peters, M. Sievert (2013), Impacts if Pico-PV Systems usage using a Randomized Controlled Trial and Qualitative Methods. Final Report on behalf of the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. Available at [http://www.iob-evaluatie.nl/resources/impacts-pico-pv-systems-usage-using-randomised-controlled-trial-and-qualitative-methods]
Rwanda 2013	Peters, J., M. Sievert, A. Munyehirwe, and L. Lenz. (2014) The provision of grid electricity to households through the Electricity Access Roll-out Programme. Final Report on behalf of the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. Available at [http://www.iob-evaluatie.nl/EARP]
Senegal 2009	Bensch, G., J. Peters, and M. Sievert (2013), Fear of the Dark? How access to electric lighting changes attitude and behavior in rural Senegal. *Journal of Rural and Community Development*, 8(1), 1-19.

Senegal 2011	Bensch, G., J. Peters, and M. Sievert (2011), Report on ERSEN Baseline Study. Baseline report on behalf of the German Technical Cooperation (GTZ).
Senegal 2014	Baseline data collection for Impact Evaluation of ENERSA S.A. on behalf of the Dutch Development Company, FMO.
Uganda 2009	Neelsen, S., J. Peters (2011), electricity Usage in Micro-Enterprises – Evidence from Lake Victoria, Uganda. *Energy for Sustainable Development* 15 (1): 21-31. Neelsen, S., J. Peters (2013) Micro-Enterprise Electricity Usage in Two Export-Oriented Fishing Communities at Lake Victoria, Uganda. Energy Sector Management Assistance Program (ESMAP), the Africa Electrification Initiative (AEI), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Available at [http://produse.org/imglib/downloads/PRODUSE_study/PRODUSE%20Study_Case%20Study%20Uganda.pdf]
Zambia 2011	Neelsen, S., J. Peters, and G. Bensch (2011), Renewable Energy Based Electricity Generation for Isolated Mini-Grids, Zambia. Baseline Report on the GEF project on behalf of the United Nations Industrial Development Organization (UNIDO).