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The Lighting Transition in Africa – From Kerosene to LED and the Emerging Dry-Cell Battery Problem

Abstract

Non-electrified people in Africa, still more than 500 million today, have been using kerosene and candles for their lighting purposes for decades. The lighting quality of these sources is low and in particular kerosene usage is associated with harmful soot emissions. Alleviating this grievance has always been a major goal of electrification programs. The present paper shows that in recent years a transition has taken place among the rural non-electrified population in Africa: without any external support from governmental or non-governmental organisations people have replaced kerosene lamps and candles through LED lamps, which are mostly powered by dry-cell batteries. LED lamps are available in rural shops virtually everywhere and provide brighter and cleaner lighting than traditional lamps. The downside of this massive increase of LED usage is a soaring consumption of dry-cell batteries. Because of the toxic content of many dry-cell batteries and since people dispose of discharged batteries inappropriately in latrines or the nature, harmful effects on the local environment are likely. We conclude by suggesting that rapid action is needed to put in place an effective waste management system.

JEL Classification: O13, O33, Q53, Q56

Keywords: Electrification; energy access; technology adoption; off-grid energy usage; e-waste

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1 Gunther Bensch, RWI; Jörg Peters, RWI and AMERU, University of the Witwatersrand, Johannesburg, South Africa; Maximiliane Sievert, RWI. *– The data underlying this research was collected for impact evaluations commissioned by the Policy and Evaluation Department of the Ministry of Foreign Affairs of the Netherlands (IOB), the Netherlands' Enterprise Agency (RVO), the Netherlands' Development Bank (FMO), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Peters and Sievert gratefully acknowledge the support of a special grant (Sondertatbestand) from the German Federal Ministry for Economic Affairs and Energy and the Ministry of Innovation, Science, and Research of the State of North Rhine-Westphalia.* *– All correspondence to: Jörg Peters, RWI, Hohenzollernstr. 1-3, 45128 Essen, Germany, e-mail: peters@rwi-essen.de*

1. Introduction

In rural Africa, over 500 million people and thus 85 % of the population are lacking access to electricity (World Bank/IEA 2015). To meet their daily energy demands for simple services such as cooking, access to information, and lighting they have to rely on off-grid energy sources. For decades, people have been using candles or kerosene in wick lamps and hurricane lanterns to provide basic lighting services. The lighting quality of these sources in terms of brightness is low and in particular kerosene usage is associated with harmful soot emissions. In this paper, we present new evidence suggesting that a technology that recently has become accessible in most parts of the world is changing these patterns rapidly: Light-emitting diodes (LED).

Without any external intervention from governmental or non-governmental organisations, the rural non-electrified population has replaced kerosene lamps and candles through LED lamps, mostly powered by dry-cell batteries. As a mass-product fabricated in East Asia, LED end-user prices have decreased considerably over the last years. The virtue of LED lamps is their high efficiency and low energy consumption compared to classical electric lighting sources like incandescent light bulbs, but in particular compared to kerosene lamps or candles. LED lamps therefore provide brighter and cleaner lighting than traditional lamps. In addition, ceasing kerosene usage reduces the emission of climate active carbon dioxide and black carbon (Lam et al. 2012*a*, UNEP 2012). The downside of the massive increase of LED usage is a soaring consumption of dry-cell batteries in off-grid areas. Dry-cell batteries contain heavy metals and are in general informally disposed of locally. While the nexus between these toxics and people's health and the environment is not fully understood, local disposal at high concentrations is very likely to be harmful for the population.

The trend from traditional off-grid lighting sources to LED has been largely ignored by governments and donor agencies active in the electrification sector. Beliefs about kerosene as the dominating fuel are still prevailing, also because official censuses so far do not account for dry-cell battery LED lights as a lighting option.[1] The evidence we present is based on rural household surveys we conducted in Benin, Burkina Faso, Mozambique, Rwanda, Senegal, Tanzania, and Zambia between 2006 and 2014. These surveys were part of evaluation studies on the impacts of electrification projects and thus have a clear focus on energy and lighting usage.

This paper has three policy implications. First and most importantly, our findings show that dry-cell battery consumption is escalating in rural regions of Sub-Saharan Africa where waste management systems do not exist. Here, quick action is needed to understand the implications this has for the local environment and, if necessary, to put in place an effective waste management system. Second, our findings have implications for socio-economic impact potentials of electrification programs. Households to be electrified will experience fewer impacts on lighting quality and air pollution when using LED lamps instead of fuel-based lamps at baseline. This is of importance for the design of the Sustainable Energy for All initiative, the UN-led global effort to reach all hitherto non-electrified regions with electricity by 2030. Third, from a technology adoption perspective it is interesting to shed more light on the LED technology's success story. Except for mobile phones, no other technology has made such deep inroads to the periphery of the continent without any external support.

The remainder of this paper is organized as follows: in Section 2 we first present lighting usage patterns before the transition to LED based on a secondary data set, followed by the lighting usage patterns we observe in our data. In Section 3, we examine the economic reasons behind the transition from kerosene to LED. Section 4 shows the dry-cell battery disposal behaviour of rural households in the surveyed regions and summarizes the existing knowledge on environmental hazards related to this. Section 5 concludes.

[1] They are either not recent enough or do not differentiate between battery-run LED lamps and other lighting options such as rechargeable lamps. See, for example the latest General Census of the Population and of Housing, Agriculture and Livestock in Senegal (ANSD 2014) or the Lighting Africa Nigeria Consumer Insights Market Study (2013).

2. The lighting transition

On a historical scale, dramatic transformations in the cost and provision of artificial illumination in industrialized countries from tallow candles (i.e. candles made from moulded animal fat) to modern electric lighting have been impressively outlined for the case of Great Britain by Fouquet and Pearson (2006). In Africa, this last step has not been made for many years, since unlike Great Britain and other industrialized countries access to grid-based electricity is widely lacking. For a selection of African countries, Table 1 shows lighting sources that were used among non-electrified[2] households in 2008, so before the LED technology was so widely available. The consumption data is based on rural lighting market studies and can be considered the most comprehensive set of information on lighting usage in sub-Saharan Africa (UNEP/ GEF 2013, IFC 2011). In all depicted countries, kerosene and candles were the dominating lighting sources and batteries still took a negligible share of two to 14 % of the households' total lighting costs. Except for Zambia, where households almost exclusively used candles, national average monthly consumption figures ranged between 5 and 9 litres of kerosene, 3 and 13 candles and 0.8 to 1.2 batteries.

Table 1: Lighting consumption among non-electrified households in selected sub-Saharan African countries in 2008

	Non-electrified population, in %	Share in total lighting cost among non-electrified households, in %		
		Kerosene	Candles	Batteries
Ethiopia	83	77	8	14
Ghana	40	90	4	6
Kenya	84	89	4	6
Tanzania	86	78	17	5
Zambia	82	17	81	2

Source: UNEP/GEF (2015)

In general, systematic information on energy and lighting usage is hardly existent. The typical datasets available for African countries, the Demographic and Health Surveys (DHS) or the Living Standard Measurement Studies (LSMS), for example, do

[2] Households qualify as electrified if they are connected to an electricity grid or if they use a Solar Home System or a generator. For details see OECD/IEA (2010).

not systematically contain information on lighting usage.[3] The data we present in the following has been collected in the course of impact evaluations in rural electrification interventions we have conducted between 2006 and 2015 in Benin, Burkina Faso, and Senegal in Western Africa and Mozambique, Rwanda, Tanzania, and Zambia in Eastern Africa. Most surveys cover between ten and 50 villages from different areas of the countries, with total sample sizes ranging between 150 and 1500 interviews per survey. The purpose of these evaluations was to evaluate the effect electricity access has on socio-economic living conditions of the interventions' target groups. For this reason, we dedicated a lot of attention to the way people use lighting as one major impact transmission channel of electrification (e.g. through night-time activities like home studying). A data description can be found in the appendix including references to published reports and peer-reviewed publications that provide more details about these data sets.

Table 2 shows the lighting sources used by non-electrified households in the surveyed regions. We define the non-electrified population in line with Table 1 as those households that did not have access to electricity in the form of grid connections, generators, Solar Home Systems (SHS), and smaller-sized plug-and-play Pico solar PV systems[4]. Note that these surveys are representative for the areas in which they were conducted. These areas are typical for the rural settings in the respective country. None of our surveys was conducted in peri-urban areas or the outskirts of cities, some even in pretty remote areas. Hence, our LED usage rates will rather underestimate the country wide usage rates if off-grid areas that are closer to the existing infrastructure and urban centers were included.

[3] The DHS surveys only elicit whether the interviewed household has access to electricity. No question is asked on the usage of lighting. Among LSMS studies conducted in Sub-Saharan Africa since 2006, only four addressed lighting, one through a binary question on different lighting energy sources (Uganda) and the other three asking for the major lighting energy source (Ethiopia, Malawi and Tanzania).

[4] Usage rates of SHS and Pico-PV systems have also increased considerably, as can be taken from Table A1 in the Appendix.

First of all, the surveys we conducted until 2008 confirm the UNEP data presented in Table 1. The surveyed households in Benin, Mozambique, and Rwanda solely used the classical off-grid lighting sources kerosene and candles. Battery run torches were available in some of the surveyed communities (not shown in the table), but since efficient LED light were not yet available battery consumption was prohibitively expensive. In all surveys conducted after 2009 we observe considerable usage rates for dry-cell battery LED lights. In particular, in Western African countries dry-cell batteries have replaced kerosene and candles to a very large extent.

For countries in other African regions, traditional lighting sources are still prevalent, but on the decline. In Rwanda, for example, kerosene and candles are still widely used, but dry-cell battery LED usage is increasing steadily. This can be taken not only from the binary usage indicators but also from the shares in total lighting hours shown on the right column of the table. In all countries, battery-run lamps increase their share in total lighting over time. In Tanzania, our most recent survey, exhibits very high LED usage rates.

Table 2: Lighting consumption of the non-electrified population in our survey samples

		Non-electrified population, in %	Lighting usage rates among non-electrified households, in %			Share in total lighting hours, in %	
			candles	kerosene	batteries	fuel-run lamps	battery-run lamps
Benin	2006	54	12	100	98	99	0
Burkina Faso	2010	67	0	29	100	32	63
	2012	49	0	10	99	22	76
Mozambique	2008	51	87	57	8	99	0
Rwanda I	2007/8	67	11	81	15	100	0
Rwanda II	2011	100	24	57	50	63	36
	2012	58	23	45	44	58	42
Rwanda III	2011	97	26	65	24	82	15
	2013	62	32	39	45	73	26
Senegal I	2009	58	44	18	99	35	65
Senegal II	2011	78	21	9	97	11	89
Senegal III	2014	79	0	1	97	2	95
Tanzania	2014	64	9	61	68	47	52
Zambia	2011	53	69	17	85	56	43

So far, we have handled LED lights as a homogenous lighting source. Yet, LED lights are used in different shapes ranging from hand-crafted lamps with one diode to fairly bright ready-made multi-diode lamps. In Table 3, we show the typical LED lamps we have encountered in the different countries, next to classical kerosene lamps and pico solar PV lamps. We differentiate between three different LED lamp types: simple LED flashlights, ready-made battery-run LED lamps, and hand-crafted LED lamps. Ready-made LED lamps are widely available in rural areas and they exist as well in various shapings. Some of them mimic the appearance of hurricane lamps, for example, and may have several dozens of diodes. Hand-crafted LED lamps are especially used by the poorest households. These are typically one or two diodes that are removed from ready-made torches or lamps and connected to dry-cell batteries. In Rwanda, for example, they are then wrapped in banana leaves in a very makeshift manner and installed at room walls or on a stick that can be carried around.

Table 3 furthermore displays the brightness performance of lamps currently available on the African market in terms of their luminous flux, measured in lumen, the total "amount" of emitted visible light. It can be seen that the lighting output of LED lamps may vary heavily, which depends on the number of diodes as well as on the performance of diodes and dry-cell batteries. Hand-crafted torches typically use a combination of few and inefficient diodes with low-capacity batteries and thus barely provide more light than a candle or a tin wick lamp, i.e. around 10 lumens. Ready-made LED lamps with several dozen diodes existing to date can easily emit as much as 50 to 100 lumens and more. For comparison, a 12 Watt electric compact fluorescent lamp (CFL), the typical energy saver lamp used in grid connected rural households, emits around 600 lumens. There is, hence, still a gap to grid-powered lighting, although the difference in illuminance is lower, since LED lamps emit more directed light compared to classical light bulbs and energy savers, which are designed to provide ambience light.

Table 3: Product range of typical portable lighting devices

	Tin wick lamp	Glass cover hurricane latern	Single or multiple diode hand-crafted torch	LED Flash-light	Ready-made battery-run LED lamp	Pico solar photovoltaics task lamp
			 		 	
energy carrier	kerosene	kerosene	dry-cell batteries	dry-cell batteries	dry-cell batteries	solar
luminous flux (in lumen)	11	8-82	~10	10-150	10-150	25-200

Sources: Luminous flux data comes from O'Sullivan and Barnes (2007), Mills (2003), Adelmann (2014), Grimm et al. (2015), Lighting Global (2015) and own market research.

3. Economics of LED adoption

The question of why the poor adopt a certain technology and why they do not is of utmost importance for the successful design of development policy. Many prominent technology examples exist that are perceived by the international community and governments as being beneficial for poor households, but that are not easily adopted by the population: insecticide-treated bednets (Cohen and Dupas 2010), improved cookstoves (Bensch et al. 2015, Lewis and Pattanayak 2012), water purification (Ashraf et al. 2010), and fertilizers (Duflo et al. 2011), to name but a few. These technologies require small investments, which seem to be clearly worthwhile from an outsider's perspective, because the pay-off is high. The evidence that explores the observed low adoption rates suggests that consumers often do not invest because they lack the information about the benefits, they have a low appreciation for benefits that materialize only in the long-run, they are unwilling or unable to bring up the investment costs or the technology is not suitable for local customs.

Against this background, what are the driving factors behind the successful diffusion of the LED technology? The major difference to the above mentioned technologies probably is that lighting is a priority of people living in rural areas.[5] Moreover, unlike those other technologies that require a certain investment, the different sorts of LED lamps depicted in Table 3 allow households to perfectly adapt their lighting consumption to their financing capacities. In other words, the investment can be scaled almost continuously. Very poor households replace kerosene wick lamps or candles by hand-crafted LED lamps for which the investment costs are below one $US (see Grimm et al. 2015). As capacity to pay increases, households may then switch to multi-diode ready-made lamps that are available from 1-2 $US up as the number of diodes increases.

Moreover, LED usage is cheaper or at least not more expensive than kerosene and candles. In a laboratory test with a set of dry-cell batteries and LED lamps from local markets in Liberia, Adelmann (2014) finds that the battery-driven LED lamps and kerosene lanterns perform similarly with costs of around one $US per kilolumenhour (klmh), i.e. the costs for providing 1000 lumens of light for one hour. Based on our survey data from the year 2010 to 2014, we find that the costs to run LED battery lamps for one hour tend to be lower (between 0.02 and 0.035 $US PPP on average) than for kerosene lamps (around 0.03 to 0.06 $US PPP). In general, while there has rather been a decrease in LED and battery costs due to technological advancements and scale economies, kerosene prices have soared over the observation period. The price of kerosene increased 240 percent between 2000 and 2012 in the developing

[5] In our surveys, electric lighting is by far mentioned the most important reason why households want electricity. This can also be seen in electricity consumption patterns in newly electrified areas where many households use little electricity for anything else but lighting (World Bank IEG 2008).

world, from an average price of roughly 0.50 $US per liter in 2000 to about 1.20 $US per liter in 2012. In high-cost markets kerosene costs can be as high as 1.80 $US to 2.10 $US per liter (Hesser 2013).

Not least and beyond cost considerations, people in off-grid areas have an outright antipathy against kerosene and also candles. According to focus group discussions, which we conducted complementarily to the structured surveys presented above, people dislike kerosene because it is perceived as dirty, smelly, and also unhealthy.[6] Kerosene is also frequently considered as "outdated" or "old-fashioned" (Lighting Africa 2013). LED lamps, on the other hand, are perceived as clean and more convenient.

4. Dry-cell battery disposal and disposal hazards

In general, there is no effective waste management in rural Africa. Separate waste collection or end-of-life recycling does not exist, neither for domestic waste, nor for hazardous waste. As can be taken from Table , our data shows that the battery waste is frequently disposed of in the nature, latrines, or open burning sites releasing their toxics to different degrees directly into the local environment including general soil and farming land, water, and air.

Since dry-cell battery consumption was very low at the time of our early surveys and thus the waste management topic only gained relevance over time, we started eliciting this information in the surveys after 2011. Nonetheless, Table covers most of the countries included in the previous analysis. In addition, there is no reason to believe that waste management will be much different in other rural areas in Africa and the patterns we observe in Table are probably transferable to other countries. None of the different modes of disposal can be considered as appropriate, although dumping

[6] Exposure to kerosene lamps may in fact impair lung function and increase infectious illnesses like tuberculosis, as well as the likelihood of asthma and cancer (Lam et al. 2012*b*, Epstein et al. 2013).

dry-cell batteries in latrines is probably even worse compared to informal garbage disposal and dumping them into nature, because concentration levels become high (Lighting Global 2011). One main driver for how batteries are disposed of is the population density. If population density is high, there is little space to dispose of garbage informally and people use latrines. In addition, according to our qualitative interviews with rural households, there is some sort of vague awareness of the toxic character of dry-cell batteries. For example, people in Rwanda often explain that they dump batteries into latrines in order to protect their children. In general, acceptability of littering public space decreases with population density.

Table 4: Mode of disposal of dry-cell batteries

		Mode of dry-cell battery disposal, in %				Monthly consumption of batteries among battery users		House-hold size	Population density in survey areas, in people/km^2
		nature	garbage (non-managed)	latrines	other	non-electrified	electrified		
Burkina Faso	2012	61	33	6	0	8.9	8.5	8.0	50
Rwanda II	2012	2	3	86	9	4.3	3.7	5.1	450
Rwanda III	2013	10	7	82	1	6.4	5.5	5.1	450
Senegal	2014	64	28	7	1	14.2	14.6	14.5	150
Tanzania	2014	15	69	14	2	6.7	5.8	5.7	10

Note: Other modes of dry-cell battery disposal of are mostly throwing the batteries in ditches or giving them to friends or children.
Sources: Population data on district or province level used to calculate population density figures has been taken from the most recent censuses of the different countries.

The table also specifies the amount of batteries used among non-electrified and electrified households. It becomes obvious that, first, the consumption data strongly correlates with household sizes and, second, that electrified households continue using batteries for lighting (see also Table A1 in the Appendix). This shows that people only shift gradually to cleaner and more efficient lighting.[7] This is particularly the case for households with solar systems, which are sometimes not sufficient to enlighten the whole household.

[7] This concurrent use of traditional and modern fuels is also observed for cooking fuels where it is referred to as fuel stacking (see Masera et al. 2000 and Hosier 2004).

The total extent of the dry-cell battery problem can be exposed by extrapolating the consumption data for rural Rwanda, for which we have detailed data for all parts of the country. Using the battery consumption figures from Table 4 and official figures on the rural population as well as the official rural electrification rate of 5 % (NISR 2014, IEA 2014), in total 67,000,000 dry-cell batteries are disposed in latrines and the nature in the countryside every year. This corresponds to more than 2,500 dry-cell batteries per square kilometer.

In particular for densely populated regions (like Rwanda), the threat this might induce for public health is very obvious, although little is known about the content of dry-cell batteries sold in Africa and the dose-response relationship of exposed people. More specifically, the two main dry-cell battery types, zinc carbon and alkaline, contain lead, cadmium and mercury, which the World Health Organization rate among the "ten chemicals of major public health concern" (WHO 2015).

Lead is often found in high concentrations (as compared to the EU batteries directive of 2006) in zinc carbon batteries, less so for alkaline batteries (Recknagel et al. 2014). It is a carcinogen and a recognized toxicant for causing adverse effects on the developing child. High levels of exposure may affect the kidneys, gastrointestinal tract, reproductive system, and the nervous system (Schwartz and Steward 2007; Gottesfeld and Pohkrel 2011; Lighting Global 2011). Likewise, *Cadmium* is carcinogenic and a recognized developmental and reproductive toxicant. Long term exposure is associated with renal dysfunctions and bone defects. Surveys among dry-cell batteries from the international market came to the conclusion that cadmium is less prevalent and if so, again, rather in zinc carbon batteries (Barrett et al. 2012, Recknagel et al. 2014). Finally, *mercury* is a recognized developmental toxicant that may cause brain and kidney damage and affect the nervous system. While many countries also in the developing world have banned or restricted the use of mercury, it is partly still found in alkaline batteries (Uram et al. 2010).

To conclude, the extent to which dry-cell batteries that are not disposed of appropriately pose a health threat strongly depends on the dose of these toxic heavy metals they contain. Little is known about the content of dry-cell batteries produced for the African market.

5. Conclusion

The evidence we have presented in this paper indicates that off-grid lighting usage is undergoing a transition from kerosene lamps and candle usage to dry-cell battery LED lamps. In particular in Western African countries LED lamps are used by the vast majority of rural households, but also in other parts of the continent these lamps are on the rise. Even though we also find increasing penetration rates for solar lanterns and solar home systems, the rise of battery-powered lighting is likely to continue in rural off-grid areas for many years. Solar sales volumes will not be sufficient to reach the large off-grid population in Africa (Navigant Research 2014). In addition, also electrified households continue to use battery powered LED.

From a welfare planner's perspective, this is in principle a transformation to be welcomed, since LED lighting is brighter, cleaner and preferred by rural dwellers as compared to kerosene. Interesting lessons on technology adoption can be learned, also for other technologies that the international community wants to disseminate in developing countries. While it is trivial that a technology has to be in line with the target group's preferences, a more insightful virtue of LED lamps explaining their advance in Africa seems to be the scalability of the investment that needs to be made. People can almost continuously decide on the size of the lighting device they use according to their capability to invest. The relative lumpiness, also of small-scale investments, is frequently an impediment for the adoption of other technologies.

However, quick action is needed to implement effective waste management systems for dry-cell batteries, which are currently disposed of simply in the nature or in latrines. Even if the heavy metal content of these batteries is low, the mere amount of batteries that accrues and that is stored in high concentrations in people's backyard will create a public health problem, in particular in densely populated countries. Research is needed that examines the toxic content of dry-cell batteries sold on African markets and possibly limit values for toxic substances have to be introduced. These efforts should address rechargeable batteries from solar lanterns and solar home systems as well considering the increasing penetration rates of these products and the toxicity of the installed rechargeable batteries.

If raw material prices rise, markets will seek to exploit the dry-cell battery potentials in Africa. Policy should definitely promote this by getting the framework conditions right for private recycling investments. However, whether this investment will in fact ever be profitable is not clear and even if, this will not happen in the short run. Therefore, the subject of massively increasing battery usage in rural Africa has to move up the agenda of the international community and national governments. A joint attempt should be made to establish an effective collection system in rural areas straight away to make sure batteries' toxic content does not end up in local food chains.

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Appendix

Table A1: Basic lighting information on the electrified population in our survey samples

		Electricity source				Usage rates for lighting, in %			Share in total lighting hours, in %		
		grid electricity	solar panel	pico-pv lamp	other	candles	kerosene	batteries	fuel-run lamps	battery-run lamps	electric lamps
Benin	2006	31*	0		24	9	84	93	73	0	27
Burkina	2010		26		7	0	24	99	25	49	26
Faso	2012		45*		7	0	7	98	12	41	46
Mozambique	2008		33		16	82	51	12	92	0	8
Rwanda I	2007/8	30*	0		3	20	62	15	70	0	30
Rwanda II	2011		0			24	57	50	63	36	0
	2012		0	42*		15	32	38	34	30	36
Rwanda III	2011		1		2	27	64	24	81	15	4
	2013	34*	1	2	2	41	31	33	47	16	36
Senegal I	2009		40*		2	42	12	99	23	40	37
Senegal II	2011		18		5	23	8	97	10	79	11
Senegal III	2014		16	2	5	0	1	96	1	73	25
Tanzania	2014		15	16	10	11	49	64	57	11	32
Zambia	2011		34		17	72	15	91	46	32	22

Note: Asterisks refer to electrification rate figures that have been boosted by donor-driven interventions (see Table A2).

Description of data sets

The data used for the empirical analysis has been gathered in the seven sub-Saharan African countries Benin, Burkina Faso, Senegal, Mozambique, Rwanda, Tanzania and Zambia – the former three being located in West Africa, the latter four in East Africa. The data has been collected between December 2006 and December 2014 in cooperation with national partner organizations specialized in survey implementation. All surveys took place in the context of impact evaluations for energy interventions supported or financed by development agencies such as Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Netherlands Ministry of Foreign Affairs. The interventions typically had a regional focus. As can be taken from Table A2, the data stems from 11 surveys conducted in both rural and urban settings. The surveys were either baseline surveys for upcoming projects or part of evaluation studies on energy access interventions ranging from improved cookstoves to central grid extension. These latter evaluation study samples comprise both households with access to the new energy technology and comparable households without.

Table A2: Basic survey characteristics

country	survey date	sample size	energy access technology	references
Benin	1-2/2007	419	central grid	Peters, Vance and Harsdorff (2011, 2013)
Burkina Faso	11/2010	1200	none *(baseline)*	
	10-11/2012	922	solar PV	Bensch et al. (2013*a*)
Mozambique	7/2008	140	none *(baseline)*	Bensch et al. (2010)
Rwanda I	2007/08	633	grid electricity	Bensch and Peters (2010); Bensch, Peters and Kluve (2011)
Rwanda II	12/2011	307	none *(baseline)*	Grimm et al. (2014)
	6/2012	307	pico solar PV	Grimm et al. (2013)
Rwanda III	4-5/2011	1486	none *(baseline)*	Peters et al. (2014)
	5-8/2013	1318	central grid	Lenz et al. (2015)
Senegal I	10-11/2009	797	solar PV	Bensch et al. (2013*b*)
Senegal II	3/2011	482	none *(baseline)*	
Senegal III	4/2014	390	none *(baseline)*	
Tanzania	11-12/2014	1000	none *(baseline)*	
Zambia	5/2011	180	none *(baseline)*	Neelsen et al. (2011)

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