Impact evaluation of Netherlands supported programmes in the area of Energy and Development Cooperation in Rwanda

Impacts of Pico-PV Systems Usage using a Randomized Controlled Trial and Qualitative Methods

ToughStuff Rwanda, social enterprise
supported by the Daey Ouwens Fund for small-scale renewable energy projects

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This report is part of an evaluation commissioned by the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. It belongs to a series of impact evaluations of renewable energy and development programmes supported by the Netherlands, with a focus on the medium and long term effects of these programmes on end-users or final beneficiaries. A characteristic of these studies is the use of mixed methods, that is, quantitative research techniques in combination with qualitative techniques. The purpose of the impact evaluations is to account for assistance provided and to draw lessons from the findings for improvement of policy and policy implementation. The results of these impact evaluations will serve as inputs to a policy evaluation of the "Promoting Renewable Energy Programme" (PREP) to be concluded in 2014.

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1 Introduction

Despite favourable economic indicators and a noticeable effort of the Government of Rwanda and several donors to bring electricity to rural areas, the vast majority of households in rural Rwanda is still without electricity access. These households rely on traditional energy sources such as kerosene, dry-cell batteries, or candles for lighting purposes and dry-cell batteries for radio usage. Starting at an electrification rate of around six percent in 2009, the national grid roll-out programme EARP connects around 60,000 households each year. By the end of 2012, 230,000 households have been newly connected implying that an electrification rate of 16% has been attained.[2] Nevertheless, even forecasts for a post-EARP electrification rate in 2017 of around 50 percent indicate that many Rwandans will then still be without grid electricity.[3]

In recent years, the international debate about access to electricity has been affected noticeably by a transformation on the market for decentralized electricity sources: The costs of solar systems and light emitting diodes (LED) have decreased considerably making them a potential alternative to investment intensive on-grid electrification programs. Beyond public interventions initiated by governments, donors or NGOs, this decrease of costs has led to an increased usage of dry-cell battery driven LED devices in many rural areas in Africa. However compared to Senegal and Burkina Faso (Bensch, Peters and Sievert 2012, Bensch et al. 2011), for example, where the vast majority of households even in remote areas are using these lamps, the share of LED-users is surprisingly low in Rwanda (Bedi et al. 2012). In Rwanda, as in many other African countries, the LED-lamps are sold on markets and small shops, also in rural areas. Yet, in many cases the devices are of questionable quality, which might threat the sustainability of this infant market if customers lose trust in the new products. The international community has responded to this development by promoting so-called Pico-PV systems that meet sufficient quality standards. The most prominent intervention is the World Bank program 'Lighting Africa'. This program has established quality standards and promotes the adoption of Pico-PV systems in Africa in cooperation with governments as well as private companies.

Pico-PV systems are usually equipped with a small 1-10 Watt solar panel and operate small LED-lamps. More advanced systems additionally allow charging mobile phones or radios. Thereby, these systems already cover the main demand for electricity of rural dwellers. Several studies on electrification projects show that in many cases rural dwellers effectively only use electricity for lighting, mobile phone charging, and small entertainment devices (see, for example, Acker and Kammen 1996, Bensch, Kluve and Peters 2011, Bensch, Peters and Schraml 2010, Reiche et al. 2010, Harsdorff and Peters 2010, Wamukonya and Davis 2001). The electricity consumption is accordingly low and it is sometimes argued that on-grid electrification projects are in this context oversized. Advocates of Pico-PV systems bring forward that – with the exception of television – Pico-PV systems can deliver these basic services at much lower costs. Besides this least-cost discussion, in most countries it is no either-or question anyhow, as grid extension programs are underway, still leaving vast areas of the country uncovered. Hence, decentralized solutions such as Solar Home Systems or

[2] http://www.newtimes.co.rw/news/index.php?i=15176&a=60668

[3] For further details on the grid roll-out programme and the countries state of affairs, please refer to the baseline report for the evaluation of EARP (Bedi et. al 2012).

Pico-PV are technologies that are rather complementary to on-grid electricity. While the role of Pico-PV had been unclear within the global endeavour to achieve universal access to electricity by 2030 (UN 2010), the Sustainable Energy For All Global Tracking Framework has recently acknowledged the role of Pico-PV in an explicit way by including the technology as a "transitional alternative to grid-based electricity" and as a potential "long-term solution" in remote areas (SE4All 2013: 79).

In this report, we evaluate take-up behaviour and impacts of a Lighting Africa-certificated Pico-PV kit marketed by the British company *ToughStuff International.* ToughStuff has received a start-up support from the Dutch Daey Ouwens fund to launch its activities in Rwanda. The Pico-PV kits marketed by ToughStuff in Rwanda comprise a small 1W panel, a 40 lumen lamp, a mobile phone charger and a radio charger. According to the ToughStuff proposal to the Daey Ouwens Fund, the company builds on quite considerable experience in Africa as they claim to have sold already 125,000 solar kits within two months in Kenya and Madagascar. The ToughStuff activities in Rwanda started in early 2011 and the objective is to sell roughly 166,000 solar kits by September 2013. The idea is to sell the kits through a grassroots distribution system with so-called 'coordinators' in every district of the country and a myriad of so-called 'agents'.

The present evaluation is based on a mixed-method approach comprising an analysis using a field experimental design, a survey among actual users and an analysis based on open interviews with the ToughStuff target group as well as ToughStuff staff in the headquarter and in the field, policy makers and competing Pico-PV companies in Rwanda. The experimental part of the study consists of a randomized controlled trial (RCT). For the RCT, 150 ToughStuff Pico-PV kits were randomly distributed among 300 households in 15 villages after a baseline survey in late 2011 (see Grimm, Peters, and Sievert 2012). These 300 households were revisited in June 2012 for a follow-up survey. For the real user survey, 66 households that have bought a ToughStuff Pico-PV kit at regular ToughStuff sales-men (or women) were visited in June 2012.

The remainder of this report is organized as follows: Section 2 describes the market for LED-lamps and Pico-PV systems in Rwanda and the specific ToughStuff product used for the present study. Section 3 presents the methodological approach including the identification strategy, an outline of the applied randomization process, the sampling and the implementation of the survey as well as the concrete distribution of randomly allocated solar kits. Section 4 presents results from the RCT and compares the findings to those among real users. Section 5 analyses the sustainability of the intervention. Section 6 presents a point-by-point answer to the research questions. Section 7 concludes.

2 The intervention and the context

2.1 Pico-PV and dry-cell driven torches in Rwanda

Rwanda has a vibrant energy sector in which access to electricity plays a dominating role. While the focus clearly is on the huge Electricity Access Roll-Out Program (EARP) and no particular government interventions so far are targeting the solar sector, the Government of Rwanda explicitly welcomes activities that intent to improve the access to solar energy in rural areas. Also for Pico-PV, no particular promotion scheme is in place, but the Government cooperates with Lighting Africa and in general is very favourable towards private sector players who intent to start activities in the country.

Nonetheless, the number of enterprises and institutions working on Pico-PV system dissemination was small. The few existing firms operate almost exclusively in the Rwandan capital, Kigali, and other cities. Next to ToughStuff, three enterprises with a distribution strategy to reach rural areas have emerged in the country: *Great Lakes Energy, Solar Sisters and Barefoot Power*. *Great Lakes Energy* has been operating in Rwanda since 2005 and markets products certificated by Lighting Africa. The enterprise used to work with a network of 150 rural businesses that were trained on a 'train the trainers' basis. At the time of the start of this study they were, however, about to revise their business model after quality problems with the supplied lamps and a flawed distribution network. *Solar Sisters* is a US based social enterprise that relies on a similar marketing strategy like ToughStuff and intends building up a network of independent saleswomen who market the 'Solar Sisters Pico-PV systems'. The company's East-Africa office is located in Uganda and the sales network in Rwanda so far relies on cooperation with Great Lakes Energy. The company is supported by several sponsoring partners such as the Ebay Foundation or ExxonMobil.[4] The Australian social enterprise *Barefoot Power* has entered the Rwandan market only in early 2012 and tries to build up a distribution network as they have already done in Uganda, Kenya, and India. Their approach is to partner with organizations that already count with a network in rural areas, such as non-profit organizations, community groups, micro-entrepreneurs, faith-based organizations, etc. In Rwanda, they are currently negotiating a partnership with NGOs like CARE and SNV. Involved persons are to work on a commission basis, receiving between 20 and 30 percent of the sales. Their products are also certified by Lighting Africa.

Apart from these three enterprises that explicitly target rural areas, Pico-PV systems are systematically sold only in Kigali: Some sellers are bigger retail enterprises that have simply included Pico-PV systems into their product range being sold in the shop.[5] Hence, there is no particular marketing strategy to target a specific group of people (e.g. rural or poorer households). Other players are not permanently active in Rwanda and the Pico-PV systems are rather distributed as donations on special occasions. Philips, for example, donated 300 small solar panels and a small LED reading lamp in 2010, when Rwanda hosted the United Nations World Environment Day.[6] A systematic approach to disseminate their products does not exist.

A few companies exist that sell larger solar home systems with panels of 20 Watt or more (see Kirai, Saini and Hankins 2009). For the time being, none of them serves the 1-10 Watt Pico-PV market, but at least one of them, a company called *bboxx*, is planning to offer also smaller devices with a 10 Watt solar panel (Cole and Hogarth 2011).

Another LED based off-grid lighting alternative is provided by *Nuru Energy*. The company offers rechargeable lamps that can be charged through a pedal generator. Nuru trains entrepreneurs in several rural areas and equips them with a pedal generator. The entrepreneurs receive a certain quantity of lamps through a loan provided by a micro-finance partner and sell and charge the lamps for a fee (Cole and Hogarth 2011).

In terms of the delivered lighting service the Pico-PV kits with their small electric diodes compete with dry-cell battery driven LED-lamps that can be bought in rural shops all over the country. The

[4] www.solarsister.org
[5] Examples are BrazAfric or Murika Procurement & Logistics.
[6] http://www.newscenter.philips.com/main/standard/news/press/2010/20100605_rwanda.wpd.

most common ones are small LED-torches and mobile LED-lamps that come as a battery instead of kerosene driven hurricane lantern. In addition, many rural households use hand-crafted torches, i.e. LED-lamps that are removed from torches and installed somewhere in the house or a stick that can be carried around (for illustration, see Appendix 5). These devices are not quality assured, but cost only between 500 (for hand-crafted torches) and 3000 FRW (for a LED hurricane lantern) (1 EUR = 786 FRW). A dry-cell battery package of two pieces is sold in rural shops at 100-300 FRW. They are said to last for around 10 hours running with small batteries, sometimes also longer. Although this is not more expensive than kerosene (and the lighting quality is slightly better), ready-made torches and mobile LED-lamps are not widely used in rural Rwanda. Hand-crafted LED torches are used though by around 50 percent of the households surveyed for this study. Given that both acquiring a battery-driven LED-lamp or a Pico-PV system require an investment and given that both deliver comparable services at least with regards to lighting, they can be considered as competitors.

2.2 Description of the intervention

The Daey Ouwens contribution to the ToughStuff activities in Rwanda aims to support the establishment of a market for Pico-PV systems in Rwanda with a focus on rural areas. In general, the Daey Ouwens Fund grants subsidies on behalf of the Dutch ministry of Foreign Affairs to provide "*more people in Least Developed Countries (LDCs) with access to energy by promoting small-scale projects in the area of renewable and job-creating forms of energy supply*".[7] For the period from May, 1st 2011 to August, 31st 2013, ToughStuff is receiving a subsidy of around 670,000 EUR to start its activities in Rwanda. This accounts for half of the costs ToughStuff faces in order to set-up its activities (ToughStuff 2011). ToughStuff started to set-up its activities in Rwanda in the first half of 2011.

The ToughStuff Pico-PV kit is offered as a modular set ("mix-and-match"): the 1 Watt solar panel comes with a 40 lumen lamp, a mobile phone charger and a battery package to be used in radios typically employed in Rwanda.[8] There are different options to use the panel. First, it can be used to directly charge the lamp with four low-power LEDs that can be used in three dimming levels. After one day of solar charging it is fully charged and provides lighting for between 6 and 30 hours depending on the chosen intensity level. Second, ToughStuff provides a mobile phone connector plug and radio connectors that can be used to directly operate a radio that runs on 1 to 4 D-cell batteries. Third, the kit includes a rechargeable power pack that can be charged with the solar panel and that can be used to back-up all ToughStuff products, i.e. to operate the lamp or the radio or to charge a mobile phone. All modules can also be bought separately. The complete package costs around 23 EUR, the smallest version with only the solar panel and an LED lamp costs around 12 EUR. [9]

[7] http://www.agentschapnl.nl/programmas-regelingen/daey-ouwens-fund.
[8] See Appendix 4 for photos of all devices.
[9] While at the time of the baseline study the only available TS panel had been the 1 Watt panel, TS has introduced a 1.5 Watt panel in late 2012.

Table 1: Prices of ToughStuff products

APPLIANCE	Price In FRW[10]	Price In EUR
Solar Panel	5,500	7.00
LED Lamp	4,500	5.70
Battery Power Pack	5,100	6.50
Active Radio Connectors	1,600	2.00
Passive Radio Connectors	600	0.80
Mobile Phone Connectors	550	0.70
TOTAL KIT	**17,850**	**22.70**

Since the Pico-PV systems constitute a completely new technology particularly for rural households, a retail infrastructure is indispensable to market ToughStuff's solar kits. The retail infrastructure is needed to sensitize and inform people about potential benefits of the product as well as to maintain contact to customers in case of problems and after sales service requirements. For this purpose, ToughStuff relies on a network of independent salesmen that are supervised by ToughStuff district managers. According to the proposal to the Daey Ouwens Fund these salesmen are virtually all female, the so-called 'ToughStuff Ladies'. We refer to them as *ToughStuff agents*. The company aims at recruiting and training more than 1,000 agents that will receive a start-up kit for demonstration purposes on consignment. The idea is that these agents demonstrate and sell the products first to friends and neighbours and also provide after sales service. Afterwards, ToughStuff counts on mouth-to-mouth propaganda, but the agents are of course also free to market further lamps beyond their peer group. The dissemination strategy is inspired by the marketing approach of the US-company Tupperware. While the agents work independently and earn on commission (i.e. per sold solar kit), district managers receive a fixed salary. ToughStuff plans to sell 166,000 solar kits by 2013. It is foreseen to cover all 30 Rwandan districts (ToughStuff 2011).

3 Evaluation approach

3.1 Evaluation objective

This evaluation aims at assessing the impacts – positive or negative, intended or not – related to the establishment of a market-based distribution system for ToughStuff Pico-PV systems. It focuses on households and addresses questions related to the outcome and impact level as well as on the sustainability of the ToughStuff marketing approach.

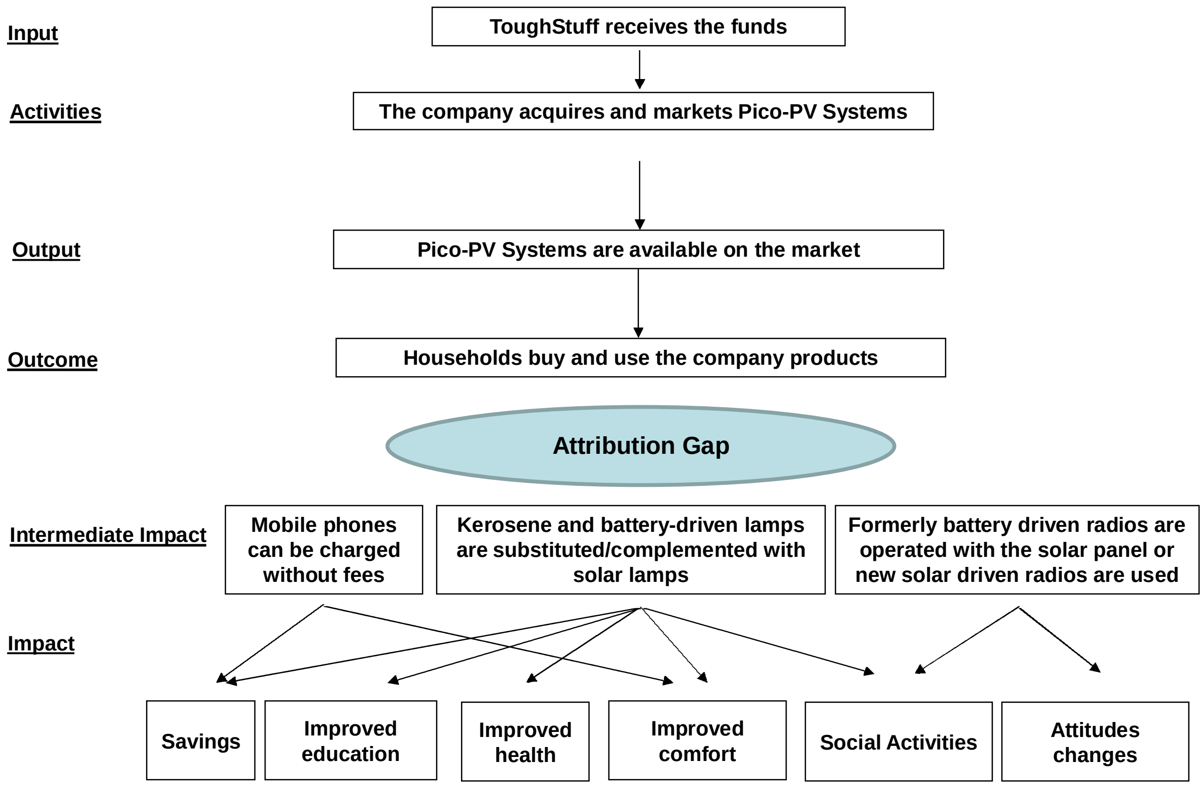
Although being a small-scale treatment, the intervention under evaluation might affect the beneficiary's living conditions via various channels and in various ways. First, radio ownership is expected to increase radio usage and, hence, to improve access to information. This might eventually

[10] 1 EUR = 786 FRW as of December 2011.

lead to changes in attitudes including health or gender relevant aspects, but also to altered social activities. For those households who already use radios the availability of solar charging might bring down battery consumption with consequences for the household's budget and battery disposal. Second, the availability of a solar driven mobile phone charger might increase mobile phone usage, which could also improve the access to information. Households who already used mobile phones before might save expenditures for charging their phone and the time to reach the next charging possibility. Third, the ToughStuff lamp provides for cheaper, cleaner and brighter lighting, which could translate into a change of activity patterns after nightfall. People might pursue productive or social activities or simply stay up longer. School kids are enabled to study after sunset with better lighting conditions. To the extent that candles or in particular kerosene is replaced by the ToughStuff lamp, a reduction in the emission of harmful particulate matter can be expected. In fact, the discussion about household air pollution and the disastrous effects it has on people's health – according to WHO (2009) around two million people die every year due to household air pollution - harmful – has so far been mostly dominated by the usage of solid cooking fuels. The harmful effects of kerosene have nonetheless also been constantly addressed in the literature. There is sporadic but quite alarming evidence for extremely high particulate matter (PM) emissions and, consequently, harmful health effects of kerosene (Epstein et al. 2013, Fullerton et al. 2009, Pokhrel et al. 2010, Schare and Smith 1995).

The particularly perfidious feature of traditional kerosene based lighting is that they are used at night when most family members are at home and one must be in close proximity to the lamp to use the light. In particular, school children are heavily exposed to the PM emissions while doing their homework after nightfall. In addition to health effects related to particulate matter emissions, severe burns induced by kerosene usage in both stoves and lamps have frequently been evidenced in the literature (Ahuja and Bhattacharya 2002, Mabrouk, El Badawy, and Sherif 2000, Peck et al. 2008, Sawhney 1989, Schwebel et al. 2009). In addition, kerosene combustion emits black carbon, which contributes to global warming processes by absorbing sunlight in the atmosphere (Lam et al. 2013). Since black carbon stays in the atmosphere for only a few days or weeks, but has immediate heating effects (unlike classical climate gases like carbon dioxide or methane), the reduction of black carbon emissions has been identified as a quick win against climate change (see Shindell et al. 2012).

Figure 1: The ToughStuff results chain



_Source: Own illustration

On the outcome level, we address the following questions: (i) How many systems have been sold (sales records) or purchased (number of households; systems per household)? (ii) Who (gender specific) in the household has made the decision to buy the Pico-PV system and who uses it? (iii) Which services of the package are being used? (iv) For which purpose, for how much time and where are the lamps being used? To which extent are they used inside or outside the house? (v) What proportion of the total lighting hours used in the household is provided by the solar lamps? What other sources are being used? Is there a relation between the lighting source and the use of light? (vi) How reliable is the lighting source? Does the panel suffice to use the radio and the telephone charger? (vii) Does the ToughStuff distribution approach work out and are consumers satisfied with the offered service? (viii) How many ToughStuff agents are trained and effectively selling the solar kits?

On the impact level: (i) How many lighting hours are consumed by the household? (ii) How have expenditures for energy changed? (iii) To what extent has the perception of safety changed? (iv) To what extent has comfort/convenience changed? What monetary value do households attribute to this increased convenience, disaggregated by gender? (v) Has there been a change in activities during the evening and night? (Children studying at home; other – or more – social activities; income generating activities)? (vi) Is there a perceived improvement in indoor air quality? (vii) Has the Pico-PV system been an incentive to consider the purchase of other solar devices, amongst them a solar home system? (viii) How have, in response to the possibly increased radio exposure, attitudes towards and awareness of women's status, fertility, contraception and family planning, malaria prevention and HIV/AIDS changed? Furthermore, we will examine impacts on activity patterns after nightfall of households, which might change in the wake of electrification due to increased usage of lighting and radio. Here, the time children dedicate to home studying is an indicator. Figure 1 illustrates these questions in the form of a results chain.

3.2 Research approach and identification strategy

This evaluation pursues a mixed-methods approach. We rely on two different instruments: First, a large sample survey component comprising a randomized controlled trial (RCT) and a real-user survey, which serve to analyse the determinants of adoption of Pico-PV kits and the impacts of using them. Second, semi-structured and open interviews conducted with selected representatives of the target group as well as staff members of ToughStuff, governmental institutions and ToughStuff's competitors, which serve to get a deeper understanding of those contextual aspects that cannot be grasped through large sample surveys based on structured questionnaires, including the sustainability of the program under study. In what follows, we present each single instrument in detail.

The **large sample size survey** parts employ structured questionnaires to examine the impacts the usage of Pico-PV kits has on households. These questionnaires cover virtually all socio-economic aspects that characterise the household's living conditions with a particular focus on the use of lighting devices, radios and mobile phones, and energy expenditure. The major part of this evaluation is the RCT, which is complemented by a survey among real ToughStuff customers in regions outside the RCT study area, who have purchased a ToughStuff kit on the regular market. For the implementation of the RCT, the Pico-PV systems are randomly assigned at the time of the baseline survey. The randomized kits include a 1 Watt panel, a 4-LED-diodes lamp including a rechargeable battery, a mobile phone charger, a radio charger, a radio typically used in rural Rwanda including rechargeable batteries, and a battery package that can be used to store electricity produced by the panel and charge the other batteries or a mobile phone without sunlight. The impacts are subsequently assessed by conducting a follow-up survey several months later. The baseline survey serves for the collection of pre-program data to base the randomization on and to increase the precision of the impact assessment (see Section 3.3. for details on the implementation). In conjunction with the follow-up survey an additional survey among real world users has been conducted.

With respect to the curse of most observational studies – the self-selection into the treatment – the RCT is the best approach to assess impacts conditional on owning such a Pico-PV system, because it avoids the confusion of impacts of the program with other factors that are correlated with the outcomes of interest and selection into the group of owners ("treatment"). As a consequence, unobserved characteristics cannot distort the impact assessment afterwards. All differences in follow-up outcomes can be attributed to the treatment.

To visualize the distorting effects of such unobservable characteristics, consider the example of children's reading hours at night as an intermediate impact. It can be expected that certain characteristics of households imply that these are more inclined to buy a Pico-PV system than others. As a stylized example, more *modern* households are keener on having electric light than others. At the same time, more modern households might also urge their children to read – more than non-modern households. As a consequence, in an observational study among Pico-PV system users it is likely that the more modern households have more lamps and their children read more. A comparison between Pico-PV users and non-users would testify a difference in reading hours that one would falsely ascribe to the Pico-PV ownership.

In many RCTs potential selection problems creep in again in the form of so-called non-compliance: Treatment group households might decide not to use the treatment. In our case, we count on a certain number of households randomly assigned into the treatment group who decide not to use or even sell the Pico-PV kit. We will then examine both the Intention to Treat-effect (ITT) and the Average Treatment Effect on the Treated (ATT). The ITT compares treatment group households to the control group – irrespective of effective Pico-PV kit usage and is, hence, not threatened by selection processes. The ATT inquires the effect on those who effectively use the Pico-PV kit – and thus could be distorted by treatment households opting for selling the Pico-PV kit. Here, we will apply instrumented variable (IV) estimations with the random assignment into the treatment group as very strong instrument for the effective usage of the Pico-PV kit.

To increase the external validity of this RCT, a survey among households that have decided to buy a ToughStuff kit in the regular distribution network was conducted. This **real user survey** enables us to check the extent to which our RCT sample represents real Tough Stuff customers. The real user survey was conducted at the time of the follow-up survey. This information can then be used to stratify both the randomized treatment group and the randomized control group into “real world users” and “real world non-users” allowing us to approximate which impact can be expected in the ToughStuff project

The central survey tool for the large sample size surveys is a structured household questionnaire (see Appendix 10). Besides relevant socio-economic aspects of the household including household composition, migration, health, and the financial situation, it focuses especially on characteristics that are expected to be affected by the treatment. In particular, it encompasses usage of different lighting devices in number and duration and purpose of usage as well as usage of radio and mobile phones. Furthermore, the structured questionnaire includes questions on security and gender relevant issues and activities after nightfall. In addition, the questionnaire seeks information on the household’s knowledge about contraceptives or preventive health care like mosquito nets. These questions might enable us to assess if attitudes towards family planning and health risks are altered by Pico-PV system usage.

This larger sample size surveys are complemented by **semi-structured and open interviews** conducted with selected representatives of the target group (both survey participants and other rural households) as well as staff members of ToughStuff, governmental institutions, sector key informants and ToughStuff’s competitors. In open interviews and focus group discussions with households in the target region of the large sample size surveys, respondents are given the opportunity to determine the direction of the interview. Questions were only asked in a very general way (e.g. “Which lighting sources do you use and what are the related problems?”). The focus of these interviews was on lighting, radio and mobile phone usage, activities at night-time, the diffusion of dry-cell battery driven LED lamps and health issues related to kerosene usage.

ToughStuff staff members were mainly interviewed to get an impression on the implementation of the project on the ground, to verify statements in the proposal submitted to the Daey Ouwens Fund and, eventually, to assess the feasibility and sustainability of the company’s approach in Rwanda. Government representatives from EWSA –the National Power Utility– and MININFRA –the Ministry of Infrastructure– were interviewed to assess the relevance Pico-PV has for the official sector policy and the institutional environment of the intervention. Representatives of ToughStuff's competitors were met to, first, avoid interfering with their roll-out plans in regions selected for the RCT (also to avoid treatment contamination), and second to compare their activities to the ToughStuff approach.

Table 2 lists all survey tools that have been implemented for the purpose of this evaluation.

Table 2: Different Study Modules

Survey Tool	Content	Sample Size	Interview Type
Large sample size surveys			
Randomized Controlled Trial	Comprehensive Socio-economic questionnaire covering most household characteristics (revenues, expenditures, education, health and gender issues, activities at night-time) with focus on energy and lighting usage.	300	Structured questionnaire
Real user survey	See above plus focus on ToughStuff kit usage.	66	Structured questionnaire
Semi-structured and open interviews			
a. Qualitative household interviews	Lighting/radio/mobile phone usage, diffusion of dry-cell battery lamps, health issues of kerosene usage. Satisfaction with ToughStuff kits.	37	Open interviews, Focus Group Discussion
b. Village characteristics (respondent: village head or alternative key resource person)	Village size. Availability of fuels, dry-cell batteries and lamps. Major village particularities.	15	Short questionnaire
c. Health stations/hospitals.	Health issues related to kerosene usage (respiratory diseases, burns and accidents)	2	Open interviews
d. ToughStuff coordinators	Number of sold kits on district level, list of ToughStuff agents, general assessment of the business/marketing approach.	8	Semi-structured interviews
e. ToughStuff agents	Number of sold ToughStuff kits, problems and potentials of their daily work.	3	Semi-structured interviews
f. ToughStuff management	Business approach, content of proposal to Daey Ouwens Fund.	3	Semi-structured interviews
g. Government representatives	Sector policy and relevance of Pico-PV. Institutional and regulatory environment.	3	Semi-structured interviews

Survey Tool	Content	Sample Size	Interview Type
h. ToughStuff competitors and other key informants	Business opportunities in the sector. Institutional environment.	5	Open interviews

3.3 Survey design and implementation

One of the major purposes of the preparatory mission in November 2011 was the selection of sites to be included in the surveys. For the **randomized controlled trial**, after extensive field trips to rural areas and based on discussions with ToughStuff representatives as well as further Pico-PV experts, we identified four regions that are located in non-electrified rural areas. In order to avoid treatment contamination, another pre-condition for a region to be eligible for our study was the actual non-availability of Pico-PV Systems at the time of the baseline and the expected non-availability at the time of the follow-up survey. In fact, we selected sites for which it appeared to be highly unlikely that private companies or donor organizations will roll out Pico-PV activities or other electrification interventions within one year. ToughStuff itself was not promoting its products actively in the regions either. However, given the decentralized set-up of their marketing system with completely autonomous sales persons on the ground they could not completely preclude that their product somehow trickles down to the regions. The regions are located in four different districts: Two of them are located in the Southern Province, one in the Western, and one in the Northern Province.[11]

According to Rwandan solar experts, these regions show a "medium solar radiation level".[12] The eastern province, which shows the highest solar radiation level, has been left out as the favourable sunshine condition and higher purchasing power attracted several private and donor organizations to distribute similar panels already at the time of the survey. ToughStuff had also already started to recruit district managers and sales women in the Eastern Province and had already sold several kits.

For the concrete selection of sites to be surveyed we conducted field visits. Within the four regions we visited various local centres, seeking for information on the availability of different lighting sources in the communities, possible electrification interventions, and main sources of income. Those communities that evidently did not have unusual access to "modern" lighting sources such as mobile LED lamps and did not exhibit extraordinary income patterns (for example a large tea plant nearby) where chosen for the survey. In rural Rwanda, households are typically scattered across the hills surrounding a small agglomeration next to a road. Hence, no obvious boundaries of settlements are perceivable and a community is not always easy to define. In addition, official administrative entities are neither helpful, as they are not organised around geographical criteria. Their borders sometimes divide a geographical entity of households into different administrative units. For our

[11] A map of the survey regions is provided in Appendix 3.

[12] According to personal communications with PV-experts, Rwanda counts with a yearly average of 5.5 hours of sunlight per day. The Eastern Province counts with around 6 hours per day.

purpose, we therefore selected small agglomerations, typically next to roads or cross-roads, and included 200 households around this point to constitute one survey site.

In each of the in total 15 surveyed sites, 20 households have been selected using simple random sampling, thereby including approximately every 5th household. In total, 300 households were visited for the baseline survey in December 2011. The survey was presented to the participating households as part of a general survey on energy usage in relation to on-going and well-known energy interventions. Furthermore, the randomly assigned Pico-PV system was presented to participants not as a gift, but as a compensation for participation in the survey. Not least, control group households received a compensation consisting of a sack of 5kg of rice and one litre of cooking oil.[13] As a side effect, this compensation for the control group addresses a potential ethical concern that is sometimes brought forward against RCTs: Randomly assigning a treatment to one group may induce uncomfortable feelings in the other group. Neither treatment nor control group members were informed about the experiment.

An overview on the surveyed sites is provided in Appendix 2. The collected baseline data was then employed to ensure an ex-ante balancing of the treatment and the control group using a combined stratification and re-randomization approach. Compared to pure randomization this substantially improves the precision of the impact assessment (i.e. increase the power of the study) given that the balancing criteria have good predictive power for future outcomes (Bruhn and McKenzie 2009). For details on the randomization process, please refer to Appendix 6.

The randomization was done by the RWI/ISS researchers. ToughStuff representatives, local authorities, and the local consultancy IB&C were only informed on the final randomization results. The next challenge was a logistical one: While the data required to stratify was of course part of the baseline questionnaire, it had to be digitalized right away in order to allow for these stratification procedures to be applied. This also implied that we could not distribute the solar kits immediately after the survey, but had to come back to the remote surveyed sites a few days later.

By applying stratification instead of a pure random draw we can furthermore reduce bias that is induced by attrition – the drop-out of households between baseline and follow-up survey. In particular RCTs sometimes suffer from attrition because control group members lose interest in participating in another survey wave. Furthermore, a few ongoing relocation programs in Rwanda might induce attrition as households move away between baseline and follow-up. If attrition occurs, it is no longer ensured that the treatment and control groups are balanced on average. While in a pure random draw there is no possibility for re-establishing balance, with stratification we can drop one observation or the corresponding stratum and readjust the sample (Bruhns and McKenzie 2009, Imbens 2011).

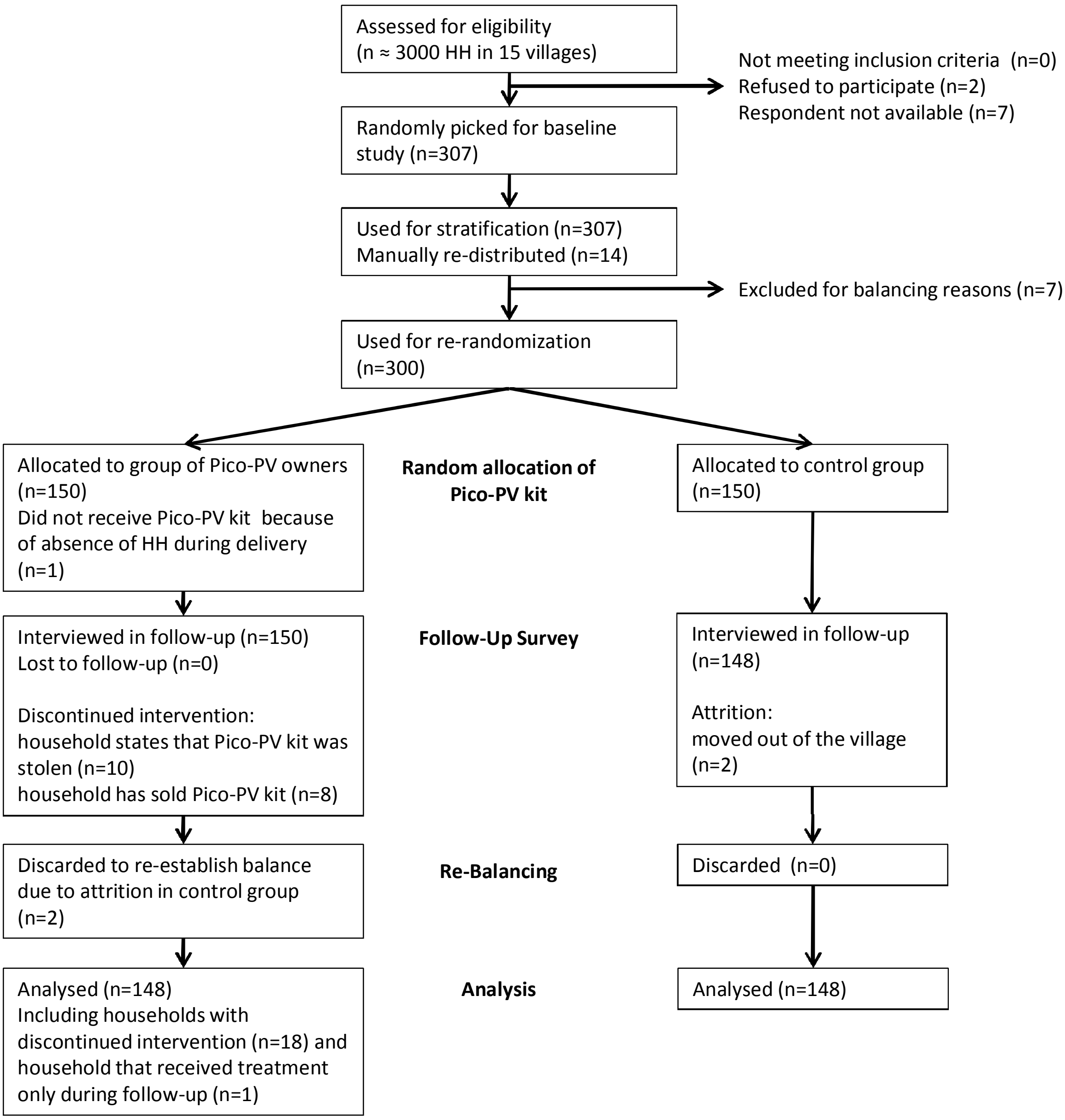
We addressed the risk that winners simply sell the Pico-PV kits by preparing a short contract to be signed by the district mayors and the winners that obliged the winners not to sell the Pico-PV system (see Appendix 8). We developed this strategy in close cooperation with our local consultant who deemed this to be effective, since the governmental authority is well respected even in remote areas of the country and Rwandans generally tend to comply with formal agreements. In the same time we

[13] This implementation design follows the approach presented in De Mel, McKenzie, and Woodruff (2008) and was also applied in a RCT with improved cooking stoves in Senegal (Bensch and Peters 2012).

were assured that such a procedure would not induce any ethical problems. A monitoring visit among all winners each two months was conducted to ensure the proper functioning of the Pico-PV systems and may remind the winners of their commitment not to sell the systems.

Nonetheless, winning households might sell the Pico-PV kit. The implication of this is that we have to distinguish between the *intention to treat effect* (ITT) and the *average treatment effect on the treated* (ATT*,* see Section 3.2.)*.* The IV approach required to obtain the ATT depends on the *compliance rate*, i.e. the share of households that have not sold the Pico-PV kit. In fact and in line with expectations, a few Pico-PV kits disappeared, but the number of *non-compliant* treatment households remains manageable at 19. Hence, 87 percent of the kits were still in use in the treatment group at the time of the follow-up. Attrition is non-existent in the treatment group and low in the control group: Only 2 households could not been retrieved for the follow-up survey, since they moved away after the baseline. In order to re-establish balancing, for every lost observation due to attrition we pruned one observation from the other group in the respective stratum. Following the recommendation in Bose (2010), Figure 2 illustrates the participant flow summarizing the loss or exclusion of households at different stages.

Figure 2: Participants flow



Source: own illustration in accordance with guidelines provided in Bose (2010)

For the **real user survey**, we identified those ToughStuff coordinators that had sold more than 10 solar kits. This was only the case in the districts of Ngororero, Gasabo and Muhanga. Within these districts, we asked the coordinators to establish contact with their agents that sold most kits. Afterwards, all clients from these agents were chosen for an interview. Since some agents did not keep proper record of the clients' address, the survey team just went to a location where several clients lived and asked people in the street whether they knew households that own a ToughStuff Pico-PV kit. In Muhanga, this approach did not work out because the coordinator was not able to indicate the identities of her agents. She seems to have sold the solar kits directly to people who considered becoming an agent (which requires buying the first kit), but who only bought the first kit and never re-contacted her again afterwards. She did not register the address of these persons. This is why finally no interviews have been conducted in Muhanga. In general, since the relationship between the different ToughStuff supply chain members (headquarters, coordinators, agents, customers) was much vaguer than outlined in the proposal submitted to the Daey Ouwens Fund, the logistics of finding customers were much more difficult than originally thought during the planning. Therefore, we only managed to interview 66 instead of the originally planned 100 real users.

The **qualitative and open interviews** with households, village chiefs, hospitals, and schools as well as parts of the interviews with ToughStuff coordinators were conducted by RWI/ISS researchers together with IB&C during the field trips. RWI/ISS also visited EWSA, ToughStuff management staff and ToughStuff competitors. Subsequently, IB&C conducted additional interviews with selected interview partners to answer open questions. Also, IB&C obtained a comprehensive list of ToughStuff agents in 8 out of 14 districts by calling all ToughStuff coordinators. These ToughStuff coordinators were also asked to verify sales numbers obtained from ToughStuff headquarters Kigali.

4 Results

4.1 Data quality assessment of large sample size surveys

In the following, we analyse the quality of the collected data of the RCT and real user survey by examining response rates and conducting checks for internal consistency.

The overall response rate is generally high. Only few questions exhibit missing values at all and the share always stays below 1 percent. Also, 'do not know' answers and 'refused to answer' never exceed 2 percent. Even specifically sensitive information such as expenditures have an average non-response rate of only 1%. The highest rate of "do not know" answers is for expenditures on clothing. Here, 5 percent of the households are unable to estimate the related expenditures. In order to avoid losing a substantial number of observations for the analysis of expenditure pattern by aggregating the different expenditure categories, we imputed missing expenditures by using predicted values from an OLS estimation.[14] In the impact analysis section of this report, we checked our results for sensitivity on whether we include the imputed values or not and find no differences in results.

Questions related to usage patterns of the ToughStuff lamp are mostly complete. Some few questions have at maximum three missing values (out of 150). These missing values have seemingly been caused by enumerators who did not skip and follow the questionnaire correctly. For our main impact indicator on lighting hours, we observe four missing values. These can be ascribed to missing lighting hours of four ToughStuff lamp users. These four observations are dropped for calculating impacts on lighting and lumen hours.

Furthermore, we scrutinized the internal consistency of the household data: Both cross-checking household information within one wave, but also between the waves demonstrates a high degree of consistency. Hence, it seems that a bias due to misreporting can be assumed to be rather small. On the one hand, one could suspect that especially control households might want to pretend that they

[14] For predicting the missing expenditures we use household characteristics that in most cases are identical to characteristics used during stratification and re-randomization, i.e. wealth indicators like building materials, household size, ownership of animals and modern lighting sources, or consumption of fuels.

are poorer than they actually are in order to receive more help. In particular, lighting information in the follow-up could be prone to this bias, since also control household realized that solar lamps had been given away for free during baseline and they might want to convince the enumerators that they need a solar lamp, too. However, if we compare baseline and follow-up information, we find no indication of underreporting in the follow-up. The total number of lighting hours is almost exactly the same during baseline and follow-up. This might also be due to the fact that all household interviews have been conducted in the dwellings of the respondents and enumerators were required to check given information by visual inspection of the objects mentioned during the interview. This limits the opportunity of misreporting. Neither for the contrary, overstating of treatment households due to gratefulness, have we found indication. In contrast, all households were rather sceptical and reported many critical aspects concerning the lamp.

We additionally compared our data to information from the EARP evaluation survey we conducted on behalf of IOB in other regions in rural Rwanda. All comparable indicators show a high degree of consistency, at least with a subsample of EARP households. The present households coincide very much with the lowest quintile of EARP households, which is in line with the selection of the target region of this RCT.

4.2 Socio-economic characteristics of participating households

This section examines the balancing between treatment and control group and at the same time portrays the socio-economic conditions in the areas in which the RCT was conducted. Baseline values of the households' socio-economic characteristics show that the randomization process was successful in producing two perfectly balanced groups (see Table 3). We do not find any significant difference between the treatment and the control group, neither for the characteristics used for stratification and re-randomization nor for further household characteristics.

On average, the households consist of almost 5 persons whereof 39 percent are children younger than 15 years. Most of the households have a male household head. The average age of the household head is 47 years. Most of them only have primary or even no education. Virtually all households own and cultivate arable land, while they do not have much livestock. The most common animals held by the households are cows and goats. Even for Rwandan standards, the houses are constructed with very simple materials; only few households use higher value materials like bricks for walls or concrete for the floor. Furthermore, the two groups are distributed almost identically across the four districts (which has been one of the stratification criteria). The minor and non-significant differences only occur because we manually reclassified households in case of odd numbers per stratum.

The stratification criteria we used in addition to the districts were three characteristics that are strongly correlated with the major impact indicators under evaluation: lighting hours, radio ownership and mobile phone ownership. As a result of the stratification process, the two groups are perfectly balanced with respect to these three variables (see Table **4**). We calculate lighting hours as the sum of lighting usage per day across all used lamps, excluding candles because of the low amount of emitted lumens (candles are included as binary variable during re-randomization, see below). For stratification, we (arbitrarily) distinguish three different levels of lighting consumption: more than three hours per day, three hours per day or less, and no lighting consumption. These three categories are perfectly balanced between treatment and control group. Mobile phone usage and radio ownership is equal as well: In both groups, 64 percent of households own radios and 36 percent mobile phones.

Table 3: Balance of socioeconomic characteristics between treatment and control group (baseline values)

	Treatment		Control	*t*-test/chi-2-test (total treated vs. control *p*-values)
	total (sd)	non-compliant (sd)	total (sd)	
N	129	19	148	
Household size *	4.85 (2.0)	5.5 (1.5)	5.0 (2.0)	0.491
Hh's composition				
Share children 0-15 years	39 (24)	51 (16)	38 (23)	0.680
Share elderly 65+	7 (20)	2 (6)	5 (16)	0.389
Hh's head male (in percent)	76	84	76	0.892
Age of the HH's head	47 (15)	45 (17)	48 (15)	0.795
Education of hh head (in percent) *				
None	35	53	34	0.855
Primary education	61	42	60	
Secondary education and more	4	5	5	
Cultivation of Arable Land (in percent) *	98	100	99	0.314
Ownership of Arable Land (in percent) *	95	90	95	0.791
Ownership of Cows (in percent) *				
No cow	63	84	69	0.542
One cow	22	11	19	
More than one cow	15	5	12	
Ownership of Goats (in percent) *				
No goat	68	79	74	0.476
One goat	16	5	14	
More than one goat	16	16	11	
Material of the walls (in percent) *				
Higher value than wood, mud, or clay	14	11	14	1.000
Material of the floor (in percent) *				
Higher value than earth or dung	11	5	11	0.854
District (in percent) ^{S}				
Gicumbi	19	16	20	0.997
Gisagara	26	32	27	
Huye	27	26	27	
Rusizi	27	26	27	
Number of observations	148	19	148	

Note: * used for re-randomization: ^{S} used for stratification

In addition to the stratification process, we applied a re-randomization algorithm including the additional criteria hand-crafted LED usage, mobile LED usage, kerosene consumption (for lighting only), the number of mobile phones and the consumed lighting hours (here as continuous variable). All these characteristics are also balanced. Treatment and control households consume on average 3.1 and 3.2 lighting hours per day, respectively. The difference is not statistically significant. Both groups use on average 1.55 candles per month and consume half a litre of kerosene for lighting. 36 percent of the households use hand-crafted LED-torches (do-it-yourself LED lamps disassembled from torches, mobile or fixed to the wall or the house top and connected to dry-cell batteries). Four percent of the households use ready-made mobile LED lanterns. The households own on average 0.48 mobile phones.

Table 4: Balance of outcome related characteristic between treatment and control group (baseline values)

	Treatment		Control	*t*-test/chi-2-test (total treated vs. control *p*-values)
	total (sd)	**non-compliant (sd)**	**total (sd)**	
N	129	19	148	
Lighting hours, categorized [S]				
No lamps or candles	19	26	19	
Less or equal 3h/day	51	42	51	
More than 3h/day	30	32	30	1.000
Lighting hours per day, continuous*	3.1	2.7	3.2	0.910
Usage of Hand-crafted LED* (in %)	37	26	34	0.629
Usage of Mobile LED* (in %)	3	5	4	0.520
Consumption of Candles* (pieces per month)	1.34	2.32	1.76	0.445
Consumption of Kerosene for Lighting * (in litre per month)	0.46	0.35	0.54	0.373
Radio Ownership [S] (in %)	64	32	64	1.000
Mobile Phone Ownership [S] (in %)	36	32	36	1.000
Number of Mobile Phones *	0.49	0.21	0.47	0.815

Note: * used for re-randomization: [S] used for stratification

If we look at the group of non-compliers, we see that they differ substantially along several wealth indicating characteristics. This suggests that non-compliers are generally poorer than complying households: They have more children, own less land, have less cows and goats, and have less radios and mobile phones (see also Appendix 7 for a probit regression of compliance on a set of household characteristics).

4.3 Impact assessment

Out of the 150 Pico-PV sets we originally randomized, 19 households do no longer possess the kit. Either they decided to sell it (8 households) or it got stolen (10 household). One household received the kit only during follow-up because no household member had ever been present during randomization of the kits. Among the remaining households that still have a Pico-PV kit, usage rates are very high (see Table 5). 86 percent use the kit at least once per day. While 85 percent use the kit for lighting, 68 percent use it for listening to the radio and only 10 percent use it for charging mobile phones. 62% use the battery pack that can be used to operate each of the three appliances.

In line with these technical deficiencies and the households' expressed priorities for lighting, charging pattern are dominated by the lamp: Most of the time, the kit is used to charge the lamp (26 hours) followed by operating the radio (20 hours) and charging a mobile phone (only 2 hours). The fourth option for the households is to charge the battery pack that afterwards can be used to run one of the three appliances.

The low radio and mobile phone charging usage rates are due to technical drawbacks of the kit: Virtually all households that do not use it for operating a radio say that the radio does not work at all or only poorly with the kit. Even households that use the radio state that the time they can listen to the radio is very short and that they receive less broadcast stations than operating the radio with dry-cell batteries. One may suspect from these problems that the households do not charge the radio sufficiently. In a few cases this might be (also) due to handling issue, but according to technical inspectors involved in testing the kit for Lighting Africa, the major reason for this seems to be the low capacity of the panel, which does not allow for charging all devices completely within one day. The technical issue for mobile phone charging is even more striking: 55 percent of household that have a mobile phone state that no suitable mobile phone charger exists for their mobile phone or even if the switch physically enters the phone, the charging process does not start. In fact, the ToughStuff kit at the time of the randomization did not provide a mobile phone charger adapted to Motorola phones, one of the most popular mobile phone brands in rural Rwanda. These deficiencies indicate that the Pico-PV kit had not been calibrated appropriately for usage in Rwanda until the time of the baseline survey (see also Section 5 on sustainability of the ToughStuff approach).

Box 1: Compliance: Why households do or do not use the Pico-PV kit

Although we expected on the outset of the project that most households would highly appreciated the Pico-PV kit given that lighting is a very scarce good in the surveyed areas (see Box 2), it appeared also to be very likely that households would consider selling the kit. The Pico-PV kit's value of course constitutes a considerable monetary value for household in remote rural areas. For this reason, we designed a contract that treatment group households had to sign and thereby declared not to sell the kit. The contract had been countersigned by the local administrative authority. In order to monitor what is happening in the villages, also in terms of potential trading activities of the Pico-PV kit, our field team conducted short visits to every village every two month.

While overall the Pico-PV kits have been enthusiastically accepted by all households, already during the first monitoring visits we encountered some households that had sold the kit or who claimed that the kit had been stolen. The latter might as well be a pretext, because people feel embarrassed for having sold it. Yet, also in several discussions with survey participants and not-involved households many respondents stated that there is a high risk that such devices are stolen. All interviewed households said that it is dangerous to leave the solar panels outside at night or while you are not at home. Kits were mostly sold in cases where households were confronted with shocks, i.e. a sudden essential need occurred. For example, one woman had to sell the kit since her son had stolen some of the neighbour's manioc and she had been unable to compensate the neighbour for the damage without selling the kit. The vast majority of households, though, did neither sell nor consider selling the kit. Many respondents in qualitative interviews underpinned this by saying, for example, that they "would never sell the kit". A woman who had to see a doctor urgently and didn't have the money to pay the bus to reach the nearest hospital told us that she would never sell the kit "just to get money". The reason she have was that she thinks that the kit means a perspective for the future of her family and, in addition, she would anyhow never sell a gift.

During the follow-up, we asked respondents in the structured questionnaire to imagine that we wanted to take away the PV-kit. Households were asked how much money they would be willing to pay in order to keep the kit. On average, households are willing to pay 15,300 FRW. This is 3,000 FRW less than the real price. 12 percent of the households are not willing to spend anything on the kit. 38 percent of the households offer a price higher than the real price of approximately 18,000 FRW. These numbers, though, have to be interpreted with care. While they do reflect the value people assign to the device (which is the major purpose of asking for the willingness-to-pay) it does not mean that the respondents are in fact able to pay the stated amounts. Since for most respondents 15,000 FRW constitute around 50 % of total monthly expenditures, they apparently base their stated willingness-to-pay on the assumption "If we had more money, how much would I be willing to pay?".

In line with these technical deficiencies and the households' expressed priorities for lighting, charging pattern are dominated by the lamp: Most of the time, the kit is used to charge the lamp (26 hours) followed by operating the radio (20 hours) and charging a mobile phone (only 2 hours). The fourth option for the households is to charge the battery pack that afterwards can be used to run one of the three appliances.

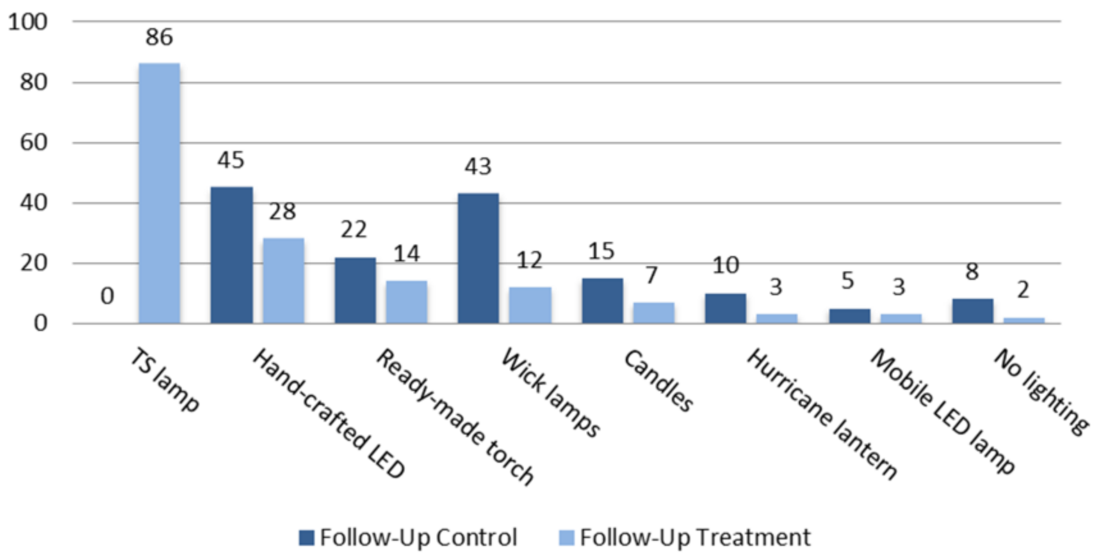
Table 5: Usage of ToughStuff Pico-PV kits

Share of households...	**Full Treatment Group (in parentheses: only compliant households)**
... using the kit at least once a day	86% (95%)
...using the kit for lighting	85% (97%)
...using the kit for listening to the radio	68% (79%)
...using the kit for charging mobile phones	10% (11%)
...use the battery pack	65% (71%)
Charging	
Hours per week the kit is used to...	
...charge the lamp	26
...listen to the radio	20
...charge the battery pack	18
...charge a mobile phone	2

4.3.1 Outcomes

Lighting

Figure 3: Usage of lighting sources



Note: Rechargeable and gas lamps are not included in the figure since only one control household uses a rechargeable lamp and only one treatment household uses a gas lamp.

All kit owning households use it for lighting. The only exceptions are four households that report to have technical problems with the lamp and cannot use it for this reason. In addition to the ToughStuff lamps, treatment households still use traditional lighting sources, even if to a much smaller extent than control households (see Figure 1). Traditional lighting sources encompass kerosene wick lamps, candles, hurricane lanterns, and LED-lamps (hand-crafted LED lamps, ready-made torches and mobile LEDs). Appendix 5 shows pictures of the different lamp types.

Box 2: Energy poverty's bottom line: lighting as a scarce good

The regions selected for this RCT are very remote areas mostly in the periphery of the country. The reason for this was to adequately reflect the long term target group of ToughStuff and potential customers of a Pico-PV kit that comprises a lighting device that is rather – even within the available Pico-PV spectrum – at the lower boundary in terms of emitted lumen. In these periphery areas lighting is indeed a scarce good. Compared to average rural areas in Africa, the households in the survey areas enlighten their homes only very sparsely using lighting devices that emit very few lumen. One or two LEDs, for example, dim a small room of around 10 square meters in a way that allows a person to distinguish the shape of objects and avoid bumping against furniture. Reading or studying is possible, but tiring and inefficient. Also, the time period people lighten their homes per day is comparatively short. As a consequence, in all conducted qualitative interviews the importance of lighting was emphasized by respondents – underlined by anecdotes and evidence. Quite a considerable share of households (around 8 percent among control households) does not use any artificial lighting at all – except for the light coming from the cooking fire. After the fire is extinct, no lighting is available; people just go to bed. In their small houses this requires some preparation and rearrangement of the inside space, for which they lit a match or a tuft of dry grass to have light for a few seconds. This lack of high-quality lighting and this scarcity of artificial lighting in general has to be taken into account when considering the ToughStuff lamp as an intervention. In spite of its modest size (it emits only around 40 lumen) it changes lighting conditions noticeably for those energy poor households. In methodological terms, the expected effect size is quite considerable.

Table 6: Number of lighting devices and consumption

	Number of lamps used per household				Operation hours per day and lamp			
	Treatment	Control	*ITT*	p-value	Treatment	Control	*ITT*	p-value
TS lamp	0.88	0.00	*0.88*	0.000	2.89	-		-
Hand-crafted LED lamps	0.35	0.47	*-0.12*	0.083	3.45	3.40	*0.05*	0.860
Ready-made torch	0.14	0.22	*-0.09*	0.049	2.23	2.12	*0.10*	0.811
Wick lamp	0.12	0.43	*-0.32*	0.000	2.47	2.98	*-0.51*	0.295
Candles	0.07	0.15	*-0.08*	0.025	2.05	1.58	*0.47*	0.272
Hurricane lamp	0.04	0.10	*-0.05*	0.078	3.2	2.43	*0.77*	0.124
Mobile LED lamp	0.03	0.05	*-0.02*	0.358	2	2.57	*-0.57*	0.351
SUM	**1.62**	**1.43**	***0.2***	**0.005**	**4.3**	**3.8**	***0.5***	**0.117**

Note: The *ITT* depicts the difference in means at the follow-up stage between the whole treatment and control group, also including non-complying households. Rechargeable lamps and gas lamps are not included in the table, since only one control household uses a rechargeable lamp and only one treatment household use a gas lamp.

While the treatment group uses on average 0.8 traditional lamps (any type), the control group uses 1.43 traditional lamps per household (see Table 6). This means the ToughStuff lamps have replaced half of the traditional lighting sources. 47 percent of the treatment group uses the ToughStuff lamp exclusively. Treatment households use above all significantly less wick lamps, but also less ready-made torches, candles, hurricane lamps, and hand-crafted LED lamps. Those traditional lamps that are still used in treatment households are used as intensively as before indicating that households rather replace one single lamp completely instead of reducing the operation time of all lamps in a household. The most common traditional lighting sources among the control group are hand-crafted LED lamps (45 percent) and wick lamps (43 percent), ready-made torches (22 percent) and candles (15 percent). Mobile LED lamps are only used by few households. Those households that do not use any lighting device normally only rely on light that is emitted from the cooking place. In some cases they also light small pieces of wood or grass.

Box 3: The diffusion of hand-crafted LED lamps in Rwanda

In recent years, the usage of hand-crafted LED lamps has increased substantially in many countries of Sub-Saharan Africa. These lamps are very simple hand-made structures using small LED disassembled from torches, cables and a set of batteries. Some people use them as portable lamps, sometimes they are installed permanently at walls or roofs.

In Rwanda, these lamps are normally very cheap and fragile. While torches and therewith LEDs are available in kiosks in basically each village, cables are only sold at the weekly markets (at around 100-150 FRW/m). Batteries are often not even bought – people frequently deplete used batteries from their radios. The remaining power of these batteries is too weak to run a radio but still sufficient to lighten small LEDs. In various Focus Group Discussions, villagers explained that they have only recently started to use such hand-crafted LED lamps and that the technology diffuses through mouth-to-mouth propaganda. In many cases, respondents state that school children talk about the hand-crafted LED technology with their school mates and bring the know-how to their homes. In our dataset the usage rate of hand-crafted LED lamps among the control group increased significantly from 34% to 46% within only six months. From in-depth interviews with 40 households that use these lamps we know that they consist of on average 3 LEDs and 3-4 batteries and consume 4 batteries per month. 40 percent of these batteries are used radio batteries, 60 percent are newly employed batteries (see Box 7 on the disposal of dry-cell batteries). This means that in many cases the households get the lighting service without additional costs for batteries, because they reuse batteries that otherwise would have been thrown away. However, the villagers report that these lamps often break because the voltage of the batteries is not balanced with the capacity of the LEDs. This seems plausible since only few of these structures come with current limiting and the LEDs are exposed to very different voltage levels depending on the number, type, and depletion status of the batteries. The LEDs break easily due to voltage overload especially if new batteries are connected.
Also depending on the number and quality of batteries and LEDs, the lamps emit very different levels of lumen, i.e. quality of lighting. On average we assume that they emit only 10 lumens which is slightly less than a candle (see also section on consumption of lumen hours)

The ToughStuff lamps are mainly used by female adults (see Table 7). The second most frequent users are male adults. Children use the lamp less frequently and among this group, older children use the lamp more frequently than smaller children. Few respondents state that it is not possible to identify one sole user, because the lamp is used for collective activities like eating or the lamp is lit when the whole family sits together and talks to each other.

Table 7: Main user of the ToughStuff lamp and activities

ToughStuff lamp is mainly used by…	**%**	**Main Activities (all users)**	**%**
Female adult >17 years old	48.6	Cooking	30
Male adult >17 years old	23.4	general inside activity	27
Female between 12 and 17 years old	10.1	studying	16
Male between 12 and 17 years old	6.6	eat	13
Collectively used by whole family	5.8	housework	5
Children between 6 and 11 years old	4.7		

Female adults use the ToughStuff lamp most frequently for cooking (see Table 8). The second more general activity of *general activities inside* refers to situations where the woman is not doing one specific activity but uses the lighting while being inside the household. Most answers that have been summarized as *housework* are preparing the bed for the family in the evening but also cleaning and other housework. Male adults use the lamp above all for general activities inside but also to study. The third most frequent activities are eating and walking outside both with seven percent. Walking outside implies both short distances like going to the toilet but also longer distances, for example, visiting friends. Male and female children between 12 and 17 years use the ToughStuff lamp for studying. Children between 6 and 11 use the ToughStuff lamp only rarely, but if they do, they also use it for studying.

Table 8: Activity per user type of ToughStuff lamp (in percent)

	First Activity		**Second Activity**		**Third Activity**	
Female adult >17 years old (N=149)	Cooking	65	general activities inside	13	housework	9
Male adult >17 years old (N=60)	general activities inside	63	Study	10	walk outside	10
Female between 12 and 17 years old (N=26)	Study	73	Cooking	19	other	8
Male between 12 and 17 years old (N=19)	Study	74	Cooking	11	other	11
Collectively used by whole family (N=12)	Eat	58	general activities inside	33	Housework	8
Children between 6 and 11 years old (N=11)	Study	91	general activities inside	9		

Note: Information on activities stem from an open question, asking what are the main activities the different lamp users are exercising while using the lamp.

A direct comparison of lamps used for the main activities exercised with the ToughStuff lamp reveals which lamps have been replaced by the ToughStuff lamp (see Table **9**). Looking at lamps used by female adults for cooking shows that the ToughStuff lamp on the one hand is used by women who formerly had not been using any lighting device for cooking and on the other hand the ToughStuff lamp replaces wick lamps. While 5253 percent of the households in the control group do not use any lighting device for cooking, only 22 percent in the treatment group do. Usage of wick lamps for cooking has been reduced from 27 percent to 6 percent. For general activities inside exercised by male adults we see the same pattern. The ToughStuff lamp replaces wick lamps (9 percent vs. 3 percent) and is used by males who formerly had not been using any lamp for these activities (81 percent vs. 68 percent).

If we analyse what kind of lighting device children use for studying, it is striking that in almost half of the households with children, children do not study at home (see Table 9)..[15] Moreover, in 26 percent of all households, children who study do not use any lighting devices for studying at all. These children either study during daytime (around 40 percent among them) or use indirect lighting from lamps that are not specifically employed for lighting the children's workplace. The share of households without children studying without explicit lighting source is slightly lower among the treatment group even if the difference is statistically not significant. Those few households among the control group that use lighting employ mainly wick lamps. The share of wick lamp users for studying is significantly lower in the treatment group and indicates that the ToughStuff lamps have replaced wick lamps.

Table 9: Lamps used for different activities (in percent of all households)

Activity	**Female adults cooking**				**Male adults activities inside**				**Children (6-17 years) studying**			
Lamp	Treat.	Ctrl.	*ITT*	p-value	Treat.	Ctrl.	*ITT*	p-value	Treat.	Ctrl.	*ITT*	p-value
Wick lamp	6	27	*-21*	0.000	3	9	*-6*	0.025	2	10	*-8*	0.006
Ready-made torch	5	10	*-5*	0.117	3	5	*-2*	0.243	1	1	*0*	0.566
Hand-crafted LED	5	7	*-2*	0.338	1	3	*-2*	0.101	2	2	*0*	0.993
Hurricane lantern	2	4	*-2*	0.315	1	1	*0*	0.996	1	2	*-1*	0.317
Candles	2	2	*0*	0.993	1	2	*-1*	0.317	1	2	*-1*	0.657
Gas	1	0	*1*	0.315	-	-		-	-	-		-
Mobile LED	0	1	*-1*	0.318	0	1	*-1*	0.318	1	1	*0*	0.566
ToughStuff lamp	63	0	*63*	0.000	26	0	*26*	0.000	24	0	*24*	0.000
None	22	52	*-30*	0.000	68	81	*-13*	0.010	22	29	*-8*	0.195
No child studying at home (only HH with children at school age)	-	-	-	-	-	-	-	-	44	52	*-8*	0.249

Note: The *ITT* depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Radio usage

Since the randomized Pico-PV kit encompasses a radio and the possibility to operate the radio by means of the PV panel, this section examines radio usage patterns in the household and the extent to which it affects the accessibility of information. In fact, radios are mostly used to listen to

[15] For a detailed analysis of children studying at home, see Section 4.3.2 on time use.

programs that transmit information (see Table 10). We asked all radio users to name their two favourite types of radio programs: the by far most preferred program among adults are news, followed by music. The third preference are programs that people refer to as "théatre". These are radio plays that try to raise awareness on different topics like reconciliation, working attitude, or justice. The last category subsumes special broadcasts topics like politics or health ('broadcasts' in Table 10).

Box 4: Radio stations in Rwanda

In Rwanda, the biggest radio station is the state-financed Radio Rwanda that reaches more than 90 percent of the population. It broadcasts 24 hours in Kinyarwanda, French, English and Swahili. Radio Rwanda maintains additionally 5 community radio stations that partly broadcast contributions from Radio Rwanda and additionally cover local news and regional information. Since 2002, also private radio stations have received licences to broadcast. Their reception area, though, is mainly restricted to Kigali and bigger towns. Within our survey area, people frequently reported that besides Rwandan radio stations they can also receive radio from Burundi or Congo.

Radio Rwanda and its community radio stations cover both entertainment and information broadcasts. For example at Radio Rusizi, the community radio of Rusizi, on a regular day where they offer program from 5 am to 23 pm, music covers 7 hours, news sum up to almost 4 hours, 3.5 hours of entertainment shows like soap operas ("theatre"), quizzes or sports events, and almost 3 hours on broadcast with some educational background. These educational broadcasts diffuse for example information on hygiene and cleanliness, on agricultural activities, on animal husbandry, on good governance, or to raise workers motivation.

Table 10: Preferred radio programs per household member

(in percent)		Treatment	Control	p-value
Head of HH	Music	46	62	0.030
(N=173)	News	84	86	0.598
	Theatre	13	5	0.056
	Broadcast	13	8	0.288
	Other	14	15	0.855
Spouse	Music	43	67	0.004
(N=139)	News	71	68	0.705
	Theatre	24	14	0.144
	Broadcast	10	9	0.816
	Other	16	12	0.542
Children	Music	76	71	0.694
6-11 years old	News	31	39	0.439
(N=66)	Theatre	22	14	0.384
	Broadcast	8	11	0.708
	Other	4	11	0.256
Male	Music	70	83	0.255
12-17 years old	News	47	63	0.246
(N=48)	Theatre	10	17	0.469
	Broadcast	13	8	0.561
	Other	13	8	0.561
Female	Music	89	84	0.605
12-17 years old	News	44	58	0.325
(N=57)	Theatre	18	16	0.847
	Broadcast	9	5	0.621
	Other	16	11	0.597

Table 11 portrays the effects of the Pico-PV kit treatment on radio ownership and usage patterns. Since the randomized Pico-PV kit encompasses a radio, the share of radio owners is close to 100 percent in the treatment group, while slightly more than 50 percent of the control group households own a radio. It is above all the head of the household who uses the radio, but the increased number of radios in the households also leads to significantly increased radio usage of other household members. The share of members listening to the radio is significantly higher in the treatment group for all household members. The listening hours for those who use a radio only increases significantly for the head of households.

Table 11: Radio ownership and usage

	Treatment	Control	*ITT*	p-value
Radio Ownership	95%	52%	*43%*	0.000
HH member listens regularly to radio				
Head of HH	86%	43%	*43%*	0.000
- Listening hours per day (only user)	4.3	3.2	*1.0*	0.003
Spouse	78%	42%	*36%*	0.000
- Listening hours per day (only user)	3.3	2.7	*0.7*	0.161
Boys 12-17 years	76%	47%	*29%*	0.007
- Listening hours per day (only user)	2.1	2.0	*0.2*	0.536
Girls 12-17 years	80%	42%	*38%*	0.000
- Listening hours per day (only user)	1.7	2.1	*-0.4*	0.061
Children 6-11 years	63%	33%	*30%*	0.000
- Listening hours per day (only user)	1.9	2.2	*0.3*	0.374

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households

Mobile phone usage

While the Pico-PV kit does not contain a mobile phone, it is supposed to improve access to phone charging and thereby might increase usage rates or even ownership. As Table 12 shows, the usage of mobile phones is not influenced by the treatment: In both groups, the majority of households does not have any mobile phone (64 percent, see Table 12). 27 percent possess one mobile phone, and only few households have more than one mobile phone. 25 percent of all household heads use a mobile phone, but only 10 percent of spouses do. None of the subtle differences between treatment and control group is statistically significant.

Table 12: Mobile phone ownership and usage on household level

On Household level	Treatment	Control	*ITT*	p-value
HH owns ... mobile phone				
no	64%	64%	*0%*	
1	26%	28%	*-2%*	0.760
2	9%	6%	*3%*	
>2	1%	1%	*0%*	
Head of HH uses mobile phone	26%	24%	*2%*	0.615
Spouse uses mobile phone	11%	9%	*2%*	0.545
Usage (times per week)	51.3	41.4	*9.9*	0.131

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Treatment households use the Pico-PV kit only rarely to charge their mobile phone. This does not come as a surprise, since the kits exhibit severe technical problems with the mobile phone charger (see Section 4.3). Only 15 percent among the treatment group charge their own mobile phone with the kit (see Table 13). Furthermore, eight households in the treatment group (i.e. 5 percent) charge mobile phones for other people; six of them do not have mobile phones of their own. Only one household receives money for charging the mobile phone (100 FRW per charge).

Box 5: Mobile phone charging

In spite of the survey regions' remoteness mobile phones are more and more used. The network covers most parts of Rwanda, including most of the remote areas. In all villages we surveyed mobile phone network was available somewhere in the village. Only four percent of the surveyed households do not have network coverage at their homestead. A considerable share of households owns and uses mobile phones. Charging the phone, though, is a challenge in non-electrified communities. In most of them, some charging station exists that is commercially run by hair cutters or shops that possess a generator, also for other purposes. Here, people charge their mobile phones for a price of 100-200 FRW per charge. Many villagers also report to visit neighbouring electrified villages implying a walk of one hour or more (58 minutes on average according to the structured questionnaire). Normally people leave their mobile phone at the charging station and pick it up the next day. Sometimes they also wait for it to be charged.

All respondents in open interviews and FGD assigned a high priority to mobile phone usage, which is the reason why these high costs – either in monetary terms or in terms of the time burden – are accepted. This example also visualizes that access to modern energy services cannot be lacking as such. Rather, it is a matter of costs and timely burden that people have to assume.

Unfortunately, the ToughStuff kit did not provide for a remedy because of the wrong phone charger it was equipped with (see Section 4.3 and Section 5). Even if people own a phone to which the charger fits in many cases it did not work. Some treatment group members also stated to be scared of damaging the phone by using the ToughStuff kit to charge it. Obviously, there were some bad rumors around due to the technical deficiencies of the ToughStuff kit.

Accordingly, the vast majority of households still charge their mobile phone at commercial shops. The share is 17 percent lower among the treatment group with the difference being statistically significant. Charging fees vary between 100 and 200 FRW per charge. In spite of the limited number of households that use their kit for charging mobile phones, the share of people who pay for charging is significantly lower in the treatment group. However, already during the baseline survey we observed this difference. When we estimate a DID model that takes baseline values into account, the significance of the difference vanishes. The total weekly expenditures for mobile phone charging do not differ (both in cross-sectional and DID comparison).

The rest of the households charge their mobile phone somewhere free of charge (health stations, schools or somewhere in the neighbourhood). The number of times mobile phones are charged is not influenced by the Pico-PV treatment. In both groups, households charge their mobile phone between one and seven times per week, on average each mobile phone owning household charges the phone 2.3 times per week.

Table 13: Mobile phone charging

	Treatment	Control	*ITT*	p-value
Frequency (times per week)	2.4	2.25	*0.2*	0.574
Share that pays for charging	91%	98%	*-7%*	0.093
Weekly expenditures (in FRW)	206	244	*- 38.0*	0.221
Place (in percent)				
At home with ToughStuff	15	0	*15.0*	0.003
At a shop	79	96	*17.0*	0.008
At a non-commercial institution	8	6	*2.0*	0.696

Note: Only households that own at least one mobile phone (N=100). The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

4.3.2 Impacts

Lighting and lumen hours

While baseline levels for lighting hours are almost perfectly balanced between the treatment and control group, the treatment group consumes significantly more lighting hours after having received the ToughStuff lamp (15 percent more, see Table 14). Lighting hours in the follow-up have been calculated as the sum of average lighting usage per day across all used lamps including also candles and normal torches. Furthermore, not only the quantity of lighting hours consumed differs between the treatment and control group. Concerning the quality of lighting, i.e. the consumption of lumen hours, the difference is even more pronounced. The different lighting sources used by the households emit very different amounts of lumen (lm). In comparison with traditional lighting sources, the ToughStuff lamp reaches medium lumen levels. It emits 40 lm, while a candle only emits around 12 lm, a hurricane lantern around 32 lm and a mobile LED lamp reaches levels around 100 lm (O'Sullivan and Barnes 2006). Lumen levels emitted by hand-crafted LED lamps vary substantially depending on the number and quality of LEDs and batteries used. After laboratory tests with two different LED structures connected to two different battery packages we estimate an average level of 10 lm emitted by hand-crafted LED lamps.[16]

These findings are also confirmed if we only look at those households that effectively use the ToughStuff kit by estimating the ATT via an IV model. The ATT for lighting hours amounts to 1.1 hours, for lumen hours it is 102 lumen hours. The results of the model that also accounts for baseline levels are presented in Appendix 7.

Table 14: Lighting hours and lumen hours

Lighting hours and Lumen hours	Treatment	Control	*ITT*	p-value
Lighting hours complete Follow-Up	4.55	3.85	*0.59*	0.093
Lumen hours complete Follow-Up	135	48	*86*	0.000

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Time Usage

The improved accessibility of higher quality lighting is often expected to influence the time allocation of treated households. In order to scrutinize this question, we look at three different indicators: total time household members are awake, study hours of children at school age and activities after nightfall.

Table 15: Time awake, head of household and spouse

Time awake	Treatment	Control	*ITT*	p-value
Get up, head of HH	5h43	5h47	*-4*	0.448
Go to bed, head of HH	20h23	20h20	*3*	0.795

[16] No reliable lumen estimates existed for the hand-crafted LED lamps, since they have only recently emerged. We therefore took two typical sample lamps from one of the survey villages to Germany and had them tested at Hochschule Ulm, where the lumen emissions where tested using standard measurement instruments (integrating (Ulbricht) sphere).

Time awake, Head of HH (N=248)	14h28	14h27	*1*	0.956
Get up, spouse	5h40	5h43	*-3*	0.420
Go to bed, spouse	20h26	20h19	*7*	0.351
Time awake, Spouse (N=224)	14h46	14h36	*10*	0.246
Time awake, Children female 12-17 (N=224)	14h37	14h52	*-14*	0.287
Time awake, Children male 12-17 (N=224)	14h32	14h36	*-4*	0.860
Time awake, Children female 6-11 (N=224)	13h58	13h49	*9*	0.397
Time awake, Children male 6-11 (N=224)	13h43	13h42	*1*	0.966

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

For time usage, we find that the time household members are awake does not change. Pico-PV kit owners do not get up earlier nor go to bed later than the control group. Table 15 displays the time of getting up and going to bed for the two main users of the ToughStuff lamps. Looking at the ATT, almost all findings are confirmed. The DID/IV model though indicates significant effects for male children between 6 and 11.

However, we find significant effects on the time allocation of children at school age. Children of Pico-PV kit owners study significantly longer after nightfall than children of non-owners, even though the total study time per day does not increase. Children apparently reallocate study time from daytime to night-time (see Table 16, also for disaggregated estimates). More precisely, the data suggests, that the increase in average study time after nightfall is caused by more children studying after nightfall. While the share of households among the treatment group in which at least one child studies after nightfall is around 40 percent, it is only 20 percent in the control group. The study time of children that had already studied after nightfall before does not increase.

Table 16: Study time children at school age

Daily study time (in minutes)	N	Treatment	Control	*ITT*	p-value
all children, total	209	54	50	*3*	0.712
all children, after nightfall	209	40	25	*15*	0.001
male children 6-11, total	100	37	26	*11*	0.201
male children 6-11, after nightfall	100	29	12	*37*	0.010
female children 6-11, total	92	52	41	*10*	0.581
female children 6-11, after nightfall	92	27	11	*16*	0.010
male children 12-17, total	89	61	54	*7*	0.514

male children 12-17, after nightfall	89	50	32	*18*	0.080
female children 12-17, total	94	62	58	*4*	0.662
female children 12-17, after nightfall	94	44	37	*7*	0.448

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Table 17 displays activities of household members after nightfall. Activities exercised by less than 15 percent of the households have been excluded from the table. For the head of household, the usage of the ToughStuff lamp influences above all the share of head of households that listen to the radio and that do housework. For spouses, only the share of spouses that listen to the radio increases. Activities of children do not change substantially. Only children between 6 and 11 play less and female children between 12 and 17 listen more to the radio.

Table 17: Activities after nightfall

Share of HH members exercising...(in percent)		Treatment	Control	*ITT*	p-value
Head of HH	Listen to the radio	51	33	*18*	0.002
(N=294)	Go out/meet people	48	47	*1*	0.821
	Do housework	33	23	*10*	0.059
	Pray	22	19	*3*	0.525
Spouse	Do housework	54	57	*-3*	0.631
(N=278)	Listen to the radio	45	27	*19*	0.001
	Go out/meet people	19	24	*-5*	0.306
Children	Go out/meet people	37	32	*5*	0.150
6-11 years old	Play	15	33	*-18*	0.002
(N=216)	Listen to radio	17	13	*4*	0.413
Male	Go out/ meet people	58	52	*7*	0.374
12-17 years old	Play	53	49	*04*	0.581
(N=188)	Listen to radio	19	15	*5*	0.402
Female	Listen to radio	39	24	*15*	0.084
12-17 years old	Do housework	28	26	*2*	0.791
(N=118)	Play	21	18	*04*	0.651
	Go out/ meet people	16	15	*15*	0.904

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Perceived security

In many rural areas in Africa, villages are in complete darkness after nightfall, which makes people feel uncomfortable. The remedy electric lighting provides for this is evident, but first and generally, capturing this in a systematic way is of course a challenge. Second and more specifically, unlike grid electricity, which provides lighting to the whole village (via public lighting or outdoor lamps), the ToughStuff kit is a more subtle upgrade compared to traditional lighting sources. Nonetheless, building on experiences from former studies (e.g. Bensch, Peters, and Sievert 2013) we tried to approach security issues by asking respondents for some subjective statements: Basically all households think that darkness is dangerous; 99 percent of all households affirm that this statement is true. No difference between the groups can be observed. Furthermore, all households were asked whether they are afraid in different situation when it is dark outside. Results are presented in Table 18. While households in both groups are similarly afraid when being outdoors and when their children are outdoors, the treatment group exhibits a significantly lower share of households that are afraid when they are at home after nightfall. This is in line with expectation, since ToughStuff lamps are mainly used inside the house and not outside. The usage of a ToughStuff lamp cannot be expected to substantially change lighting levels outside the house. If we estimate the DID/IV model, though, the effect is only significant at the 15 percent level.

Table 18: Perceived security

Afraid when…	Treatment	Control	*ITT*	p-value
…being outdoors after 8 pm	40	41	*-1*	0.768
…children are outdoor after 8 pm	52	56	*-4*	0.608
…being at home during the night	34	47	*-13*	0.023

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Furthermore, we examine the extent to which people change their behaviour in terms of going out after nightfall. Here, some differences between the groups at the follow-up stage exist. The significance of the differences, however, vanishes if we correct for baseline levels through the DID/IV estimation suggesting that the difference between treatment and control group depicted in Table **19** had already existed at the time of the randomization and is not induced by the treatment.

Table 19: Going out after nightfall

Times per week	Treatment	Control	*ITT*	p-value
head of household	2.8	2.5	*0.3*	0.437
spouse	0.7	0.7	*0*	0.966
Male child 12-17	0.5	1	*-0.5*	0.105
Female child 12-17	0.2	0.5	*-0.3*	0.077
Children <12	0.2	0.2	*0*	0.879

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Information

In line with the usage patterns described in Section 4.3.1, radio is by far the most important source of information in the surveyed villages. More than 90 percent of treatment households and 40 percent of control households answer to an open question on their main source of information that they exclusively or together with other sources receive information through the radio (see Table 20).). Apart from this, direct conversations with other people (community gatherings, neighbours and friends) are the most important sources of information. TVs and newspaper are only used by a negligible number of households. While for treated households the importance of radio is substantially higher, control households rely more on community gathering and information exchange with neighbours and friends. This obviously creates potentials for spillovers of increased access to information for some households to the whole village.

Table 20: Main source of information (multiple answers possible)

	Treatment	Control	*ITT*	p-value
Radio	91	40	*51*	0.000
Community gathering	70	82	*-12*	0.018
Neighbours/friends	28	28	*0*	0.942

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Despite the increased usage of radio, we do not find evidence that the improved access to information translates into a higher awareness on topics that might be considered relevant from a development policy point of view. Knowledge or awareness on family planning and preventive health care does not seem to increase (see Table 21). Only for condom usage we see a significant difference of treatment households using even more rarely condoms that control households. This difference, though, is also observable at baseline levels. Through estimating the DID/IV model the difference vanishes. These findings, of course, do not come as a surprise. Even if access to information is clearly improved because of the treatment, the effect size of improved access to information on these specific indicators can be expected to be rather subtle. The reason is that it is difficult to capture the broad effect of improved access to information in indicators that can be used in structured questionnaires. Furthermore, this kind of behavioural change also take time to materialize and may not have unfold completely after only six month. Because of this probably small effect size a large sample size would be required to detect the effect. In other words, the fact that we do not find significant effects here does not mean that they do not exist.

Table 21: Knowledge and awareness indicators

Share of HH that uses…	Treatment	Control	*ITT*	p-value
Mosquito nets	88	86	*2*	0.728
Contraceptive Methods	55	53	*2*	0.775
Condoms	3	12	*-9*	0.013

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Health and environment

As outlined in Section 3.1., kerosene usage is associated with quite severe health threats, most notably respiratory diseases. Although the relative contribution of kerosene lamps to household air pollution is rather low compared to firewood and charcoal usage for cooking purposes, it is the immediate exposure of people sitting next to a wick lamp for studying purposes, for example, that makes kerosene a substantial health threat.

As can be seen in Section 4.3.1, in 10 percent of the control group households kids use wick lamps to study. This share is substantially and significantly lower in the treatment group (2 percent), so for the kids in these households a reduction in exposure can be expected. Likewise, the share of women who use a wick lamp for cooking is substantially and significantly lower in the treatment group (27 percent in the control group, six percent in the treatment group, see Table 9).

Table 22: Health

(in percent)		Treatment	Control	*ITT*	p-value
Male adult	Headache	18	17	*1*	0.752
	Respiratory diseases	7	7	*0*	0.940
	Eye problem	7	7	*0*	0.828
Female adult	Headache	35	31	*4*	0.427
	Respiratory diseases	5	6	*-1*	0.791
	Eye problem	9	13	*-4*	0.26
Male 6-11 years old	Headache	7	14	*-7*	0.275
	Respiratory diseases	2	2	*0*	0.965
	Eye problem	2	6	*-4*	0.279
Female 6-11 years old	Headache	19	4	*15*	0.025
	Respiratory diseases	0	0	*0*	---
	Eye problem	9	10	*-1*	0.859
Male 12-17 years old	Headache	5	9	*-4*	0.398
	Respiratory diseases	0	0	*0*	---
	Eye problem	2	0	*2*	0.326
Female 12-17 years old	Headache	8	15	*-7*	0.283
	Respiratory diseases	4	0	*4*	0.210
	Eye problem	6	3	*3*	0.472

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

We now examine the extent to which this translates into a perceived improvement of air quality and, potentially, into a decrease in respiratory disease symptoms. While at the baseline stage the judgement of most households was that air quality in their houses was good (among both groups around 67 percent of the households rated the indoor air quality as good, the rest rating it as bad). In the follow-up survey 45 percent of treated households say that the air quality in their houses has improved in comparison to the baseline period. The share among control households is substantially lower and only reaching 3 percent. Virtually all treated households ascribe this improvement to the

ToughStuff lamp. However, looking at reported health indicators (see Table 22), we cannot observe that this improved air quality translates into a better health status of the household members. As in the case of improved access to information, the effect size of the treatment on these indicators might be too small to be detectable given the sample size at hand. Besides emitting health threatening particles, kerosene lamps constitute a health threat, since they may cause various accidents. These can be categorised into three types: Accidents that cause fire (i.e. burning objects, clothes, or whole houses), accidents that burn people, and accidents that arrive if the kerosene is accidentally drunken by small children (see Section 3.1). In our sample, though, we hardly observe any accidents (see Table 23).

Table 23: Accidents due to kerosene lamp

Share of households that experienced accidents due to kerosene lamps in last 6 month:	Treatment	Control	*ITT*	p-value
Fires	1	4	*-3*	0.152
Burns	2	0	*2*	0.082
Drinking accidently kerosene	0	0	*0*	-

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

Box 6: Perception of Kerosene's Health Effect

In all open interviews we conducted in the villages people enthusiastically stated their disfavor for kerosene (much more than for firewood, for example). It happened frequently that people in interviews virtually spit out the word "petrol" in order to express their disgust. For many people, kerosene is an evil thing and the epitome for energy poverty. In most cases, it was sufficient to prudently start a conversation about lighting or energy in general to spark this. There was no need to explicitly point at classical disadvantages of kerosene.

When participants in a focus group discussion were generally asked for the disadvantages of kerosene lamps, all participants agreed that the emitted smoke is one of the major drawbacks. A dynamic discussion emerged in which all participants contributed different anecdotes on kerosene induced smoke and its implications for the family members:

- recurring eye problems
- kids having black nasal mucus
- kids prefer candles for doing their homework because of the smoke
- kids ask for battery lamps because of smoke

We also asked different people for accidents and burns induced by kerosene. In this case, this was done directly, since no interview partner raised this issue by her/himself. Nobody remembered an accident or burns in their surroundings. When being asked for whether kids have ever drunken kerosene (something that is reported in the literature for other countries) most people started laughing and found this absurd. The staff members of health stations and a hospital we visited to inquire about cases of serious burns or intoxications related to kerosene usage were also rather surprised. They have not had a single incidence related to kerosene in recent years.

A possibly detrimental environmental effect of hand-crafted LED lamp and radio usage is caused by inappropriate disposal of used batteries. The vast majority of households that use batteries throw them into the toilet (92 percent), which in most cases is just a three-four meter hole near the house. Some few households dispose the batteries with their garbage (2 percent) or throw it somewhere into the nature (3 percent). The remaining five percent of the households give their used batteries away as a gift: These are normally batteries that are discharged to an extent that they do not suffice to run a radio, but which still can be used for hand-crafted LED lamps.

Box 7: Battery disposal

According to the villagers the consumption of dry-cell batteries has increased substantially over the last years. First, because more people own a radio, second and more recently, people are increasingly using ready-made torches or hand-crafted LED. Although no particular sensitization has taken place, people are vaguely aware of potentially harmful effects of batteries. Virtually all households throw discharged batteries into their toilet, which is basically just a 3-4 meter hole in the backyard.

As a matter of course, the toxic metals can be expected to end up in ground and surface water. The extent to which this happens is unclear, though, since little is known about this process, neither in Rwanda nor in the literature. Nonetheless, people chose this way of disposing the batteries because they do not want to simply throw them away (as they do for other forms of garbage). Many respondents in qualitative interviews, for example, said that they are afraid of children playing with discharged batteries.

There is no possibility to dispose batteries somewhat appropriately. A village chief who was asked for implications of disposing batteries into the toilet also was aware of the fact that this might not be a good thing, but he seemed to consider this rather to have moral implications like protecting your environment as a higher good. In other words, he did not perceive this as a hazard to his community. On the other hand, he considered a public collection of batteries a feasible option, which would not be too difficult to be implemented in his views.

Table 24: Number of batteries used per month

	Treatment	Control	*ITT*	p-value
Small batteries	0.52	1.23	*- 0.71*	0.025
for radio	0.02	0.10	*- 0.08*	0.204
for lighting	0.5	1.13	*- 0.63*	0.044
Big batteries	2.5	2.5	*0*	0.991
for radio	1.86	1.66	*0.21*	0.369
for lighting	0.63	0.76	*- 0.13*	0.466
Total batteries	3.02	3.74	*- 0.72*	0.125

Note: The ITT depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

If we look at the number of batteries used by the households, we see that only the number of small batteries is influenced by the usage of ToughStuff. This is consistent with our findings on usage pattern of batteries and the Pico-PV kit: Big batteries are mainly used for radio (more than 75 percent). Since many households encountered problems with operating the radio with the solar panel, they have partly not replaced their former radio with the new one or they started to use the new radio with normal dry-cell batteries. This is why we do not see any reduction in the consumption of big batteries. Small batteries are basically only used for lighting (more than 90 percent), mainly in ready-made torches. As the usage of these torches has been substantially reduced through the ToughStuff lamp, also usage of small batteries is significantly lower among treatment households. If we sum up the total amount of small and big batteries, we see a small difference that is near to statistical significance. The DID/IV model also estimates a difference of approximately 1 battery per month that is statistically significant at the 10 percent level. This reduction is obviously still driven by small batteries used for lighting.

Energy Expenditures

Expenditures for energy are dominated by money spent on cooking fuels (charcoal and firewood). At the baseline stage, it accounts for around one third of all energy expenditures. Since expenditures for cooking energy are not affected by the Pico-PV kit and households had difficulties in estimating the exact amounts of bought firewood (in demarcation to self-collected firewood), we exclude them in the following. The second most important expenditure category is expenditures for kerosene for lighting followed by big batteries. While we see a significant reduction on kerosene expenditures, expenditures on big batteries are hardly influenced. We furthermore observe a significant reduction of expenditures for small batteries and candles. This is in line with the observation that above all lamps that run on kerosene, candles and battery run torches have been replaced by the ToughStuff lamp. While more than 90 percent of the expenditures on small batteries are on lighting, more than three fourth of big batteries are used for radios. This explains why the consumption of small batteries has been reduced in contrast to the consumption of big batteries. Expenditures on mobile phone are only slightly lower among treatment household with the difference being not significant – in line with the observation that the ToughStuff kit was hardly used for mobile phone charging.

Table 25: Expenditures

Monthly expenditures per category (in FRW)	Treatment	Control	*ITT*	p-value
Candles	42	109	*-67*	0.025
Kerosene for lighting	155	609	*-454*	0.000
Charcoal	2	0	*2*	0.318
Big batteries	358	352	*6*	0.899
Small batteries	30	72	*-42*	0.013
Mobile phone charging	137	169	*-32*	0.294
Total traditional energy sources (without cooking energy)	723	1311	*-588*	0.000
Total expenditures (without cooking energy)	34739	29731	*5008*	0.392
Share of energy expenditure on total expenditures (without cooking energy)	0.03	0.07	*-0.04*	0.000

Note: The *ITT* depicts the difference in means at the follow-up stage between the whole treatment and control group, including also non-complying households.

In total, energy expenditures without cooking energy account for approximately 3 percent of total household expenditures among treatment households and 7 percent among control households. This difference is statistically significant. The DID/IV model confirms all these findings.

4.4 How do the RCT results compare to ToughStuff real users?

In order to scrutinize the extent to which the findings from the RCT can be expected to materialize also among real ToughStuff clients, we surveyed 66 households that have bought the ToughStuff kit on the regular market, i.e. with a ToughStuff agent. Overall, a comparison of basic socio-economic characteristics shows that real users are generally richer than the RCT households (see Table 26).

Table 26: Socioeconomic characteristics of real users compared to randomisation users

	Real user (sd)	**Randomisation users (sd)**	***t*-test/chi-2-test *p*-values)**
Household size *	5.15 (2.5)	4.85 (2.0)	0.349
Hh's composition			
Share children 0-15 years	39 (26)	39 (24)	0.948
Share elderly 65+	1 (1)	7 (20)	0.006
Hh's head male (in percent)	92	76	0.005
Age of the HH's head	38 (11)	47 (15)	0.000
Education of hh head (in percent) *			
None	6	35	
Primary education	68	61	
Secondary education and more	26	4	0.000
Cultivation of Arable Land (in percent) *	97	98	0.176
Ownership of Arable Land (in percent) *	86	95	0.022
Ownership of Cows (in percent) *			
No cow	46	63	

One cow	30	22	
More than one cow	24	15	0.054
Ownership of Goats (in percent) *			
No goat	72	68	
One goat	11	16	
More than one goat	17	16	0.560
Material of the walls (in percent) *			
Higher value than wood, mud, or clay	76	14	0.000
Material of the floor (in percent)			
Higher value than earth or dung	35	11	0.000
Monthly household expenditure (in RW Francs)	79,826 (71,633)	26,734 (26,612)	
Has electricity source	15	0	0.000
Number of observations	66	148	

While the household size and the share of children in the household of real users are comparable to the randomisation users, the share of elderly is substantially lower in the real user sample. The reason for this is that during the RCT, the ToughStuff kits have also been given to households that consist of elderly only. These households apparently do not buy the kits and, hence, do not emerge in the real user sample. The highest share of elderly among real user is 25 percent. This age difference is also visible in the average age of the head of households which is significantly lower among real users. Furthermore, real users are headed more often by men than the randomisation users and have achieved higher educational levels. This higher education also translates into dissimilar occupations: While randomisation users are primarily subsistence farmers (90%), only 53 percent of real users heads of households are subsistence farmers. 9 percent are government employees (mostly teachers), 18 percent are self-employed (mostly small shop owner and traders), and 17 percent engage in other dependent occupations, often temporary worker. This employment structure has its origin in ToughStuff's business strategy. In many regions, they have started to work with teachers unions, local authorities and building companies[17]. These organizations offer ToughStuff kits to their employees and for payment the organization deducts instalments from their employees' monthly salary. A wealth gap is also evident when looking at construction material of the houses. Both walls and floors of real users are more often made of higher value materials like bricks or concrete.

Interestingly, some real users have another source of electricity at home: 4 households are connected to the national grid (EWSA), 5 households have a solar home system and 2 households use car batteries. Partly they had already been using the electricity source before buying the ToughStuff kit; partly they got the other electricity source after having bought the solar kit.

Table 27: Usage of ToughStuff Pico-PV kits

Share of households that…	**Real User**	**RCT user**	***t*-test/chi-2-test *p*-values)**
… bought the whole kit	82%		
…bought the lamp	99%		

[17] This approach differs from what was announced in the original proposal. For details see Section 5 on "Sustainability Assessment".

Share of households that…	Real User	RCT user	*t*-test/chi-2-test *p*-values)
…bought the direct radio connector	92%		
…bought the mobile phone charger	88%		
…bought the battery pack	91%		
… use the kit at least once a day	70%	86%	0.007
…use the kit for lighting	85%	85%	0.937
…use the kit for listening to the radio	39%	68%	0.000
…use the kit for charging mobile phones	12%	10%	0.529
…use the battery pack	35%	62%	0.000
Charging			
Hours per week the kit is used to…			
…charge the lamp	36	26	0.002
…listen to the radio	8	20	0.001
…charge the battery pack	12	18	0.045
…charge a mobile phone	2	2	0.782
TOTAL charging hours	56	64	0.234

Most of the real users have bought the whole kit (see Table 27). Among customers that did not buy the whole kit including all three services, the lamp sells best, followed by the radio connector, battery pack and mobile phone charger. The decision for buying the kit has in most cases been taken by the male head of the household (73 percent), in some cases jointly by head of household and spouse (17 percent), and only in few cases the female spouse (3 percent). In all households that are headed by a female, the female head of household decided to buy the kit (8 percent).

Real users use their kit slightly less frequently than randomisation users. The priorities concerning the different devices are comparable, though: The most frequently used device is the lamp, followed by the radio connector, the battery pack and only in few cases the mobile phone charger is used. Yet, the intensity of radio and battery package usage is higher among RCT users. This is also reflected in the charging behaviour: real users charge the radio and battery pack fewer hours than RCT users do. The lamp, in contrast, is charged more hours by real users.

The reasons for non-usage of the different devices among real users are similar to those of randomization households: Those households that do not use the kit give reasons that indicate that they have technical problems with components or that the capacity of the panel is too low. Unfortunately, it is not always clear from the answers if they really have technical problems and broken devices or if the non-functioning is due to insufficient charging.

Asking the households for their willingness to pay for the kit they use, they would spend on average 12,500 FRW. Those households that have bought the whole kit are willing to pay slightly more, namely 12,800. This is though still 5,000 FRW less than the real price. 23 percent of the households are not willing to spend anything on the kit. 38 percent of the households state a price higher than the real price of approximately 18,000 FRW.

If we look at the usage behaviour of the ToughStuff lamp, we observe that they are very similar among the two groups (see Table 28). Both real users and RCT users operate the lamp around 2.8

hours per day. Looking at further lighting indicators, though, it becomes clear that real users in total consume much more light than RCT users. While the total number of lamps is slightly and statistically not significantly higher among real users, consumed lighting hours and especially lumen hours are substantially higher. Nobody among the real users uses the ToughStuff as the only lighting source as 47 percent among randomisation users do.

Table 28: Lighting indicators

Lighting hours and Lumen hours	Real user	RCT user	p-value
Number of ToughStuff lamps	0.86	0.88	0.775
Operation hours per day and lamp (TS lamp)	2.7	2.9	0.232
Number of lamps in household (total)	1.82	1.62	0.147
Lighting hours complete Follow-Up	5.33	4.55	0.093
Lumen hours complete Follow-Up	532	145	0.001

The main users and activities of the ToughStuff lamp among real users are quite similar to those of RCT households.

Table 29: Main user of the ToughStuff lamp and activities

ToughStuff lamp is mainly used by…	**%**	**Main Activities (all users)**	**%**
Female adult >17 years old	37.3	general inside activity	28
Male adult >17 years old	31.4	Cooking	25
Male between 12 and 17 years old	8.8	studying	20
Female between 12 and 17 years old	7.8	eat	12
Collectively used by whole family	9.8	housework	5
Children between 6 and 11 years old	4.9		

Altogether, the results from our real user survey indicate that what we find in our field laboratory adequately reflects the real world in many, although not in all, regards. In particular, the usage patterns in terms of how users divide the available capacity into the three services – lighting, radio and mobile phone charging – are confirmed. Furthermore, the capacity problems and technical issues we encounter in our RCT sample do not appear to be due to the fact that the kits in the RCT were provided for free, since they also emerge among real customers. The differences the real user survey shows in terms of socio-economic characteristics are in contrast to what the ToughStuff proposal claims as the target group for the ToughStuff product (the poorest ones, see Section 5). Given the comparatively high price of the ToughStuff kit in relation to people's disposable income in rural areas, it is, however, plausible that rather not-so-poor households decide to buy the kit. The differences in terms of education, main occupation or gender reflect the expected self-selection into treatment process commonly observed in observational (non-randomized) studies. Overcoming such differences (and the non-observable ones that are very likely) was exactly the purpose of the RCT.

4.5 External Validity

External validity refers to the question whether results observed in a certain study can be expected to be transferable to other regions or whether they would also apply if the program under study was upscaled (outside the randomised experiment). It is frequently argued that RCTs are more prone to external validity problems than observational studies. The reason is that they are often conducted in very limited areas used as the field laboratory and that people might alter their behaviour compared to their ordinary non-RCT life because they are aware of participating in an experiment. More systematically, the following sources of external validity can be summarized in socio-economic RCTs (see Duflo, Glennerster and Kremer 2008):

General Equilibrium Effects

General Equilibrium Effects are effects that only occur or become perceivable if the treatment is provided to a larger population or for a longer period. Hence, these effects might have repercussions on the RCT sample and can only be captured by the RCT if the period between randomization and the impact assessment is long enough and the study population is large enough. In the present case, one could theoretically think of decreasing prices of traditional lighting sources because of a decreasing demand, which are consumed more by households both in the RCT sample and beyond. This effect can be expected to be very small, though, since energy prices are mostly driven by regional markets if not world markets. On the other hand, in case one would upscale the program to the whole country (i.e. distribute Pico-PV kits on a large scale), for example, such effects could occur for products with a regional value chain (i.e. that do not only depend on world market prices)..

Hawthorne- and John-Henry-Effects

Hawthorne- and John-Henry-effects occur if participants in an experiment change their behaviour because they know that they are participating in an experiment. Since it is a matter of informed consent in most cases that participants in an RCT know to some extent that they are under scrutiny in an experiment, these effects can hardly be excluded completely in most RCTs. However, there are ways to keep them as small as possible, mostly by reducing the attention that is evoked in the participating household and the villages. The surveys used for this study were presented as part of a general survey on energy usage in relation to on-going and well-known energy interventions. This is especially credible as the grid roll-out programme EARP is massively approaching rural areas and even if the survey regions here are not scheduled to be connected to the electricity grid in the near future, most of the residents are aware of the electrification programme that possibly will also reach their communities. Furthermore, the randomly assigned Pico-PV system was not labelled as a gift, but as a compensation for participation in the survey. Also, households assigned to the control group received a compensation consisting of a sack of 5kg of rice and one litre of cooking oil.[18] As a side effect, this compensation for the control group addresses a potential ethical concern that is sometimes brought forward against RCTs: Randomly assigning a treatment to one group may induce uncomfortable feelings in the other group.

Generalizability

According to Duflo, Glennerster and Kremer (2008), issues of transferability might arise for three reasons: First, if the treatment in the RCT has been provided to the treatment group with *special care*, which could not be done in an upscaled form of the program. Here, the way in which we provided the ToughStuff kit (most importantly the training) was in line with what ToughStuff had announced to do for regular customers. Although the level of care was probably higher compared to other Pico-PV kits that are just sold in shops (and do not comprise a training), this was to compensate the more complex modular character of the ToughStuff kit.

A second issue of transferability is the *representativeness of the region* in which the RCT was conducted compared to other regions to which the program could be extended. On purpose, we selected regions that are very remote and have very limited access to modern energy sources. In addition, these regions will not be connected to the electricity grid in the next decades. This might not by all means represent the typical target area of commercial Pico-PV dissemination approaches. For ability-to-pay reasons such approaches might rather focus on the periphery of the grid covered areas or even on grid-connected and urban areas, in which Pico-PV devices are used as back-up in times of outages. However, the selection of our study regions was in line with what the ToughStuff approach envisaged – providing a source of modern energy to the poorest (according to the proposal, see Section 5). In addition, it was the aim of this evaluation to assess the extent to which Pico-PV can generally contribute to the combat against energy poverty. This contribution, as a matter of course, would happen in regions that are far beyond the outreach of the grid (or other more expensive electricity sources with higher capacities). Hence, the results obtained in this study are transferable to other set-ups in which Pico-PV are not only marketed for commercial reasons, but as an instrument to provide modern energy to the energy poor.

The third issue of transferability asks whether one can translate the obtained results in an RCT to "*similar but not identical programs*" (Duflo, Glennerster and Kremer 2008). In our case, we first need to scrutinise the extent to which our RCT treatment group successfully mimics the behaviour of real ToughStuff customers who decide to purchase a ToughStuff kit using the regular marketing network. It was one major reason for doing the real user survey to verify this. We use the data from this survey to identify treatment group members who are similar to the real users in our sample. For this purpose, we applied Coarsened Exact Matching (CEM), a stratification matching approach proposed by Iacus, King and Porro (2011, 2012). This approach stratifies both real users and treated RCT users according to covariates that can be expected to be correlated with outcome indicators (lighting usage etc.) in order to identify subgroups within each of the two groups that are similar with regards to these covariates. We pick various wealth characteristics (ownership of cows, housing conditions), the type of primary occupation as well as age and educational level of the household head. Only 31 households from the RCT treatment group can be compared to the real user survey. This finding is no

[18] This implementation design follows the approach presented in De Mel, McKenzie, and Woodruff (2008) and was also applied in a RCT with improved cooking stoves in Senegal (Bensch and Peters 2012).

surprise taking into account the findings presented in Section 4.4. Any further analysis is very much limited by this small common support part of the sample, but if we look at major impact indicators (lighting hours, lumen hours, or study time after nightfall) the general direction of impacts is confirmed. While differences remain to be positive, they become smaller in size and non-significant. All this is intuitive, since the effect size decreases if more or better lighting sources (due to higher income etc.) are available at the outset. Furthermore, the non-significance of results does in this case not mean that no effects exist but simply that standard errors are very large given the very small sample size of this matched subsample. In general, the usage patterns described in Section 4.4 suggest that observed impacts among RCT households can also be expected to materialize among real users even if to smaller extent.

Another question with regards to similar but not identical problems is whether ToughStuff is able to represent Pico-PV "as such". Here, it is important to emphasize that the technical problems ToughStuff has are probably at least to some extent due to the modular character of the kit. Hence, results we obtained for radio and mobile phone charging are not transferable to Pico-PV kits that provide a comprehensive kit (and maybe even not to an improved modular ToughStuff kit). Findings for lighting usage, though, can be transferred to other Pico-PV devices of comparable size (40 lumen).

Furthermore, a "similar but not identical program" beyond the narrow evaluative focus on ToughStuff is one that disseminates Pico-PV kits in a more subsidized manner, which can also be done in regions with lower capacity to pay. In particular, to the degree that Pico-PV kits are regarded as an instrument to combat energy poverty in remote areas, our randomized treatment is quite close to such a real-world program and the results can be transferred to a reasonable extent.

5 Sustainability assessment

In this section we present results of our qualitative assessment of the ToughStuff approach and compare the situation observed in the country and the field with the proposal ToughStuff submitted to the Daey Ouwens Fund in 2011. It partly draws upon the household data presented in the previous sections, but mostly upon interviews we conducted with the international ToughStuff management, their staff in Kigali as well as the coordinators and agents on the ground.

First of all, ToughStuff sales numbers deserve some attention. In their proposal, ToughStuff envisages to sell 166,212 solar kits until mid-2013. First, during our follow-up mission and related interviews in Kigali we were informed that, by mid-2012, around 5,500 kits had been sold which is already far below the target figures. After calling all ToughStuff coordinators on the district level, though, we only made up slightly more than 1,000 kits in the field. Afterwards, the amount of sold kits was revised by the ToughStuff Kigali management to 1,380. Of course, as it happens recurrently with new products, sales might catch up after having reached a critical number of customers. Yet, at the time of the follow-up survey the ToughStuff activities were already in the middle of the Daey Ouwens Fund project period (scheduled from May 2011 until September 2013) and, accordingly, this threshold should have been reached in order to achieve the envisaged sales numbers by the end of the project. In the meantime, during a Daey Ouwens Fund mission to Rwanda in the second half of 2012, it has been officially communicated to the Daey Ouwens Fund that the envisaged sales numbers will not be reached and new target numbers have been set.

By examining the explicit and implicit assumptions underlying the proposal it becomes evident that from the beginning the sales numbers have been far from realistic. Given the total number of households in rural Rwanda of 1,82 million[19], the envisaged number of 166,212 sold kits corresponds to a penetration rate of more than 9%. This was already not very plausible at the time of the proposal, especially if considering the households' capacity-to-pay and the fact that several similar Pico-PV products and cheap LED-lamps are available countrywide (see Section 2.1). [20]

The proposal refers to an amortization period of only two months. Given a price of the kit of around 10,000 FRW/13 Euros (panel and lamp) this can be judged as unrealistic at a first glance, in particular since the proposal constantly emphasizes that poor strata are targeted. Looking at our data it becomes clear that the capability to pay of rural Rwandan households is much lower than what is assumed in the proposal. In particular, if the poorer strata are targeted. A typical rural household in our RCT sample expends roughly 900 FRW/1.15 Euros on lighting fuels (kerosene, candles, dry-cell batteries) per month, 170 FRW on mobile phone charging and 280 FRW on dry-cell batteries for radios. One might argue that the capability to pay is higher in not-so remote areas (although it is particularly this periphery that constitutes the target area of ToughStuff and Pico-PV products in

[19] According to the World Bank Development Indicators, the rural population is around 8.2 million. A conservative estimation for the household size is 4.5 members per household.

[20] Great Lakes energy sells Pico-PV kits at around 40 Euros that charge mobile phones and a lamp; Barefoot sells a comparable kit that charges mobile phones and a lamp at around 20 Euros and a smaller one that only charges a mobile phone at 15 EUR.

general, since this is where energy poor people live and remain to be non-electrified). Therefore, we revert to the EARP evaluation survey we conducted on behalf of IOB in rural Rwanda. For this study, we surveyed non-electrified villages in 2011 that are either in direct proximity to the medium-voltage grid or relatively close to the grid so that they are included in the EARP schedule. Here, a typical household expends around 1270 FRW/1.60 Euros on lighting fuels (kerosene, candles, dry-cell batteries) per month, 533 FRW on mobile phone charging and 470 FRW on dry-cell batteries for radios.

Even if one considers these not-so-remote areas from our EARP surveys and if one assumes that all three energy service demands can be met by a ToughStuff kit (encompassing a lamp, a mobile phone charger and a radio charger) it would take the average household 8 months to save the money needed to buy the kit.[21] Since rural African households are typically credit-constrained, it becomes obvious that this is hardly doable for most households.[22] ToughStuff's primary target group, "low-income consumers in Rwanda living at the base of the economic pyramid", will have particular difficulties to mobilize the funds out of their energy cost savings: The poorest quintile pays on average only 770 FRW/ 1 Euros on lighting fuels (kerosene, candles, dry-cell batteries), 150 FRW on mobile phone charging and 210 FRW on dry-cell batteries for radios and accordingly the investment into the kit amortizes in 16 month.

There might be some market niche to be filled by ToughStuff: The upper quintile in the EARP data set would amortize the kit after 5 months. But this would imply that rather relatively rich households in rural areas are targeted that remain non-electrified for the coming years. In addition, some urban or electrified rural households might use the kit as backup. While it is highly unlikely that this niche will accommodate the expectations in total sales figures, it is also neither the target group proclaimed in the ToughStuff proposal, nor the one of the Daey Ouwens Fund – the energy poor.

Moreover, in spite of the presentation of the ToughStuff kit in the proposal as being a field-tested and appropriate technology designed for the needs of African households, the kit does not seem to be mature for widespread marketing. The power pack was not working in many cases and the mobile phone charger marketed during the first months (and thus also used for the RCT) was not adapted to the needs in the Rwandan market (see Section 5.3.3). Most of the interviewed ToughStuff agents themselves complained about the bad quality of the product. Some of these issues have meanwhile been addressed by the ToughStuff staff: a new mobile phone charger and a new battery package have been included and the panel size has been increased from 1 W to 1.5 W. It is very questionable, though, if such a trial-and-error-approach is recommendable in a market in which trust is a pivotal factor to demarcate quite expensive products from low-quality products that are flooding the market. In these regards, the question arises why the Lighting Africa certificate has not precluded an obviously non-mature product from entering the market. According to interviews with Lighting Africa staff this was due to the modular character of the ToughStuff kit. The mix-and-match approach of ToughStuff is unique in the Lighting Africa portfolio and the testing procedure did simply not account for this. Rather, it was concentrated on the lighting device without testing the various compositions in which the kit can be used. The certificate ToughStuff received in November 2011 even only

[21] The period does not change substantially if one only looks at lighting assuming the household buys only the panel and the lamp.

[22] This simple calculation does not account for this credit constraint of households. If one accounted for this, it would be expressed by assuming a high interest rate, which makes the real economic amortisation time much longer than 8 months.

concerned the lamp and the solar panel (i.e. the battery package and the radio and phone charger were not tested at all).

In particular against the background of these technical problems, the after sales network and service plays a crucial role to make a difference in comparison to low-quality products. However, it was virtually non-existent at the time of our follow-up survey and, hence, no reason for customers to pay the higher price compared to other solar or dry-cell battery driven devices. Again, this is not in line with what was announced in the proposal in terms of how after sales service will be ensured (see Section 3.2.3 of the proposal). Neither were the interviewed ToughStuff agents trained for providing after sales services, nor does the technical support phone line exist that was announced in the proposal.

The proposal emphasizes over and over again that the marketing system (exclusively) works with women. The sales women are even named as the "Secondary Target Group" of the intervention – next to the users of the ToughStuff kits themselves (page 4). It was announced that 1,046 "ToughStuff Ladies" would be recruited (page 6). A "truly unique self-growing women-to-women network" was announced to be established. This has not happened. Only few ToughStuff agents are women. In addition, at the time of the study only around 60 TS agents were active and the number of 1,046 was abandoned by the ToughStuff management.[23]

Furthermore, there are some minor aspects that had been promised in the proposal and actually have not been implemented. For details, please refer to Appendix 9.

[23] In fact, during the 2012 Daey Ouwens Fund mission the ToughStuff distribution approach was changed and the idea of marketing the product through sales women (the "ToughStuff ladies") was abandoned.

6 Register of research questions

6.1 Input and policy relevance

1) *What attempts have been made to target and include women at all stages in the programme/project cycle?*

Originally, the whole marketing strategy of ToughStuff was foreseen to rely on a women's network. Thereby ToughStuff intended to create employment specifically for women and also target primarily women as clients. Nevertheless, this approach has not been implemented. For details on the implemented marketing strategy, refer to Section 5.

On the client side, there is de facto no specific approach to reach women. While the decision to buy the kit is primarily taken by male household members (see Section 4.4), the main users of the kit are in fact women (see Section 4.3.1).

2) *What are the financing mechanisms for the programme/project and does this include measures to ensure equity in access to energy (e.g. access to credit for women)?*

In their proposal to the Daey Ouwens Fund, no financing mechanisms had been planned as ToughStuff assumed that the kit would only be a minor investment for the households paying off already after two months. This assumption turned out not to be realistic and the affordability of the kits are a major obstacle for ToughStuff to reach their sales numbers (see Section 5).

Eventually, ToughStuff started to cooperate with teacher unions, women groups, local authorities and tea companies who sell the kits to their employees. On the one hand, these employees have higher purchasing power compared to other rural households without regular monetary income. On the other hand, these companies and institutions offer an effective credit program by deducting instalments for the kit from their employees' monthly salary.

6.2 Output

1) *What have been the dynamics in time of the sales of the solar devices?*

Sales of the solar devices have been low. While in their proposal, ToughStuff envisages selling 166,000 solar kits until mid-2013, by June 2012 the amount of sold kits only amounted around 1,400 solar kits. For more details, see Section 5.

2) *What have been the total (development and recurrent) costs and the costs per main output and beneficiary (retailers and beneficiaries)?*

In their proposal to the Daey Ouwens Fund, ToughStuff estimates the total costs for setting up their activities in Rwanda at around 1,340,000 EUR. Half of the money has been provided by the Daey Ouwens Fund, half of it has been added by ToughStuff's own funds. They initially planned to sell 166,000 kits until August 2013. Theoretically, if they had sold this number of kits, they would have earned approximately 3,800,000 EUR in addition. Dividing the total sum (5,100,000 EUR) by the number of kits, we calculate an average cost per kit of 31 EUR.

Beyond this market preparation phase ending in August 2013, the ToughStuff approach is expected to be self-sustaining. From this moment on, the price of the product, i.e. 22.70 EUR is expected to cover all running costs.

However, calculating with sales numbers effectively reached by ToughStuff until mid-2012 (1,380 costumers) and optimistically extrapolating these numbers to August 2013 (selling twice as many kits per month during the remaining 14 months as during the first 13 months, i.e. additional 3,000 kits) total costs until August 2013 amounted to 1,440,000 EUR. The total cost per kit would be more than ten times higher than expected, amounting to 331 EUR. Given the low number of total beneficiaries it is questionable whether the price of 22.70 EUR is sufficient to cover the costs for maintaining the sales structure in Rwanda beyond August 2013.

For assessing the amount of subsidy per kit, we divide the total Daey Ouwens contribution by the number of kits sold.[24] If one assumes that the envisaged sales number of 166,000 kits will be achieved, the subsidy per kit amounts to 4 EUR. If we use the number of effectively sold kits and use our extrapolation for sales numbers until August 2013, the subsidy is substantially higher, amounting to 153 EUR. In case a sustainable marketing approach was built up by ToughStuff, as a matter of course, the subsidies per kit would decrease with every sold kit after August 2013. [25]

3) How cost-effective is the supply of solar lamps/devices, taking into consideration the inputs in terms of supplies, personnel, technical assistance ("value-for-money"). What benchmark can be used? To what extent are costs covered in the price to the consumers?

If one assumes that the problems described in Section 5 are by and large infant industry issues, they will be overcome in the longer run. The ToughStuff approach is built on this assumption implying that their activities are self-sustaining after some years. Hence, all running costs need to be covered. However, this assumption critically depends on a certain level of sales numbers to be reached. As outlined in Section 5, it can be doubted that the sales numbers in reality suffice to ensure the self-sufficiency of the activities.

In principal, the benchmark for comparison are other public electrification interventions, although this comparison is of course difficult because of the differences in quality of the provided services. On the other hand, high-quality Pico-PV products should also be compared to lower quality LED- and solar products that are meanwhile readily available also in rural areas. While these devices might be inferior in terms of product duration, the provided energy service (mostly lighting) are typically the same.

[24] ToughStuff has received further subsidies by FMO and the Norwegian Investment Fund for Development Countries invested into the ToughStuff expansion into Africa. While these funds also have been used for the roll-out in Rwanda, the extent to which this happened is unclear.

[25] After the Daey Ouwens Fund mission in 2012, both the ToughStuff marketing approach and the subsidy disbursement have been modified, which might of course alter the subsidy per sold kit calculations.

6.3 Outcomes

1) *Who (gender specific) in the household has made the decision to buy the solar lamp?*

See Section 4.4 on real users.

2) *For which purpose, for how much time and where are the lamps used? To which extent inside/ outside the house?*

See Section 4.3.1 on lighting.

3) *What proportion of the total lighting hours in the households is provided by the solar lamps? Which other sources are being used? Is there a relation between the lighting source and the use of light?*

See Section 4.3.1 on lighting.

4) *What has been the change in the production and consumption of the energy source previously used for lighting?*

See Section 4.3.1 on lighting.

5) *How reliable is the lighting source?*

See Section 4.3 and Section 5.

6) *What has been the change in expenditures (at household level) for energy consumption?*

See Section 4.3.2 on energy expenditures.

6.4 Impacts

1) *How have expenditures for energy (per period) changed (lighting and fees to charge mobiles)?*

See Section 4.3.2 on energy expenditures.

2) *To what extent has (the perception of) safety changed?*

See Section 4.3.2 on perceived security.

3) *Has there been a change in activities during night times? (Children studying at home, social activities, income generating activities)?*

See Section 4.3.2 on time usage.

4) *Is there a perceived improvement in indoor air quality?*

See Section 4.3.2 on health.

5) *To what extent has comfort/convenience changed, disaggregated by gender? What monetary value do households attribute to this increased convenience?*

See Section 4.3.2 on perceived security and Box 1 on appreciation of the Pico-PV kits.

6) *Has the solar lamp been an incentive to consider the purchase of other solar devices, amongst them a solar home system?*

There is no indication that ToughStuff users are more inclined to buy other solar devices. Among the randomization households no household had bought other solar devices until the follow-up. Few of the real users have a solar home system at home (see Section 4.4). It is not clear from our data, though, whether the households already had the solar home system when they bought the ToughStuff lamp or whether they bought the solar home system afterwards.

7) *How are benefits distributed among households in different income groups? Has the activity had an effect on gender equity in access to, use of and benefits from energy sources?*

There is no clear pattern regarding the distribution of benefits among households in different income groups. On the one hand, the theoretical impact potential is higher among poorer households, since they are hardly using any lighting sources in the before situation. On the other hand, higher income households, who are normally also better educated, use the ToughStuff lamp more appropriately and thereby exploit the maximum technical potential of the lamp.

As described in Section 4.3.1., the lamp is primarily used by women.

8) *What positive and/ or negative unintended effects occurred?*

We did not find any positive or negative unintended effects.

6.5 Sustainability

1) *How reliable is the lighting source?*

See Section 4.3 and Section 5.

2) *What is the perceived lifetime of a solar lamp?*

See Section 5.

3) *Has there been a shift from non-renewable to renewable energy sources? If so, what are the likely effects on CO_2 emissions?*

The ToughStuff kit has produced a shift from non-renewable to renewable energy sources through the replacement of traditional lighting sources (see Section 4.3.1 on lighting and 4.3.2 on energy expenditures). Each household saves on average 1.02 candles and 0.44 litres of kerosene per month. Calculating with a CO2 emission factor of 2.52 kg CO2/l and 2.95 kg CO2 /kg of paraffin waxes26,

[26] Emission factors have been adopted from the Intergovernmental Panel on Climate Change (IPCC), available at: http://www.carbonmetrics.com/ipcc-emission-factors-tool

monthly CO_2 savings amount to 1.26 kg CO_2 per household and month[27]. For comparison, driving 100 km in a regular car emits around 24 kg of CO_2.

Furthermore, the ToughStuff kit replaces only dry-cell batteries for lighting and radio operation that do not emit CO_2 during operation. For mobile phone charging we do not have any reliable information on the exact source of electricity that is used for charging in case mobile phones are not charged with the ToughStuff kit. This prevents us from calculating exact CO_2 savings through mobile phone charging. Nevertheless, given the fact that only few households use the ToughStuff kit for charging mobiles, emission savings can be assumed to be negligible. All calculations abstain from emissions occurred during the production process of the energy sources.

[27] Assuming an average weight of 50g per candle.

7 Conclusion

This report presented the results of a mixed-methods evaluation of the market based introduction of Pico-PV systems produced by the British company ToughStuff. The evaluation comprises one large survey based component and one that is based on semi-structured and open interviews. At the core of the large survey based part is a randomized controlled trial (RCT) for which 150 ToughStuff kits were randomly assigned to a subsample of 300 households surveyed in 15 remote communities in rural Rwanda. The purpose of the RCT is to obtain an unbiased estimation of impacts that can be expected from Pico-PV usage. The RCT was complemented by a survey among households that had decided to purchase a ToughStuff kit on the regular market. The second component relies on semi-structured and open interviews conducted with selected representatives of the target group, ToughStuff staff members and sector key informants. The major purpose of this latter part is to assess the sustainability of the ToughStuff activity and to provide contextual information.

Two major findings can be synthesized: First, in energy poor areas the Pico-PV kits constitute a considerable improvement of living conditions. The results from both the large survey and the open interviews in the field coherently suggest this. Although the lighting quality is not comparable to the quality (and quantity) of lighting provided by a grid connection, the ToughStuff lamp is much brighter and in particular cleaner than kerosene wick lamps or candles. Virtually all households in our RCT sample use the lighting device on a regular basis and in most cases it has crowded out the traditional lighting source even completely. This access to an improved lighting source has changed the households' time usage in some regards (activities after nightfall like studying or activities outside the house), but did not lead to substantial changes and new activities. In parts, such changes might need some time to unfold. For example, while indoor air quality seems to have improved, a decrease of respiratory symptoms cannot yet be observed. In terms of the other energy services the ToughStuff kit provides in principle (mobile phone charging and radio charging/usage), our study unfortunately does not allow much investigation of usage patterns and impacts. The reason is that the kit as it was calibrated at the time of the randomization had too many defects.

The second major finding is that although the Pico-PV kit was quite enthusiastically taken up by those households that "won" a kit in the RCT it is rather unlikely that such kits can be disseminated in a commercially viable way in comparable regions. Even households from richer strata in remote areas cannot be expected to bring up the investment costs required to buy a Pico-PV kit. There is some chance that the richer strata in not-so-remote areas might be able to invest in such kits. But this will hardly be sufficient to generate sales numbers that are in turn required to build up a sustainable marketing approach. In addition, at least in Rwanda many of these not-so-remote areas will be reached within the next years by the ambitious grid roll-out program. While some of the results presented in this report are related to particularities of the ToughStuff kit and especially the technical problems, at least for the lighting device (which was working in most cases without problems) the findings generally reflect the challenge of the new Pico-PV movement and its ambition to pursue self-sustaining market approaches. This becomes even more evident if one takes into account the strong competition the high-quality products face from lower-quality products (LED lamps, solar products) that are available in rural areas at much lower prices.

The extent to which the engagement of the international community in Pico-PV markets can be justified depends on whether Pico-PV constitutes an alternative to grid-based electricity access or at least a bridging technology (as postulated by the SE4All Global Tracking Framework). The cost spread between providing electricity access via the extension of the electricity grid or by establishing mini-grids on the one hand and Pico-PV systems on the other hand is enormous. While Pico-PV systems that provide basic energy services cost only between 20 and 100 USD, grid-based electrification implies cost of around 500-1000 USD per household. The findings of this study underpin that Pico-PV can be a temporary alternative to grid based electricity access in the sense of a bridging technology and provides clearly better lighting services as compared to traditional lighting sources. In the SE4All map a household would achieve Tier 1 both concerning electricity supply and use of electricity services[28]. While households with grid-based electricity would normally qualify for at least Tier 2 in terms of electricity supply, a considerable share of grid connected households in rural Africa effectively does not qualify for a higher Tier than Tier 1 in terms of used electricity services (SE4All 2013: 84). .

Altogether, while Pico-PV kits can meet the need for basic energy services in very remote areas, they cannot satisfy the whole electricity demand in regions in which ToughStuff or other Pico-PV providers find customers who exhibit the capability to pay. Here, it will be rather used as a complement to traditional energy sources than a complete replacement of it. Accordingly, Pico-PV kits cannot be seen as a full equivalent to grid electricity in regions exhibiting higher energy consumption, so it has to remain a bridging technology towards a connection at a later point in time. What is crucial both for the acceptance of this new technology and the actual take-up is, of course, the proper functioning and ease in usage of the kit. It has turned out that a relatively mature product such as the ToughStuff kit that has been tested and massively sold in other countries might still exhibit severe technical problems under real usage conditions in a new country.

[28] The SE4All defines two dimensions of its electricity access multi-tier measurement: electricity supply and electricity services effectively used. With regard to electricity supply, the ToughStuff 1W-1.5W panel would be on the edge to qualify for Tier 1 that requires a peak available capacity of "more than 1 Watt for more than 4 hours per day, available also during evenings". As for the use of electricity services, it theoretically provides the required services, i.e. task lighting and phone charging or radio (SE4All 2013).

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Appendix 1: Study timeline

Pre-Departure Preparation of the Study *until November 22, 2011*

Desk Study of relevant project documents and literature; adaptation of existing survey methodology; questionnaire design in French; Excel matrix for data entry; coordination with local partner IB&C

In-Country Preparation of Baseline Study (RWI/ISS Mission) *between November 23 and 30, 2011*

- Coordination with local partner IB&C, ToughStuff representative, Pico-PV experts, and national partners
- Field trips to project regions;
- Choice on survey sites and planning of survey organisation and logistics, with the assistance of the local partner IB&C and ToughStuff representatives;
- Design details of the study;
- Revision of the questionnaire;
- Training in Kigali of the enumerators on the questionnaire and data entry;
- Final review of questionnaire and survey organisation and logistics.

Realization of Baseline Survey *between December 1 and 8, 2011*

Survey implementation by RWI researcher and enumerators.

Data Compilation *until December 13, 2011*

Data entry by enumerators

Randomization and Distribution of Pico-PV Systems *January 9 and 15, 2012*

Random assignment of treatment to surveyed household; distribution of Pico-PV Systems and compensations by IB&C and ToughStuff technicians

In-Country Preparation of Follow-Up Study (RWI/ISS Mission) *between June 13 and 23, 2012*

- Coordination with local partner IB&C and ToughStuff representatives
- Field trips to survey sites and planning of survey organisation and logistics, with the assistance of the local partner IB&C;
- Qualitative interviews with Pico-PV experts, and national partners;
- Revision of the questionnaire;
- Training in Kigali of the enumerators on the questionnaire;
- Accompany the enumerator team during first survey days. Focus group discussions with survey participants and other rural dwellers

Realization of Follow-Up Survey *between June 17 and July 9, 2012*

Survey implementation by RWI researcher and enumerators.

Data Compilation *until end of August, 2012*

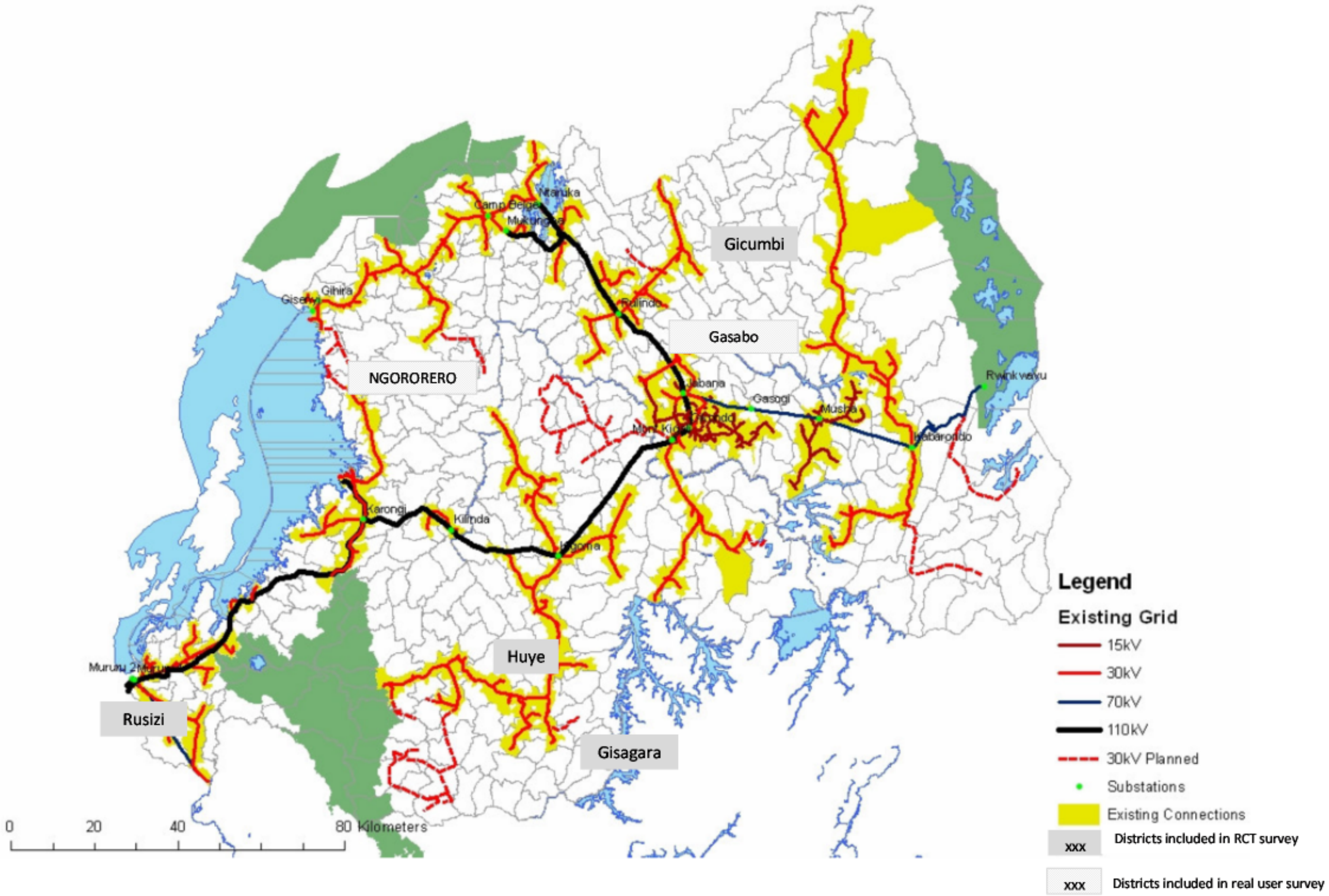
Data entry by enumerators and revision by RWI

Source: Own illustration

Appendix 2: List of surveyed sites for RCT

Province	District	Sector	Cell	Umugudugu(s)	Observations	# of Randomized Pico-PV Systems
North	Gicumbi	Nyamiyaga	Mataba	Mataba, Rugarama, Ruyaga	19	9
		Nyamiyaga	Kabeza, Rugari	Karambo, Rugari	20	8
		Rutare	Gasharu, Kigabiro, Munanira	Bushokanyambo, Buyegero, Kabusunzu, Mataba, Munini, Nyakavunga, Rutare	20	12
South	Gisagara	Mukindo	Gitega, Mukiza	Kabati, Kigoyi, Nyamabuye, Ruko	19	6
		Mukindo	Runyinya	Akimpinga, Akakarinda, Gasharu, Itaba, Impinga, Mpungwe, Munyegera, Taba	20	10
		Mukindo	Gitega	Agaharu, Agatunda, Akazenga, Joma, Magi, Rebero	20	11
		Mukindo	Nyabisagara, Runyinya	Akabuga, Akamasiga, Akarugina, Makwaza, Taba	20	12
	Huye	Kigoma	Kabatwa, Rugarama	Birembo, Buremera, Kinyata, Mahwa	20	11
		Kigoma	Gishihe	Birembo, Kabingo, Karambi	19	5
		Kigoma	Gishihe, Musebeya	Gihehe, Kababaji, Katiyuga, Kavumu, Nyagasozi, Nyarurembo	23	13
		Kigoma	Gishihe, Kabuga	Birambo, Gihanda, Kabingo	19	12
West	Rusizi	Gashonga	Muti	Marebe, Rugende	20	16
		Gashonga	Buhokoro, Muti	Busekera, Gahinga, Gakombe, Kabahizi, Ryagacece	20	8
		Mururu	Kabasigirira	Bitongo, Butazigurwa, Mutimasi	20	9
		Mururu, Nkungu	Kabasigirira, Ryamuhirwa	Mutimasi, Bitongo, Nyarushushu	21	8

Appendix 3: Map of Rwanda (with survey region)



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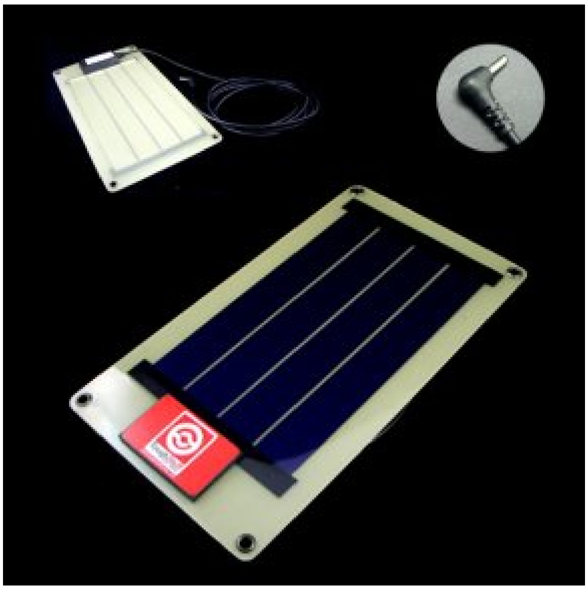
Source: own illustration based on information provided by EWSA

Appendix 4: ToughStuff appliances

The solar panel



LED lamp

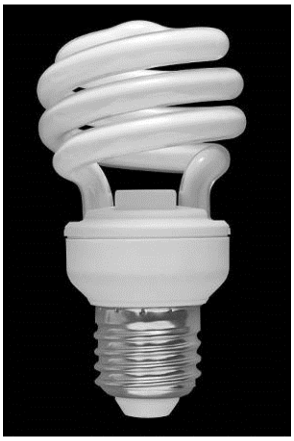
Mobile phone connectors

Radio connectors

Battery power pack

Source: http://www.toughstuffonline.com/

Appendix 5: Lighting devices

a. Incandescent Light Bulb ("Normal Light Bulb") 	b. Neon/Fluorescent Tube 
c. Energy Saver 	

D1. Rechargeable Lamp

d2. hand-crafted LED lamp

d3. Mobile LED lamp

d4. Gas Lamp

d5. Hurricane Lamp

d6. Traditional Tin Lamp

d7:ready-made torch 	

Source: Own illustration

Appendix 6: Details on implementation of randomization

In order to guarantee a random allocation of the treatment among surveyed households, we apply stratified randomization and re-randomization consecutively. Stratification implies to first group the observations according to some few baseline characteristics before the treatment is assigned randomly within each stratum. Re-randomization allocates observations first into treatment and control groups and then checks the balancing of the groups in terms of some key characteristics. This process is either repeated until a certain threshold of balance is met (*big stick method*) or the number of repetitions is defined ex-ante and then the draw with the best balance according to the minimum maximum *t*-statistic is chosen (*minmax t-stat*). We used a mixed approach and first stratified our sample before we applied a re-randomization *minmax t-stat* algorithm within each stratum.

An important question to address is how many and which stratification criteria to select. There is a trade-off between manageability and the ambition to include many criteria. Generally, it can be argued that the more criteria are included, the more comprehensively the balancing captures the real heterogeneity of the treatment and the control group and, hence, the higher the precision of the impact estimates. Yet, on the other hand the implementation of the stratification approach becomes of course more difficult the more criteria are accounted for (simply because too many strata are created).

In our specific case we selected the following household characteristics as stratification criteria that we deem to be strongly correlated with the outcome:

- consumed lighting hours per day, coarsened into three categories
- usage and non-usage of mobile phones
- usage and non-usage of radios
- location according to the four survey districts.[29]

Eventually, applying these stratification criteria yielded 48 strata, whereof three turned out to not contain observations. Since it is necessary to have an even number of observations per stratum for generating the same number of treated and control observations through the randomization, we had to deal with 33 strata that contained an odd number of observations. Instead of dropping 33 households, we sorted one observation of each stratum with an odd number into another stratum with an odd number in a different district but with the same characteristics in terms of lighting hours, mobile and radio ownership. In five cases, no such stratum could be found; these observations were then dropped. When doing the impact analysis we check the robustness with regards to this re-organization.

We applied additionally a *minmax t-stat* method in order to assure balance for further important baseline criteria that could not be accounted for in the stratification because of dimensionality reasons.[30] Examples for such “secondary” balancing criteria are usage of dry-cell battery driven LED-lamps and wealth indicators such as housing conditions or the educational level of the head of the household. For this purpose, we used a random number generator within each stratum that

[29] For baseline values of these characteristics see Section 4.2.

[30] This approach of applying stratified randomization and re-randomization consecutively is also applied in Ashraf et al. (2010).

randomly ordered all observations and assigned treatment to every second observation. We performed this process 20 times and analysed differences in means between the two generated groups regarding several outcome and wealth related characteristics. We chose the draw with the minimum *t*-statistics for differences in lighting hours that at the same time did not present statistically significant differences for any other balancing criteria (see table).

# draw	Lightinghours Diff. in Means	 p-Value	Variables with differences in means, significant at least at 15 percent level	p-value
2	-0.017	0.968	Education Head of HH	0.122
			Dummy Usage Battery Lamps	0.198
11	0.0298	0.9425	Dummy Usage Battery Lamps	0.054
18	0.0562	0.8915	-	
10	0.0562	0.8915	Dummy Usage Fixed Torches	0.03
			Kerosene Consumption	0.0716
			HH Size	0.1036
14	0.0695	0.8662	Dummy Cultivates land	0.044
			Dummy Owns Land	0.064
			Dwelling Plastered	0.103
			Dummy Usage Fixed Torches	0.148
			Education Head of HH	0.149
8	-0.12	0.7666	Education Head of HH	0.016
			Dummy Owns Land	0.064
			Dummy Usage Fixed Torches	0.091
			Candle Consumption	0.1456
9	0.12251	0.7666	Number of Goats	0.043
			Floor Material	0.097
			Number of Cows	0.145
20	0.1291	0.7544	-	
1	0.18	0.6707	Number of Goats	0.033
			Floor Material	0.042
			Kerosene Consumption	0.0691
			HH Size	0.1608
19	0.1887	0.6475	HH Size	0.1161
			Candle Consumption	0.1456
4	0.288	0.4851	Kerosene Consumption	0.0007
			Candle Consumption	0.0261
			Dummy Usage Battery Lamps	0.054
17	0.29	0.4851	HH Size	0.0376
			Dummy Usage Fixed Torches	0.054
12	-0.32	0.4364	-	
5	-0.328	0.4269	Dummy Usage Battery Lamps	0.054
			Candle Consumption	0.1456
7	-0.33	0.4177	Dummy Usage Battery Lamps	0.054
15	0.407	0.3235	Kerosene Consumption	0.0377
			Wall Material	0.096
			Dummy Usage Fixed Torches	0.148
3	0.47	0.25	-	
6	-0.6	0.8789	Dummy Owns Land	0.064
			Kerosene Consumption	0.0692
13	0.7119205	0.08	Number of Goats	0.075
16	0.71	0.0839	Dummy Usage Battery Lamps	0.054

Appendix 7: Regression results

Noncompliance to treatment		
Hh's head male	-0.922	(-0.17)
Age of the HH's head	0.031	(-0.19)
Household size	0.076	(-0.6)
Share children 0-15 years	2.391*	(-0.08)
Share elderly 65+	-5.066	(-0.17)
Education of hh head	-0.114	(-0.77)
Ownership of Arable Land	-1.449*	(-0.1)
Cow Ownership (base: no cow)		
One cow	-0.77	(-0.17)
More than one cow	-2.015	(-0.11)
Goat Ownership (base: no goat)		
One goat	-2.027*	(-0.06)
More than one goat	0.528	(-0.4)
Higher value walls	1.398	(-0.1)
Higher value floor	-0.191	(-0.87)
Dwelling plastered	-1.075	(-0.23)
District (base: Gicumbi)		
Gisagara	0.299	(-0.59)
Huye	0.019	(-0.97)
Rusizi	0.002	(-1)
Lightinghours	0.043	(-0.45)
Mobile Phone Ownership	-1.028**	(-0.02)
Radio Ownership	-2.490*	(-0.05)
Consumption of Candles	0.079	(-0.13)
Consumption of Kerosene for Lighting	0.404	(-0.27)
Usage of Fixed Torch	-0.584	(-0.25)
Usage of Mobile LED	2.533**	(-0.03)
Number of Mobile Phones	0.739	(-0.24)
_cons	-1.661	(-0.31)
Pseudo R-Squared		**0.367**
N		**148**

Note: P-values in parentheses. Stars indicate significance level with * *p*<0.1; ** *p*<0.05; *** *p*<0.01.

Section 4.3.1. `mobile phone usage´ and Section 4.3.2 `lighting´

	pay for charging mobile	lightinghours	lumenhours
treat_eff	-0.032	-0.282	-5.009
	-0.48	-0.42	-0.7
did_eff	-0.094	1.115**	102.164***
	-0.12	-0.02	0
fol	-0.03	-0.022	-3.243
	-0.48	-0.94	-0.77
BAS_consmpt_candle	0.006***	-0.005	-0.022
	-0.01	-0.82	-0.98
BAS_consmpt_kerosene	0.01	0.015	-3.294
	-0.16	-0.84	-0.25
BAS_num_HHmemb	0.006	-0.026	-1.242
	-0.52	-0.67	-0.58
BAS_num_mobilephone	-0.076***	0.604***	9.912
	0	-0.01	-0.22
BAS_dwellingplastered	0.044	-0.152	-8.746
	-0.43	-0.71	-0.56
BAS_modernwall	0.007	0.211	-5.604
	-0.88	-0.6	-0.71
BAS_modernfloor	-0.044	0.511	-22.895
	-0.44	-0.23	-0.16
BAS_torchfix	0.121***	0.711**	-9.695
	-0.01	-0.02	-0.39
BAS_mobileLED	-0.146**	0.602	149.156***
	-0.05	-0.36	0
BAS_owns_land	-0.2	0.031	6.593
	-0.19	-0.96	-0.75
hdum_no goat	-0.061	-0.453	0.498
	-0.19	-0.21	-0.97
hdum_one_goat	0.029	-0.55	-24.678
	-0.62	-0.22	-0.14
hdum_morethanone_goat			
hdum_no_cow	0.078	-0.202	-37.489**
	-0.18	-0.61	-0.01
hdum_one_cow	0.114**	0.413	-30.994*
	-0.03	-0.34	-0.06
hdum_morethanone_cow			
hdum_hoh_noedu	0.136*	0.522	13.604
	-0.09	-0.44	-0.59
hdum_hoh_primary	0.128**	0.461	11.956
	-0.03	-0.45	-0.61
hdum_hoh_secondary			
_cons	0.684**	6.835***	163.561**
	-0.03	0	-0.03
Adj. R-Squared	0.238	0.293	0.23
N	212	580	580

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * p<0.1; ** p<0.05; *** p<0.01.
Village and Stratum dummies are included.

Section 4.3.2 `time awake by household member´

Time awake (in minutes)	Head of HH	Spouse	Female 12-17	Female 6-12	Male 12-17	Male 6-12
treat_eff	-1.019	-13.57	-57.394	-19.92	-43.662	-19.519
	-0.97	-0.48	-0.22	-0.64	-0.38	-0.33
did_eff	17.37	33.566	46.485	17.657	44.272	62.633**
	-0.6	-0.17	-0.39	-0.72	-0.44	-0.02
fol	8.122	14.412	14.773	0.616	46.523	-5.422
	-0.69	-0.34	-0.69	-0.98	-0.22	-0.71
BAS_consmpt_candle	-0.704	0.114	0.453	1.769	-3.303	2.624**
	-0.62	-0.91	-0.84	-0.47	-0.22	-0.02
BAS_consmpt_kerosene	0.72	-5.562	66.970**	40.53	-1.487	8.139
	-0.89	-0.12	-0.01	-0.17	-0.96	-0.45
BAS_num_HHmemb	15.515***	8.916***	12.022	-0.031	23.053**	15.001***
	0	0	-0.18	-1	-0.02	0
BAS_num_mobilephone	23.304	17.768*	-46.692	13.421	55.014	-30.704**
	-0.14	-0.09	-0.16	-0.61	-0.12	-0.01
BAS_dwellingplastered	49.585*	9.73	-53.8	148.997***	87.903	-16.276
	-0.07	-0.65	-0.38	0	-0.22	-0.45
BAS_modernwall	-19.844	30.926	-60.367	21.811	-215.298***	30.9
	-0.47	-0.16	-0.23	-0.66	0	-0.16
BAS_modernfloor	-10.885	13.603	144.229***	-55.271	-86.593	-22.806
	-0.72	-0.54	-0.01	-0.26	-0.18	-0.35
BAS_torchfix	19.916	-32.141**	-6.21	58.393	-146.151**	-9.424
	-0.32	-0.03	-0.88	-0.17	-0.02	-0.6
BAS_mobileLED	27.053	9.767	22.453	-6.205	-16.147	108.848***
	-0.55	-0.76	-0.82	-0.95	-0.88	0
BAS_owns_land	80.005**	-11.258	-145.339	-37.462	-180.249**	-114.864**
	-0.04	-0.71	-0.11	-0.58	-0.01	-0.01
hdum_no_goat	31.895	-3.624	-124.525***	-36.432	-59.395	-9.118
	-0.19	-0.84	0	-0.37	-0.28	-0.66
hdum_one_goat	-11.684	-1.284		-109.894**		-4.708
	-0.7	-0.95		-0.04		-0.87
hdum_morethanone_goat			-61.148		-49.797	
			-0.25		-0.47	
hdum_no_cow	-16.263	-2.214	10.654	-134.232**	-35.515	-25.36
	-0.55	-0.89	-0.83	-0.02	-0.6	-0.17
hdum_one_cow	-4.554		31.679	-23.262	2.401	
	-0.87		-0.55	-0.72	-0.97	
hdum_morethanone_cow		23.473				-20.956
		-0.28				-0.4
hdum_hoh_noedu	-57.94	29.539	-25.858	-80.637	-46.614	
	-0.2	-0.38	-0.74	-0.32	-0.59	
hdum_hoh_primary	3.325	40.725	-21.684	-51.995	-29.754	21.531
	-0.94	-0.18	-0.78	-0.5	-0.7	-0.15
hdum_hoh_secondary						72.763**
						-0.03
_cons	1237.679***	1422.153***	1751.495***	1476.260***	1904.021***	1145.621***
	0	0	0	0	0	0
Adj. R-Squared	0.107	0.101	-0.03	-0.03	-0.095	0.174
N	575	475	188	189	163	190

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * p<0.1; ** p<0.05; *** p<0.01.
Village and Stratum dummies are included.

Section 4.3.2 `studytime´

Daily study time (in minutes after nightfall)	Total all children	Female 12-17	Female 6-12	Male 12-17	Male 6-12
treat_eff	-3.155	-37.618**	21.793**	-32.019*	-25.385**
	-0.75	-0.03	-0.04	-0.07	-0.03
did_eff	38.894***	60.373***	9.777	41.801**	58.265***
	0	0	-0.44	-0.05	0
fol	3.214	-6.262	9.012	11.473	-4.456
	-0.69	-0.63	-0.24	-0.39	-0.61
BAS_consmpt_candle	-1.396**	-0.565	-0.805	-2.349**	-0.514
	-0.01	-0.49	-0.2	-0.02	-0.43
BAS_consmpt_kerosene	21.743***	23.277**	22.337***	17.989	22.146***
	0	-0.01	0	-0.11	0
BAS_num_HHmemb	0.032	-1.187	-0.437	-0.684	1.791
	-0.99	-0.71	-0.84	-0.84	-0.4
BAS_num_mobilephone	7.395	12.165	-5.596	14.012	6.001
	-0.27	-0.3	-0.41	-0.27	-0.4
BAS_dwellingplastered	-10.919	-24.807	5.54	6.089	5.718
	-0.35	-0.25	-0.66	-0.81	-0.65
BAS_modernwall	3.966	2.084	-1.036	-25.787	-4.082
	-0.71	-0.91	-0.93	-0.23	-0.75
BAS_modernfloor	7.215	9.024	-12.711	-24.973	-2.883
	-0.57	-0.64	-0.31	-0.28	-0.84
BAS_torchfix	6.262	3.691	19.680*	-0.885	11.324
	-0.48	-0.8	-0.07	-0.97	-0.28
BAS_mobileLED	24.859	50.043	51.935**	29.825	28.674
	-0.22	-0.16	-0.02	-0.43	-0.16
BAS_owns_land	-11.757	-93.973***	0.539	9.666	24.468
	-0.45	0	-0.97	-0.72	-0.35
hdum_no_goat	-14.037	-10.711	-2.587	-16.738	-21.888*
	-0.13	-0.41	-0.8	-0.36	-0.07
hdum_one_goat	2.913	13.227	3.416	-26.12	-11.903
	-0.81	-0.48	-0.81	-0.28	-0.49
hdum_morethanone_goat					
hdum_no_cow	2.304	27.681**	-0.987	51.205**	17.059
	-0.84	-0.05	-0.95	-0.03	-0.26
hdum_one_cow	-11.542		-6.493	46.437*	18.704
	-0.34		-0.69	-0.06	-0.2
hdum_morethanone_cow		24.729			
		-0.19			
hdum_hoh_noedu	-19.194	34.257	-52.397**	-44.789	-54.394***
	-0.28	-0.22	-0.01	-0.15	-0.01
hdum_hoh_primary	-24.651	37.721	-45.674**	-39.602	-59.128***
	-0.13	-0.17	-0.02	-0.15	0
hdum_hoh_secondary					
_cons	79.828**	70.531	70.314	32.583	36.49
	-0.02	-0.2	-0.13	-0.62	-0.39
Adj. R-Squared	0.158	0.291	0.192	0.1	0.218
N	414	189	189	167	191

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * *p*<0.1; ** *p*<0.05; *** *p*<0.01.
Village and Stratum dummies are included.

Section 4.3.2 `perception of security´

Afraid if …. after nightfall	Children outside	at home at night	outside
treat_eff	0.047	-0.031	0.083
	-0.46	-0.61	-0.21
did_eff	-0.07	-0.121	-0.119
	-0.42	-0.15	-0.18
fol	0.033	0.113**	0.041
	-0.54	-0.03	-0.45
BAS_consmpt_candle	0	-0.001	0.001
	-0.98	-0.8	-0.76
BAS_consmpt_kerosene	0.025*	0.032**	0.02
	-0.07	-0.01	-0.23
BAS_num_HHmemb	0	-0.009	0.017
	-0.99	-0.42	-0.15
BAS_num_mobilephone	-0.035	-0.024	-0.077**
	-0.36	-0.52	-0.04
BAS_dwellingplastered	0.031	-0.036	-0.029
	-0.68	-0.61	-0.7
BAS_modernwall	-0.019	-0.147**	-0.018
	-0.8	-0.04	-0.8
BAS_modernfloor	0.054	0.049	0.113
	-0.48	-0.52	-0.15
BAS_torchfix	-0.034	0.003	0.008
	-0.52	-0.95	-0.88
BAS_mobileLED	0.164	0.078	0.007
	-0.18	-0.5	-0.96
BAS_owns_land	-0.043	-0.071	0.115
	-0.68	-0.48	-0.31
hdum_no_goat	-0.022	-0.015	0.021
	-0.73	-0.82	-0.74
hdum_one_goat	0.188**	0.127	0.104
	-0.02	-0.1	-0.2
hdum_morethanone_goat			
hdum_no_cow	0.120*	0.04	0.028
	-0.09	-0.56	-0.7
hdum_one_cow	0.069	0.024	-0.052
	-0.37	-0.74	-0.5
hdum_morethanone_cow			
hdum_hoh_noedu	-0.012	-0.111	0.171
	-0.92	-0.34	-0.15
hdum_hoh_primary	0.072	-0.03	0.188*
	-0.51	-0.78	-0.08
hdum_hoh_secondary			
_cons	-0.032	0.561***	0.385*
	-0.93	-0.01	-0.1
Adj. R-Squared	0.035	0.039	0.144
N	567	574	507

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * *p*<0.1; ** *p*<0.05; *** *p*<0.01. Village and Stratum dummies are included.

Section 4.3.2 `night time activity´

Times per week household members go out after nightfall	Head of HH	Spouse	Male 12-17	Female 12-17	Children 6-12
treat_eff	-0.099	-0.340*	-0.498	-0.830***	-0.147
	-0.76	-0.08	-0.21	0	-0.32
did_eff	0.382	0.302	-0.158	0.29	0.168
	-0.39	-0.24	-0.73	-0.29	-0.38
fol	0.145	-0.004	0.04	-0.522***	-0.268**
	-0.59	-0.98	-0.89	0	-0.02
BAS_consmpt_candle	0.018	0.020*	0.003	0.021*	0.005
	-0.33	-0.05	-0.88	-0.08	-0.52
BAS_consmpt_kerosene	-0.012	-0.017	0.007	0.012	-0.026
	-0.86	-0.64	-0.91	-0.76	-0.44
BAS_num_HHmemb	0.213***	0.023	-0.035	-0.058	-0.028
	0	-0.47	-0.58	-0.14	-0.26
BAS_num_mobilephone	-0.350*	-0.019	0.182	0.104	-0.118
	-0.09	-0.86	-0.4	-0.46	-0.21
BAS_dwellingplastered	0.588	-0.162	-0.414	-0.355	-0.056
	-0.12	-0.44	-0.37	-0.18	-0.73
BAS_modernwall	0.046	-0.324	0.161	-0.149	-0.118
	-0.9	-0.14	-0.71	-0.52	-0.42
BAS_modernfloor	-0.495	0.315	-0.658	-0.167	0.219
	-0.22	-0.16	-0.14	-0.5	-0.17
BAS_torchfix	0.147	-0.183	0.354	0.166	-0.052
	-0.58	-0.23	-0.25	-0.34	-0.66
BAS_mobileLED	-0.565	-0.712**	0.301	-0.067	-0.536*
	-0.35	-0.03	-0.7	-0.87	-0.06
BAS_owns_land	0.811	0.139	-0.017	0.503	0.395
	-0.12	-0.63	-0.98	-0.19	-0.12
hdum_no_goat	0.132	-0.039	0.277	-0.288	-0.333**
	-0.69	-0.83	-0.43	-0.13	-0.01
hdum_one_goat	-0.606	0.029	0.301	-0.235	-0.474***
	-0.14	-0.9	-0.53	-0.38	-0.01
hdum_morethanone_goat					
hdum_no_cow	0.116	-0.019	-0.684	-0.17	-0.056
	-0.75	-0.93	-0.15	-0.48	-0.66
hdum_one_cow	0.177	-0.22	-0.719	0.16	
	-0.65	-0.33	-0.13	-0.51	
hdum_morethanone_cow					-0.052
					-0.77
hdum_hoh_noedu	0.768	0.327	0.533	-0.048	0.087
	-0.21	-0.34	-0.49	-0.9	-0.74
hdum_hoh_primary	1.148**	0.154	0.114	-0.262	-0.036
	-0.04	-0.62	-0.88	-0.46	-0.88
hdum_hoh_secondary					
_cons	1.245	0.227	1.151	0.407	0.644
	-0.27	-0.71	-0.43	-0.62	-0.22
Adj. R-Squared	0.115	0.045	-0.084	0.005	0.023
N	568	467	220	237	410

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * *p*<0.1; ** *p*<0.05; *** *p*<0.01. Village and Stratum dummies are included.

Section 4.3.2 `information´

	use mosquito net	use contraceptive	use condom
treat_eff	-0.035	-0.346*	-0.355*
	-0.45	-0.07	-0.05
did_eff	0.01	0.263	0.152
	-0.87	-0.31	-0.52
fol	-0.03	0.463***	0.395***
	-0.45	0	-0.01
BAS_consmpt_candle	-0.001	-0.007	0
	-0.72	-0.51	-0.99
BAS_consmpt_kerosene	-0.012	-0.099**	-0.084**
	-0.24	-0.02	-0.02
BAS_num_HHmemb	0.003	0.111***	0.057*
	-0.73	0	-0.05
BAS_num_mobilephone	-0.027	0.224*	0.274***
	-0.35	-0.06	-0.01
BAS_dwellingplastered	-0.025	0.011	0.188
	-0.65	-0.96	-0.35
BAS_modernwall	-0.021	-0.047	-0.23
	-0.69	-0.83	-0.22
BAS_modernfloor	0.015	-0.005	-0.247
	-0.8	-0.98	-0.23
BAS_torchfix	-0.075*	-0.107	0.023
	-0.06	-0.5	-0.87
BAS_mobileLED	0.073	-0.322	-0.17
	-0.42	-0.37	-0.59
BAS_owns_land	-0.016	-0.211	-0.258
	-0.83	-0.48	-0.36
hdum_no_goat	0.009	-0.056	-0.004
	-0.85	-0.77	-0.98
hdum_one_goat	-0.035	-0.595**	-0.315
	-0.56	-0.01	-0.14
hdum_morethanone_goat			
hdum_no_cow	-0.048	0.396*	0.275
	-0.36	-0.06	-0.15
hdum_one_cow	0.001	0.186	0.075
	-0.98	-0.42	-0.72
hdum_morethanone_cow			
hdum_hoh_noedu	-0.007	-0.153	-0.017
	-0.93	-0.67	-0.96
hdum_hoh_primary	0.059	0.128	0.202
	-0.47	-0.7	-0.49
hdum_hoh_secondary			
_cons	0.979***	-0.379	-0.484
	0	-0.55	-0.41
Adj. R-Squared	0.111	0.177	0.16
N	591	590	516

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * *p*<0.1; ** *p*<0.05; *** *p*<0.01. Village and Stratum dummies are included.

Section 4.3.2 `battery consumption´ `energy expenditures´

	Battery consumption (# per month)	Monthly energy expenditures (without cooking exp.)	Total monthly exp. (without cooking)	Share of energy exp. in total exp.
treat_eff	0.256	-95.356	2173.073	-0.003
	-0.57	-0.44	-0.67	-0.73
did_eff	-1.094*	-486.471***	3490.611	-0.031**
	-0.07	0	-0.61	-0.02
fol	-0.536	-217.653**	-884.204	-0.013*
	-0.16	-0.04	-0.83	-0.09
BAS_consmpt_candle	-0.031	39.868***	33.092	0.001
	-0.23	0	-0.91	-0.12
BAS_consmpt_kerosene	0.095	140.258***	1459.18	0.002
	-0.33	0	-0.18	-0.35
BAS_num_HHmemb	0.043	22.173	3746.397***	-0.005***
	-0.58	-0.3	0	0
BAS_num_mobilephone	0.35	230.348***	14317.478***	-0.004
	-0.21	0	0	-0.53
BAS_dwellingplastered	-0.292	-216.096	11436.804**	-0.008
	-0.57	-0.13	-0.05	-0.44
BAS_modernwall	-0.846*	-178.957	19105.094***	-0.015
	-0.1	-0.2	0	-0.15
BAS_modernfloor	-0.133	465.213***	-8767.708	0.009
	-0.81	0	-0.16	-0.45
BAS_torchfix	0.836**	-360.304***	-2558.82	-0.009
	-0.03	0	-0.54	-0.27
BAS_mobileLED	2.419***	-335.793	15891.851*	-0.019
	-0.01	-0.15	-0.1	-0.29
BAS_owns_land	0.151	186.667	-1277.596	0.013
	-0.83	-0.34	-0.87	-0.4
hdum_no_goat	-0.444	-142.89	-9380.684*	0.007
	-0.33	-0.25	-0.07	-0.44
hdum_one_goat	-1.069*	-266.141*	-1.55e+04**	0.012
	-0.06	-0.09	-0.02	-0.33
hdum_morethanone_goat				
hdum_no_cow	-0.651	-241.664*	-1.77e+04***	0
	-0.19	-0.08	0	-0.98
hdum_one_cow	0.175	-84.337	-1.08e+04*	-0.01
	-0.75	-0.57	-0.08	-0.39
hdum_morethanone_cow				
hdum_hoh_noedu	-2.279***	-465.369**	16393.246*	-0.001
	-0.01	-0.05	-0.09	-0.96
hdum_hoh_primary	-1.721**	-256.134	21019.519**	0.001
	-0.03	-0.23	-0.02	-0.97
hdum_hoh_secondary				
_cons	6.815	2464.370***	55200.098***	0.080**
	-0.12	0	0	-0.01
Adj. R-Squared	0.205	0.458	0.296	0.12
N	586	592	592	590

Note: The first row value indicates the coefficient; p-value below. Stars indicate significance level with * p<0.1; ** p<0.05; *** p<0.01. Village and Stratum dummies are included.

Appendix 8: Contract for lottery winners

AGREEMENT OF COOPERATION

Between……………………………………..Representative of RWI/ISS
And the beneficiary of solar kits:

-Name:……………………………..
-Phone number:……………………
-Code of household:………………
-Village:……………………………
-Cell:………………………………
-Sector:……………………………
-District:…………………………..
-Province:………………………...

Article 1: This agreement concerns the cooperation between RWI/ISS and beneficiaries of solar kits during research on impact of electricity on living conditions of beneficiaries.

Article 2: The Agreement is valid for one year from the date of signature.

Article 3: RWI/ISS's responsibilities:

- To offer beneficiaries solar kits freely (solar kits consist of 1. solar panel, 2. lamp, 3. battery power pack, 4. active and passive radio connectors, 5. radio, and 6. phone connector)
- To conduct survey on impact of electricity on living conditions of beneficiaries
- Assist beneficiaries in collaboration with Though Stuff in any case of technical problems of solar kits

Article 4: Responsibilities of beneficiaries of solar kits:

- To follow rules given by Though Stuff about how to keep well solar kits
- To give all required information on the impact of electrification on the living conditions
- To communicate Though Stuff on the encountered problems about the use of solar kits
- Don't sell or give freely solar kits to someone else
- Turn back to RWI/ISS solar kits when beneficiaries are not able to keep them

Done at ….., the….December 2011

Signature

Beneficiary's name:……………………………………

Signature
Name……………………………………………………….
Local Authorities representative………………………………….

Signature

Name…………………………………………………..

Representative of RWI-ISS

Appendix 9: Further inconsistencies in ToughStuff proposal

- Table on page 7 announces a mobil phone payment system which will be used to monitor the TS agents and stay in touch with them. Nothing like this has been established.
- Table on page 7 promises an "Education and training program" of TS ladies/agents. Such activities have never happened.
- P11: "Technical support for the end-users is organized by the TS ladies". There is no technical support .
- P.11: "The solar products have been designed to be very easy in use and application, hence, require little or no technical support in their set-up".
- P.11: "A technical phone support line will be set up". No support line exists.
- The proposal suggests a relationship between kerosene dependency for lighting purposes and "a depletion of forestry resources" (p. 6) neglecting the well-known and intuitive fact that forest resources are not used for lighting (with one rare exception: the poorest households use lighting from their cooking place as a by-product of cooking).
- In terms of the sales incentives, the proposal claims that after having sold 2 kits the ToughStuff agents would receive a bike to increase sales. This (or anything comparable) has not happened.
- "The rural retail sector is poorly developed, which limits the availability of solar products." LED lamps with luminous flux comparable to ToughStuff are available in literally the remotest village. Solar products are not available in every village, but can usually be obtained in rural centers.
- The proposal announces that regular field surveys are conducted to check roll-out rates of solar products. In none of our survey areas such a field survey has been done.
- The proposal emphasizes the accident risk associated to kerosene lamps that might cause fires ("Whole villages…burn down to ashes") In none of our various surveys between 2006 and 2012 any serious accident was reported – let alone that villages burned down to ashes.
- - The proposal assumes a "slow" national electrification plan (page 6). The ambitious and effective Electricity Access Role Out Plan was already ongoing (and effectively implemented!) when the proposal was submitted.

Appendix 10: Digital Appendix Questionnaires